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SYNOPSES OF BIOLOGICAL DATA ON EIGHT SPECIES OF SCOMBRIDS

edited by

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La Jolla, California
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INTRODUCTION

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In 1979, at the request of the Comision Permanente del Pacifico Sur, staff members of the Inter-American Tropical Tuna Commission prepared synopses of eight species of scombrid fishes. These are to be published in Spanish in Revista de la Comision Permanente del Pacifico Sur, Number 11, in 1980. This volume contains English versions of those synopses. The Spanish and English versions are not identical, however, the latter having been updated and somewhat modified after the Spanish versions were submitted for publication.

These synopses follow closely the format prepared by Rosa (1965) for the synopses to be published by the Food and Agriculture Organization of the United Nations and cooperating organizations. However, instead of preparing detailed taxonomic reviews of the individual species, the taxonomic information for all of the scombrids and billfishes has been put into a separate chapter.

With one exception, the synopses consist almost entirely of information obtained from studies conducted in the Pacific Ocean. In a few cases, however, when better information is available from investigations made elsewhere this information is included. The exception is the synopsis for Thunnus maccoyii. This species has a nearly circumpolar distribution in the Southern Ocean and the southern portions of the Atlantic, Indian, and Pacific oceans, so it would be impractical to consider only studies pertaining to the Pacific Ocean.

A synopsis of Euthynnus spp. was prepared by Yoshida (1979a), and one for Katsuwonus pelamis is currently being prepared by staff members of the U. S. National Marine Fisheries Service (NMFS) laboratory at Honolulu, Hawaii. The manuscript for the latter was generously made available to the Tuna Commission by Mr. Richard S. Shomura, director of that laboratory. Heavy reliance was placed on the NMFS synopsis for Katsuwonus pelamis during the preparation of the Tuna Commission synopsis on that species. However, the latter includes some information not included in the NMFS synopsis, and the two synopses differ in regard to the emphases placed on different subjects. The Tuna Commission synopsis for Euthynnus lineatus consists of portions of Yoshida's (1979a) synopsis and of material compiled by Mr. Muhlia-Melo. The latter is indicated by brackets.

The Bibliography lists all the references cited in this volume, plus some others which are not cited. Codes pertaining to species appear with most of the references, the exceptions being some of the taxonomic, statistical, and gear papers. The codes for all the species discussed in a given reference are recorded, even though not all the synopses cite that reference.

CLASSIFICATION OF THE TUNAS, MACKERELS, BILLFISHES, AND RELATED SPECIES, AND THEIR GEOGRAPHICAL DISTRIBUTION

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The word "tuna" lacks precision, as it is applied to various fishes, but to fishery biologists it usually signifies members of the tribe Thunnini, a subdivision of the family Scombridae (Klawe, 1977; Collette, 1978). The term "related fishes," although widely used, is even more difficult to define. Among fishery biologists it is generally accepted that the expression "tunas and related fishes" applies to all the genera of the family Scombridae except *Rastrelliger* and *Scomber*, and to all genera of the families Istiophoridae and Xiphiidae. The mackerels, *Rastrelliger* and *Scomber*, are excluded because their mode of life, the nature of the fisheries directed toward them, and the marketing of their catches differ considerably from those of the other related fishes.

The families Scombridae, Istiophoridae, and Xiphiidae belong to the order Perciformes. This order, in turn, is divided into several suborders, one of which is the Scombroidei. Some taxonomists (*i.e.* Gregory and Conrad, 1937 and 1943; Lindberg, 1971) assign the three families to this suborder, while others (*i.e.* Gosline, 1968) consider Istiophoridae and Xiphiidae to belong to the order Xiphioidei.

If Lindberg's scheme is followed the system of classification above the generic level is as follows:

- Phylum Chordata
  - Subphylum Vertebrata
    - Superclass Gnathostomata
      - Class Teleostomi
        - Subclass Actinopterygii
          - Order Perciformes
            - Suborder Scombroidei
              - Family Scombridae
              - Family Istiophoridae
              - Family Xiphiidae

The taxonomic relationships of all the genera of the three families under consideration are shown diagramatically in Figure 1. The taxonomic position of the monotypic genus *Gasterochisma melampus*, most commonly considered to comprise the subfamily Gasterochismatinae, is in dire need of study. As stated by Collette (1978), the possibility that *Gasterochisma* may not be a member of the family Scombridae cannot be precluded. There is some doubt about the taxonomic position of the genus *Grammatorcynus*, which in Figure 1 is shown to be a member of the tribe Scomberomorini of the family Scombridae. As pointed out recently by Collette and Russo (1979), this mono-specific genus shares some characters with the tribe Scombrini. There is therefore a possibility that it may be transferred into that tribe or even left by itself.

A list of the species of the families Scombridae, Istiophoridae, and Xiphiidae appears below, with a brief summary of the geographic distribution of each species. The list is based on that of Joseph, Klawe, and Murphy (1980). Asterisks appear beside the names of the species which occur in the Pacific Ocean. The genera and species within each of the taxonomic units are arranged alphabetically. The three-letter identifiers and the standard common names in English, French, and Spanish used in this list are those accepted by the Food and Agriculture Organization of the United Nations. The three-letter identifiers are intended for use in computer processing of catch statistics and other fishery data. Lack of a common name indicates that the Food and Agriculture Organization has not yet decided upon the standard common name for that species.

FAMILY SCOMBRIDAE

Subfamily Gasterochismatinae

*Butterfly kingfish BUK
Gasterochisma melampus Richardson, 1845

Throughout the southern hemisphere, mostly between latitude 35°S and at least latitude 50°S; in the southeastern Indian Ocean as far north as latitude 26°S; distribution appears to parallel the zone just north of the West Wind Drift.

Subfamily Scombrinae

Tribe Scombrini, mackerels

*Short mackerel RAB; maquereau de Pacifique (F); caballa del Pacifico (S)
Rastrelliger brachysoma (Bleeker, 1851)

Malaysia, Indonesia, Papua New Guinea, and Solomon and Fiji islands.

*Island mackerel RAF
Rastrelliger faughni Matsui, 1967

Philippines, Taiwan, Papua New Guinea, and Indonesia.

*Indian mackerel RAG; maquereau des Indes (F); caballa de la India (S)
Rastrelliger kanagurta (Cuvier, 1817)

East coast of Africa, Seychelles, Arabian Sea, eastward through Indonesia and off northern Australia to Melanesia and Micronesia, Gulf of Thailand, Samoa, coast of China, and Ryukyus; recent immigrant, through the Suez Canal, to the Mediterranean Sea.

*Spotted chub mackerel MAA
Scomber australasicus Cuvier in Cuvier and Valenciennes, 1831

Off Australia, New Zealand, China, Japan, Hawaii, and Revillagigedo Islands in the eastern Pacific.

*Chub mackerel MAS; maquereau espagnol (F); estornino (S)
Scomber japonicus Houttuyn, 1782

Temperate and warm waters of both hemispheres, present in the Mediterranean Sea.

Atlantic mackerel MAC; maquereau de l'Atlantique (F); caballa del Atlantico (S)
Scomber scombrus Linnaeus, 1758

Temperate and near-temperate waters of the Atlantic Ocean, including the Mediterranean and Black seas.

Tribe Scomberomorini, seerfishes

*Wahoo WAH; thazard-batard (F); peto (S)
Acanthocybium *solandri* (Cuvier *in* Cuvier and Valenciennes, 1831)

Tropical and subtropical waters of the Indian, Pacific, and Atlantic oceans, including the Mediterranean Sea.

*Double-lined mackerel DBM
Grammatorcynus *bicarinatus* (Quoy and Gaimard, 1824)

Red Sea; absent from the Arabian Sea and Bay of Bengal; present off southeast Asia, Australia, Papua New Guinea, Philippines, Ryukyus, Marshalls, and Tonga.

Serra Spanish mackerel BRS; thazard serra (F); serra (S)
Scomberomorus *brasiliensis* Collette, Russo, and Zavala-Camin, 1978

Atlantic coast of Central America and South America from Belize south to Rio Grande do Sul, Brazil.

King mackerel KGM; thazard barre (F); carite lucio (S)
Scomberomorus *cavalla* (Cuvier, 1829)

Tropical western Atlantic Ocean.

*Narrow-barred king mackerel COM; thazard raye Indo-Pacifique (F); carita estriada del Indo-Pacifico (S)
Scomberomorus *commerson* (Lacepede, 1800)

Indian and western Pacific oceans, Cape of Good Hope, east Africa, Red Sea eastward to Malaysia, Gulf of Thailand, Australia, Indonesia, Fiji, Philippines, China, Taiwan, and Japan; recent immigrant to the Mediterranean Sea.

*Monterey Spanish mackerel MOS; thazard Monterey (F); carita Monterey (S)
Scomberomorus *concolor* (Lockington, 1879)

Gulf of California, formerly abundant in Monterey Bay, California.

*Indo-Pacific king mackerel GUT; thazard ponctue Indo-Pacifique (F); carita del Indo-Pacifico (S)
Scomberomorus *guttatus* (Bloch and Schneider, 1801)

Indian and Pacific oceans from Japan to India.

*Korean seerfish KOS; thazard de Coree (F); carita de Corea (S)
Scomberomorus *koreanus* Kishinouye, 1915

Indian and Pacific oceans from Korea to India.

*Streaked seerfish STS
Scomberomorus *lineolatus* (Cuvier *in* Cuvier and Valenciennes, 1831)

Coastal waters of India and Sri Lanka eastward to Southeast Asia and Indonesia.

Atlantic Spanish mackerel SSM; thazard atlantique (F); carite atlantico (S)
Scomberomorus maculatus (Mitchill, 1815)

Atlantic coast of North America from Massachusetts, U.S.A., south to Yucatan, Mexico.

*Papuan seerfish PAP; thazard de Papouasie (F); carita de Papua (S)
Scomberomorus multiradiatus Munro, 1964

Shallow waters of Gulf of Papua off the mouth of the Fly River.

*Australian spotted mackerel
Scomberomorus munroi Collette and Russo, 1980

Northern Australia and southern Papua New Guinea.

*Japanese Spanish mackerel NPH; thazard orientale (F); carita oriental (S)
Scomberomorus niphonius (Cuvier in Cuvier and Valenciennes, 1831)

Temperate and subtropical waters of the western North Pacific, Japan, Korea, and China.

Kanadi kingfish KAK; thazard kanadi (F); carita kanadi (S)
Scomberomorus plurilineatus Fourmanoir, 1966

East African coastline from Kenya to South Natal; west coast of Madagascar.

*Queensland school mackerel QUM; thazard de Queensland (F); carita de Queensland (S)
Scomberomorus queenslandicus Munro, 1943

East and west coasts of Australia.

Cero CER; thazad franc; carite chinigua (S)
Scomberomorus regalis (Bloch, 1793)

Tropical and subtropical waters of the western Atlantic Ocean, particularly in the West Indies.

*Broad-barred king mackerel BBM
Scomberomorus semifasciatus (Macleay, 1884)

Off Queensland and the Northern Territory of Australia, southern Papua New Guinea.

*Sierra SIE; thazard sierra (F); sierra (S)
Scomberomorus sierra Jordan and Starks in Jordan, 1895

Eastern Pacific Ocean, from California to Peru and around the Galapagos Islands.

*Chinese seerfish CHY; thazard de Chine (F); carita de China (S)
Scomberomorus sinensis (Lacepede, 1800)

Western Pacific Ocean from Japan to Viet Nam; present also in Kampuchea (Cambodia) in the Mekong system (does not reproduce in fresh water).

Western African Spanish mackerel MAW; thazard Ouest-Africain (F); carita Oeste-Africana (S)
Scomberomorus tritor (Cuvier in Cuvier and Valenciennes, 1831)

Eastern Atlantic off west coast of Africa; rare in the Mediterranean Sea.

Tribe Sardini, bonitos

*Slender tuna SLT
Allothunnus fallai Serventy, 1948

Southern Ocean, south of latitude 20°S; one record from eastern Pacific.

*Leaping bonito LEB
Cybiosarda elegans (Whitley, 1935)

Northern Australia and south coast of Papua New Guinea.

*Dogtooth tuna DOT; bonite orientale (F); bonito Pacifico (S)
Gymnosarda unicolor (Ruppell, 1838)

Red Sea and East Africa eastward to Australia, Papua New Guinea, and Marshall,Society, Marquesas, Tuamotu, and Pitcairn islands; sporadic in southern Japanese waters.

Plain bonito BOP; palomete (F); tasarte (S)
Orcynopsis unicolor (Geoffroy St. Hilaire, 1817)

West coast of Africa northward from Gulf of Guinea, Mediterranean Sea.

*Australian bonito BAU; bonite d'Australie (F); bonito de Australia (S)
Sarda australis (Macleay, 1880)

Limited to southeastern coast of Australia from the Tropic of Capricorn south to Tasmania; also around Norfolk Island.

*Eastern Pacific bonito BEP; bonite du Pacifique est (F); bonito del Pacifico este (S)
Sarda chiliensis (Cuvier in Cuvier and Valenciennes, 1831)

Eastern Pacific Ocean from Vancouver Island to Baja California; absent from truly tropical waters of Middle America and then present again from Peru to northern Chile.

*Indo-Pacific bonito BIP; bonite Indo-Pacifique (F); bonito del Indo-Pacifico (S)
Sarda orientalis (Temminck and Schlegel, 1844)

Coastal regions of the Indian and Pacific oceans; also present around many of the islands; east coast of Africa, Red Sea, Arabian Sea, Gulf of Bengal, Western Australia, Indonesia, China, Taiwan, Japan, occasionally in Hawaiian waters; in the eastern Pacific, Middle America to Ecuador, including the Galapagos Islands.

Atlantic bonito BON; pelamide (=bonite a dos raye) (F); bonito atlantico (S)
Sarda sarda (Bloch, 1793)

Tropical and temperate coasts of the Atlantic Ocean including the Mediterranean and Black seas.

Tribe Thunnini, tunas

*Bullet tuna BLT; auxide (F); melva (S)
Auxis rochei (Risso, 1810)

Warm waters of the Indian, Pacific, and Atlantic oceans, including the Mediterranean Sea.

*Frigate tuna FRI; auxide (F); melva (S)
Auxis thazard (Lacepede, 1800)

Warm waters of the Indian, Pacific, and Atlantic oceans.

*Kawakawa KAW; thonine orientale (F); bacoreta oriental (S)
Euthynnus affinis (Cantor, 1849)

Warm waters of the Indian and Pacific oceans; few records from the eastern Pacific Ocean.

Little tunny LTA; thonine (F); bacoreta (S)
Euthynnus alletteratus (Rafinesque, 1810)

Warm waters of the Atlantic Ocean including the Mediterranean Sea; sporadic occurrence in the Black Sea.

*Black skipjack BKJ; thonine noire (F); barrilete negro (S)
Euthynnus lineatus Kishinouye, 1920

Warm waters of the eastern Pacific Ocean; stray specimens recorded from the central Pacific Ocean.

*Skipjack tuna SKJ; listao (F); listado (S)
Katsuwonus pelamis (Linnaeus, 1758)

Cosmopolitan in warm waters; absent from the Black Sea.

*Albacore ALB; germon (=thon blanc) (F); atun blanco (S)
Thunnus alalunga (Bonnaterre, 1788)

Temperate, subtropical, and tropical waters of all oceans, including the Mediterranean Sea, but absent in the tropical waters of the eastern Pacific Ocean.

*Yellowfin tuna YFT; thon albacore (F); rabil (S)
Thunnus albacares (Bonnaterre, 1788)

Tropical and subtropical waters of the Indian, Pacific, and Atlantic oceans.

Blackfin tuna BLF; thon a nageoire noire (F); atun aleta negra (S)
Thunnus atlanticus (Lesson, 1830)

Western Atlantic Ocean, off Martha's Vineyard, Massachusetts, U.S.A., southward through the Caribbean Sea to Brazil.

*Southern bluefin tuna SBF; thon rouge du sud (F); atun del sur (S)
Thunnus maccoyii (Castelnau, 1872)

Subtropical and temperate waters of the southern region of the Indian, Pacific, and Atlantic oceans.

*Bigeye tuna BET; patudo (=thon obese) (F); patudo (S)
Thunnus obesus (Lowe, 1839)

Warm waters of the Indian, Pacific, and Atlantic oceans.

*Northern bluefin tuna BFT; thon rouge (F); atun (S)
Thunnus thynnus (Linnaeus, 1758)

Subtropical and temperate waters of the north Pacific; in the western Pacific present also in the tropical waters extending from Ryukyus to northern New Zealand, eastern Australia and eastern Tasmania; rare in the southeastern Pacific Ocean off Chile; sporadic in the eastern Indian Ocean; south and north Atlantic Ocean and the Mediterranean and Black seas, recently rare in the latter.

*Longtail tuna LOT
Thunnus tonggol (Bleeker, 1851)

Indian and western Pacific oceans, from southern Japan, where it is rare, south to Australia (north, east, and west coasts); throughout most of the Indian Ocean, including the Red Sea, but absent from most of the east African coast.

FAMILY ISTIOPHORIDAE

Subfamily Tetrapturinae, spearfishes

*Sailfish SAI; voilier (F); pez vela (S)
Istiophorus platypterus (Shaw and Nodder, 1791)

Widely distributed throughout tropical and subtropical waters of the world oceans; usually more abundant near land masses and some of the larger islands.

White marlin WHM; marlin blanc (F); aguja blanca (S)
Tetrapturus albidus Poey, 1861

Tropical and temperate waters of the Atlantic and Mediterranean.

*Shortbill spearfish SSP
Tetrapturus angustirostris Tanaka, 1914

Warm waters of the Indian and Pacific oceans; oceanic fish seldom encountered in coastal waters; reported from south Atlantic off the Cape of Good Hope.

*Striped marlin MLS; marlin raye (F); marlin rayado (S)
Tetrapturus audax (Philippi, 1887)

Warm waters of the Indian and Pacific oceans; relatively rare in the equatorial region of the central and western Pacific.

Mediterranean spearfish MSP; marlin du Mediterranee (F); marlin del Mediterraneo (S)
Tetrapturus belone Rafinesque, 1810

Mediterranean Sea.

Roundscale spearfish RSP
Tetrapturus georgei Lowe, 1840

Atlantic Ocean off Portugal and Spain, Mediterranean Sea off Sicily.

Longbill spearfish SPF; makaire becune (F); aguja picuda (S)
Tetrapturus pfluegeri Robins and de Sylva, 1963.

Coastal and oceanic waters of the tropical and subtropical Atlantic.

Subfamily Makairinae, marlins

*Black marlin BLM; makaire noir (F); aguja negra (S)
Makaira indica (Cuvier *in* Cuvier and Valenciennes, 1831)

Tropical Indian and Pacific oceans; sporadic occurrence in the Atlantic Ocean; much more abundant in coastal waters than in waters of the open sea, where it is present only in small numbers.

*Blue marlin BUM; makaire bleu (F); aguja azul (S)
Makaira nigricans Lacepede, 1802

Widely distributed throughout the Indian, Pacific, and Atlantic oceans; especially abundant in the tropical regions; rare in the Mediterranean Sea.

FAMILY XIPHIIDAE

*Swordfish SWO; espadon (F); pez espada (S)
Xiphias gladius Linnaeus, 1758

Widely distributed throughout the temperate, subtropical, and tropical waters of the world oceans and the adjacent seas; found in coastal as well as in oceanic areas.

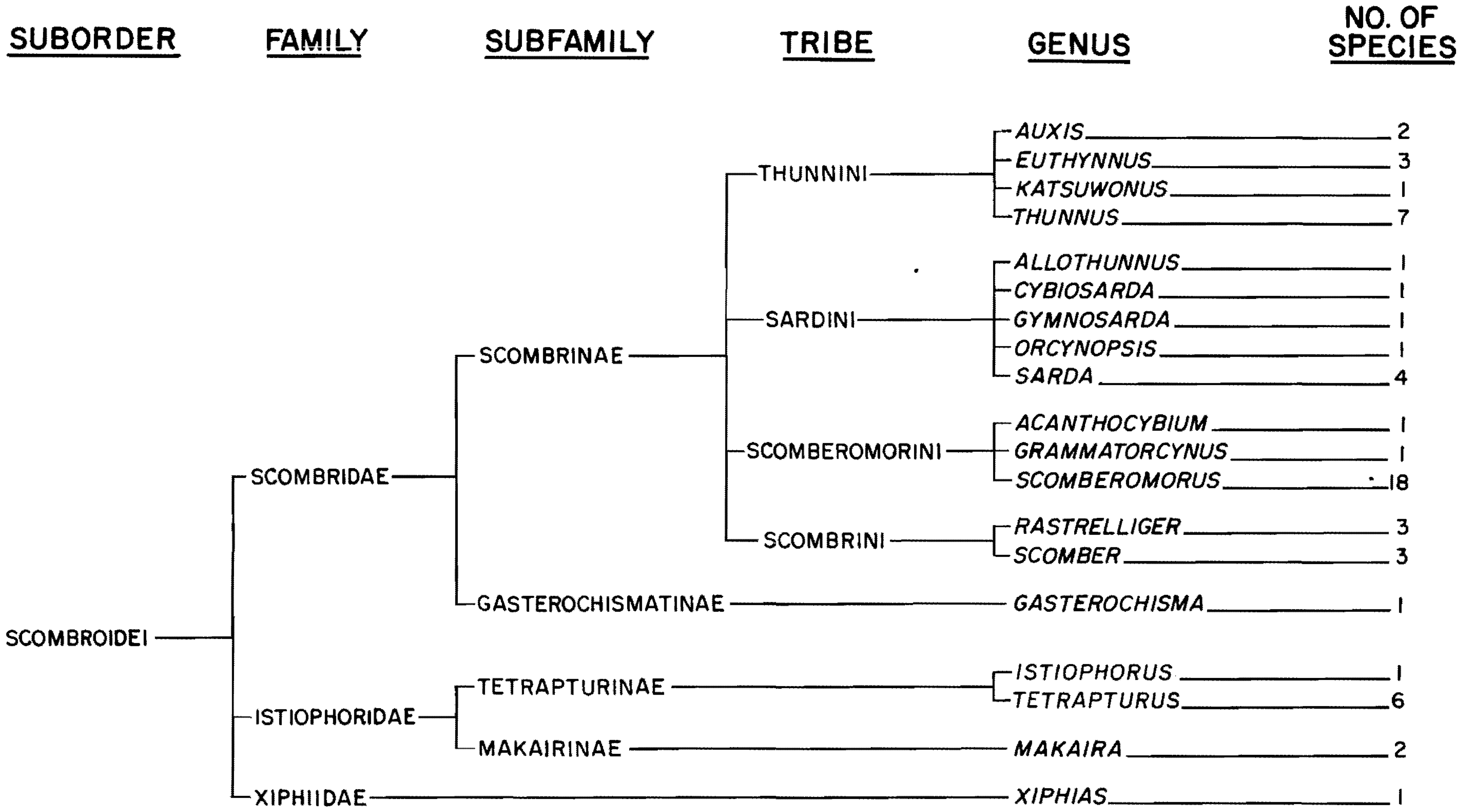

FIGURE 1. The families, subfamilies, tribes, genera, and numbers of species of the suborder Scombroidei.

SYNOPSIS OF BIOLOGICAL DATA ON THE ALBACORE TUNA, *THUNNUS ALALUNGA* (BONNATERRE, 1788), IN THE PACIFIC OCEAN

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CONTENTS

1 IDENTITY

The scientific name for the albacore tuna is Thunnus alalunga.

2 DISTRIBUTION

2.1 Total area

Accounts of the distribution of albacore are commonly based upon the results of commercial fishing, and thus the present knowledge of the albacore's distribution may be a function of the range and strategy of commercial fishing vessels (Otsu and Yoshida, 1966). However, oceanographic studies have predicted areas of probable occurrence of albacore by defining their habitat by water mass characteristics found in areas receiving little fishing effort. Figure 1 depicts the distributions of both surface and deep-swimming albacore in the Pacific Ocean. It is a composite of figures and data from de Buen (1958), Brock (1959), Koto (1966), Otsu and Yoshida (1966), Sandoval T. (1971), Kume (1974), Martinez F. (1974), and Skillman (1975). Figure 2 shows the probable distribution of deep-swimming albacore (Otsu and Yoshida, 1966), although there is some disagreement about the distribution of the north and south Pacific stocks intermingling at the equator (Suda, 1971; Kume, 1974).

The distribution of albacore across the north Pacific is centered around 35°N latitude, and extends from the Revillagigedo Islands, Mexico, to the Gulf of Alaska in the east, and from the equator to 45°N in the west, depending upon the season and ocean conditions (Yoshida and Otsu, 1963). In the south Pacific, albacore occur from the equator to 40°S in the central and western areas (Koto, 1966) and are concentrated between 10° and 30°S in the area between 150°E and 120°W (Suda, 1971). Koto extends the reported distribution eastward to 80°W, and Kume (1974) reports that longline catches have been made near the coast of Chile, where de Buen (1958) reported a small surface fishery, which failed due to the fish moving offshore beyond the range of the fleet (Inostroza C., 1979). Albacore occur at the surface around Isla de Pascua (27°S-109°W). In the southwestern Pacific, Slack (1969 and 1972), Roberts (1974), and Habib and Cade (1978) describe a surface fishery on both coasts of New Zealand, and Serventy (1941), Roughley (1951), and Hynd and Robins (1967) note sporadic surface catches of albacore around New South Wales and Tasmania.

2.2 Differential distribution

The information on this subject is discussed in Section 3.16.

2.3 Determinants of distribution changes

Water temperature has long been recognized as a determinant of the distribution of albacore (Thompson, 1917). Clemens (1961), Radovich (1961), and Clemens and Craig (1965) have stated that temperature is an important determinant, and have demonstrated that in some years up to 90 percent of the fish taken from Baja California to Alaska have come from waters between 15.6° and 19.4°C. Saito (1973) determined from experimental longlining in Fijian waters that larger, deep-swimming albacore are found in waters between 13.5° and 25.2°C. Laurs, Dotson, Dizon, and Jemison (1980) report that during telemetry experiments, free-swimming albacore enter water as cold as 9.5°C for short periods and 10°-12°C for extended periods. Clemens (1961) notes a size-temperature relationship in the eastern north Pacific and Japanese waters; the albacore migrated in a narrow temperature range, distributed by size within the range. Smaller fish tend to inhabit cooler waters while larger ones are found in relatively warmer waters.

Laurs and Lynn (1977) state that albacore concentrate along thermal discontinuities called oceanic fronts, and cite several references relating this to migration and/or catch, as do Van Campen (1960) and Laurs, Yuen, and Johnson (1977). The Transition Zone in the north Pacific and the Kuroshio Front east of Japan (Figure 3) are the two main examples of this phenomenon producing large catches (Yamanaka, 1979). Sund, Blackburn, and Williams (1980) review the literature pertaining to tunas (including albacore) and their relationship to their environment. They note that albacore avoid cooler upwelled waters (less than 15°C), in preference to Transition Zone waters, even though there may be more food available in the former. They also state that the minimum oxygen requirement of albacore is probably similar to that of yellowfin, about 2 ml/1, and that this is also a determinant of distribution, especially in the eastern tropical Pacific.

Nakamura (1969) states that water masses and their boundaries are delineators of albacore distribution and that albacore tend to migrate within these boundaries rather than across them.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Albacore are heterosexual, with no external characters to distinguish males from females (Yoshida and Otsu, 1963).

3.12 Maturity

Female albacore attain maturity and spawn at about 90 cm in length

(Ueyanagi, 1955; Otsu and Uchida, 1959). Several observers have noted mature females at slightly smaller sizes (86-98 cm) in studies done in the western (Ueyanagi, 1957), central equatorial (Otsu and Uchida, 1959), and central south Pacific (Otsu and Hansen, 1962). Male albacore may mature at larger sizes than females. Ueyanagi (1957) postulated that males reached maturity at 97 cm, on the premise that fish with testes containing milt and weighing over 150 grams per pair were ripe. Under the same criteria Otsu and Hansen (1962) found males to be ripe at 90 cm, but both studies are inconclusive due to the lack of an objective means of determining maturity. Albacore are generally believed to reach maturity at 5 years of age or older (Suda, 1958; Otsu and Uchida, 1962).

3.13 and 3.14 Mating and fertilization

According to Yoshida and Otsu (1963), no records of observations of spawning fish are available, but albacore probably occur in aggregations of male and female fish and release their gametes indiscriminately without selecting partners, the fertilization therefore being external.

3.15 Gonads

Based upon the assumption that all eggs of the most advanced group in an ovary are released in a single spawning, fecundity estimates have ranged from 0.8 to 2.6 million eggs (Ueyanagi, 1955 and 1957; Otsu and Uchida, 1959). Larger albacore tend to produce slightly more eggs per spawning (Otsu and Uchida, 1959).

3.16 Spawning

The spawning seasons for albacore from different areas of the Pacific Ocean are shown in Table 1, and the spawning areas are shown in Figure 4. Albacore spawn during the summer in oceanic subtropical waters centered around 20°N and 20°S latitude, their distribution expanding with the warm seasons and contracting with the cool (Ueyanagi, 1969). According to Otsu and Hansen (1962) and Ueyanagi, Mori, and Nishikawa (1969b), spawning does not take place in equatorial or temperate waters, but Yoshida (1971) notes juveniles under 200 mm in length between 0° and 10°S. Yoshida (1968) estimated the duration of the spawning season from the time of occurrence of juvenile albacore in billfish stomachs collected in the central Pacific. The vertebral columns of the juveniles were measured, and expected lengths were calculated for ages up to 1 year. From this, the birthdates of the individuals were back-calculated, the distribution of these birthdates defining the spawning season. Evidence of multiple spawnings have been described by Otsu and Uchida (1959), who found two or more modes in the size frequency of egg diameters found in ovaries, which may represent eggs to be spawned in single or successive seasons. Also, egg remnants and eggs approaching ripeness in the same ovaries suggest multiple spawnings. Remnants were absent in large, sexually inactive fish taken during late winter in the north Pacific, suggesting that remnants are not carried over year-to-year. However, since nothing is known regarding the rates of reabsorption of unspawned eggs, no certain conclusions may be offered.

No attempt at artificial fertilization of albacore has been reported, but Sanzo (1933) reported hatching fertilized ova from the Strait of Messina in the Mediterranean Sea and rearing them for 7 days in the laboratory. However, according to Matsumoto (1962), there is some question as to the species identification. In view of the successful fertilization and hatching of bigeye eggs by Kikawa (1953) and Kume (1962), such experiments could be successful for albacore if running-ripe fish could be captured.

3.17 Spawn

Eggs of albacore taken from the ovaries of maturing fish are described by Ueyanagi (1955) and Otsu and Uchida (1959). Only one record of running ripe fish was found, that of several fish taken off Magdalena Bay, Baja California, in March 1912 and March 1914 by M. Kondo and S. F. Takasaki of the Imperial Fisheries Institute in Tokyo (Scofield, 1914). The roe was the same size as cod roe, and light reddish-brown in color. Clemens (1961) reported observations of recently spawned individuals 93-100 cm in length among albacore caught in August near Guadelupe Island, Baja California. He considered it likely that these fish had spawned prior to their migration to inshore waters.

3.2 Pre-adult phase

3.21 Embryonic phase

Matsumoto (1958) estimated that the incubation period of fertilized tuna ova was no more than 4 days (Ueyanagi, 1969b). Sanzo (1933) described the development of the fertile eggs into larvae, which occurred in only 2 days, but Matsumoto (1962) warned that these may have been incorrectly identified, as other scombrids spawn in Sanzo's collection area at the same time as do albacore.

3.22 Larval phase

Descriptions of albacore larvae appear in Matsumoto (1962), Yabe and Ueyanagi (1962), Matsumoto, Ahlstrom, Jones, Klawe, Richards, and Ueyanagi

(1972), and Richards and Pothoff (1974). Albacore larvae are easily distinguished from other tuna larvae, except yellowfin. The placement of melanophores is the principal distinguishing characteristic between those larvae less than 10 mm standard length. Those over 10 mm are identified from a combination of melanophore characteristics and distribution of the adults, which can lead to errors. Final identification is rendered by the study of their osteology, which is more reliable.

3.23 Adolescent phase

Juvenile albacore (12-300 mm) have been found around the Marianas, Fiji, Hawaiian, and Ellice islands and east of Australia (Yabe, Ueyanagi, Kikawa, and Watanabe, 1958; Yoshida, 1965 and 1971a). Clemens (1961) reported a single 381-mm albacore caught near Guadalupe Island in December 1957, and Otsu and Uchida (1963) stated that small albacore were caught in the eastern Pacific Ocean in the summer of 1954. Small (25-43 cm) albacore were taken northeast of Japan in 1953 (Asano, 1964), and Nakamura (1969) stated that "young albacore of around 28 cm and 35 cm fork length occur in considerable abundance in Japanese coastal waters in spring and summer, although the occurrence fluctuates greatly from year to year." Roberts and James (1974) reported that 34- to 43-cm albacore were caught around New Zealand in 1970, 1972, and 1973.

3.3 Adult phase

3.31 Longevity

Uchida and Otsu (1961) found 10 age groups of fish in the Japanese north Pacific winter longline catch, and believed the eldest to be 10 years old. Albacore caught near Hawaii are larger than those taken by the Japanese winter longline fishery (Otsu and Sumida, 1970), but no age analysis of the Hawaiian fish was attempted because the size difference between the sexes hampered modal analysis.

3.32 Hardiness

Clemens (1961) and Yoshida and Otsu (1963), based on experience in handling albacore during tagging operations, concluded that they are quite hardy. Generally, most taggers agree that albacore are hardier than any of the other tunas which they have tagged. Indeed, albacore survive tagging after capture by trollers, which subjects the fish to considerable stress. Laurs (1979) has held restrained, anesthetized albacore in life-support system for up to 30 hours, and subsequently revived them.

3.33 Competitors

Iversen (1962) reported that "a comparison of the stomach contents of equatorial albacore, yellowfin and bigeye tunas indicates there may be some competition for food between the albacore and the other two species of tuna." Legand and Wauthy (1961) noted possible competition between albacore and lancet fish (Alepisaurus) in waters around New Caledonia.

3.34 Predators

Albacore are preyed upon by man, large pelagic fish such as billfish and sharks, and mammals. Jones (1971) lists albacore as one of the victims of Isistius brasiliensis, a small shark which bites chunks of flesh from the sides of fish, leaving crater-shaped wounds.

3.35 Parasites, diseases, injuries, and abnormalities

Lists of the parasites of albacore are given by Yoshida and Otsu (1963), Silas and Ummercutty (1967), Kabata (1970), Roberts (1974), Love and Moser (1977), Cressey and Cressey (1980), and others.

3.4 Nutrition and growth

3.41 and 3.42 Feeding and food

De Buen (1958), Clemens (1961), Clemens and Iselin (1962), Iversen (1962), Iverson (1971), and Laurs and Nishimoto (1973) discuss the food and feeding of albacore in different areas of the eastern Pacific. Since albacore are caught on both surface gear and longlines it is suspected that they feed in at least the upper 380 m of the ocean. In the temperate north Pacific, troll-caught albacore feed throughout the day (Pearcy, Panshin, and Keene, 1975). Iversen (1962) stated that albacore feed during both day and night, but that the stomach volumes of fish caught at night are reduced, probably due to less successful foraging since albacore are most likely sight feeders (Murphy, 1969). The species composition of the forage changes with area. Laurs and Nishimoto (1973) found a direct relationship between the amount of food in the stomachs and the biomass of micronektonic animals caught in Isaacs-Kidd midwater trawls deployed in the same area in which the fish are caught. Based on the variety of species of food elements found in their stomachs, albacore can be considered to be opportunistic feeders (Clemens, 1961). Iversen (1962) found differences in average volume and composition of stomach contents of fish caught by different methods (Figure 5) and by size of fish. He also concluded that areas of relatively high abundance of albacore did not necessarily correspond with areas of high abundance of their forage.

3.43 Growth rate

The age and growth of Pacific albacore have been estimated by the analysis of hard parts (vertebrae and scales), size composition of the catch, and tagging experiments. Shomura (1966) summarized this work and used it to estimate the parameters of the von Bertalanffy growth equation (Table 2).

Utilizing tagging data, Laurs and Wetherall (1979) have demonstrated a significantly higher growth rate (K value in the von Bertalanffy growth equation, with L_∞ held constant) for those fish taken below 38°N when compared to those taken above 38°N in the North American fishery and/or the Japanese livebait fishery.

A summary of age-length relationship values is presented in Table 3. Some discrepancies exist in deciding which mode corresponds to 1-year old fish, both among methods and among investigators using the same method. Recent advances have been made in estimating age based on the daily increments on tuna otoliths, so a solution to the problem may be near (Laurs and Nishimoto, 1979; Wild and Foreman (1980). Yoshida (1969), working with material found in billfish stomachs, estimated that juveniles grow at a rate of about 3.12 cm per month.

3.44 Environmental physiology

The tunas, including albacore, are without doubt the most highly specialized fishes in regard to high levels of sustained locomotory activity. The physiology of the tunas and its importance to their activities is discussed by Sharp and Dizon (1978) and Dizon and Brill (1979).

Albacore are negatively buoyant ram-ventilators that must swim to stay suspended in the water column. They possess several systematic anatomical adaptations that augment their increased locomotory capacity (Collette, 1978), the most striking of which is a countercurrent multiplier system (heat exchanger) which allows them to regulate their body temperatures, which may be as much as 15.3°C above ambient (Sharp and Vlymen, 1978). Also the blood pressure and blood volume of albacore are higher than those of most other fishes.

Sharp and Dotson (1977) and Dotson (1978) discuss energy requirements and fat utilization, and state that albacore probably feed during migration, and may grow during this period due to the high caloric content of the forage consumed.

3.5 Behavior

3.51 Migrations and local movements

The migration of albacore in the north Pacific has been described by Clemens (1961), Flittner (1963), Otsu and Uchida (1963), Otsu and Yoshida (1966), Rothschild and Yong (1970), Laurs and Lynn (1977), and Laurs (1979b). The migration pattern described by Clemens consists of the recruitment of albacore into the North American fishery off the coast of California, movement northward along the Pacific coast of North America, and then movement westward along the subtropical convergence until the fish reach the Japanese fisheries. Otsu and Uchida's model (Figure 6) is similar to that of Clemens, but is more detailed in movement patterns of size classes of fish. It postulates a pattern of movement from the North American fishery into the Japanese longline fishery and then the Japanese livebait fishery. Rothschild and Yong (1970) believe that the fish enter the Japanese livebait fishery first, but may pass through the area of the longline fishery in the process, relatively invulnerable to the gear.

Tagging experiments by Kikawa, Shiohama, Morita, and Kume (1977) have shown that some of the fish moving from the Kuroshio Front area would enter the North American fishery the same year, but most would enter the longline grounds together with the fish moving westward from the North American coast. They also state that it seems unlikely that the fisheries of the western north Pacific are being supported solely by recruitment from the eastern Pacific as indicated by Otsu and Uchida's model. The results of tagging experiments by Laurs (1979) suggest at least two substocks of fish comprising the north Pacific population, each with a different migratory pattern. The northern substock makes trans-Pacific migrations between the eastern and western north Pacific north at about 40°N, resulting in an interchange of fish between the North American fishery, the Japanese livebait fishery, and the longline fishery west of 180°. The southern substock enters the North American fishery south of 40°N and the longline fishery east of 180°, and only a very small proportion of this group migrates between the eastern and western Pacific to enter the Japanese livebait fishery. Albacore tagged to the west of the traditional North American fishery during their seasonal migration into the fishery migrate either to the north or south, depending on whether their point of release was north or south of 35°N, which suggests that these substocks are separate upon entering the nearshore area. During a given season there is little exchange of fish between the northern and southern substocks in the North American fishery. Sund, Blackburn, and Williams (1980) review research done on the migrations and movements of albacore.

Yoshida (1971) has postulated that in the south Pacific juvenile albacore (<300 mm) migrate southward as they grow. Sund, Blackburn, and Williams (1980) note that the construction of a migration model for south Pacific albacore is impossible at this time, due to lack of information on their habits.

3.52 Schooling

Clemens (1961) discusses schooling behavior of albacore near the west coast of North America. Albacore of the same size travel together in "school groups up to 30 km wide, composed of small aggregations of fish." At the beginning of the season these groups are small and widely separated and composed of small, scattered, and fast-moving schools. Later, at the peak of the season, the groups are more compact and are composed of greater numbers of schools. Schools of larger fish are usually more compact than schools of smaller fish. Albacore are not found in large dense schools comparable to those of yellowfin and skipjack. Albacore are sometimes caught mixed with skipjack in New Zealand waters, and with skipjack, yellowfin, and bluefin in the surface fishery of the northeastern Pacific off Baja California in September and October. They sometimes associate with masses of floating kelp (*Macrocystis pyrifera*) in the southern area of that fishery.

3.53 Responses to stimuli

Albacore respond to oceanographic features, including temperature, water color, and upwelling areas (Laurs, Yuen, and Johnson, 1977). They are also sensitive to ship noise in trolling vessels (York, 1972; Anonymous, 1977c).

4 POPULATION

4.1 Structure

4.11 Sex ratio

Immature albacore (<90 cm) generally have a sex ratio of 1:1, but males predominate in the catches of mature fish (Otsu and Uchida, 1959; Otsu and Sumida, 1968). Males have accounted for as much as 86 percent of the albacore in longline catches. Several investigators have found ratios of 1:1 or more females than males in longline-caught fish, but in these cases the fish were mostly less than 90 cm or the sample sizes were small. The sex ratio of the catch may vary from year to year (Otsu and Sumida, 1968). A summary of studies done in different areas of the Pacific appears in Table 4.

4.12 and 4.13 Size and age composition

The size composition of the fish in the catches from the various albacore fisheries differs with the gear employed and area of recapture (Kurogane and Hiyama, 1957a; Kume, 1974), year-class strength, and sex ratio (Otsu and Sumida, 1968). Longlines generally take larger fish than livebait or trolling gear. A particularly abundant year class or a change in sex ratio may affect the size composition of the catch. Otsu and Sumida (1968) report that mature male albacore (larger than 79 cm) greatly outnumber females of the same size in the Samoa longline catch (Figure 7). Any shift in sex ratio could thereby cause a shift in size composition. The mean fish size for a fishery may vary with seasons, due to a concentration of fishing effort at certain times of the year in areas containing larger or smaller fish. Suda (1954) and Otsu and Sumida (1968) found that the average size of longline-caught albacore increases from west to east in the north and south Pacific, a phenomenon probably caused by environmental changes. Honma and Kamimura (1957) and Otsu and Sumida (1968) found that the mean length of albacore taken within 5-degree latitudinal bands tends to increase from north to south in the south Pacific, with size reaching a maximum in the 20°-25°S band, and diminishes thereafter. A summary of the age and size composition of the various albacore fisheries of the Pacific is shown in Figure 8.

The variations in the size composition among years can be illustrated by comparison of the mean fork lengths of the fish in the catches of the various fisheries. This was done for the north Pacific fisheries of 1951-1973 by Wetherall and Yong (1975) and by Otsu and Sumida (1968) for the Samoan longline landings for 1962 through 1965. Shiohama (1973) notes that in the northwestern Pacific livebait ground the smaller-sized fish tend to dominate in the northern portion while larger ones dominate the southern portion, which is reflected in the shift in size of the catch as the fishery shifts northward during the season.

Wetherall and Yong (1975) note no apparent change in the size composition of the fish caught in the Japanese livebait fishery until the 1970 expansion of the fishery offshore into the Kuroshio Front area, when a declining trend, caused by the exploitation of 2- and 3-year-old (64- and 75-cm) fish, became evident. The mean fish weight for the north Pacific longline fishery has increased since 1966, however.

The size composition of the fish caught in the North American fishery has shown little fluctuation, but there is a distinct difference in size composition above and below 38°N. The southern area has two modes, each of which is about 4 cm larger than the corresponding mode of the northern area, as depicted in Figure 9.

The age composition of the catch from the north and south Pacific has also been included in Figure 8, which is derived from data in Bartoo (1979) for the north Pacific fisheries (except Hawaii longline, which is from Uchida and Otsu (1961)), Otsu and Sumida (1968) for the south Pacific longline fishery, and Habib and Cade (1978) for the New Zealand surface fishery. Ages from Clemens (1961), plus one year, and Otsu (1960) are superimposed by the compiler of this report. Table 5 shows the composition of the catches by age of the fish caught by the various fisheries of the north and south Pacific, and Figure 10 shows that the north Pacific fisheries utilize younger fish than do those of the south Pacific. The age structure of the north Pacific albacore catches for 1952, 1957, and 1962, using Otsu's (1961) ages, is given in Wetherall and Yong (1975); for 1955-1976, using Clemens' (1961) ages, in Wetherall and Yong (1975); and for 1955-1976, using Clemens' (1961) ages plus one year, in Bartoo and Weber (1979).

A summary of length-weight relationship data for albacore appears as Table 6.

4.2 Abundance and density

4.21 and 4.22 Average abundance and changes in abundance

A rough estimate of the relative apparent abundance of albacore may be ascertained by examining catch-per-unit-of-effort (CPUE) statistics. Data for the north Pacific longline fishery have been examined by Rothschild and Yong (1970), who estimated the changes in apparent abundance for 1949 through 1961. Laurs, Clemens, and Hreha (1976) analyzed CPUE data for the United States troll fishery for 1961 through 1970 and found marked annual variation between the northern and southern areas of the fishery. Bartoo and Weber (1979) discuss the trends in the total north Pacific CPUE by age groups for 1961 through 1976. They found no apparent trend until 1971, when the catches and variability increased with the offshore expansion of the Japanese livebait fishery, resulting in an increased CPUE of younger fish (ages 2, 3, and 4) with lower catch rates for ages 5 and 6. This in turn resulted in a generally decreased CPUE for the North American surface and Japanese longline fisheries. CPUE data for the north Pacific fisheries appear in Table 7, and the trends in CPUE in Figure 11. Yoshida (1971a and 1975), Skillman (1975 and 1978), and Wetherall, Riggs, and Yong (1979) calculated indexes of relative abundance for the south Pacific and American Samoa longline fisheries in kilograms per hundred hooks, metric tons per trip, metric tons per day fished, numbers caught per hundred hooks, and metric tons per thousand hooks (Tables 8, 9, and 10). There is general agreement that a downward trend in CPUE has been evident in recent years, as indicated by Figures 12 and 13.

4.23 and 4.24 Average density and changes in density

The distribution of CPUE over an area can indicate the relative density of albacore in locations receiving fishing effort. Figure 14 shows the distribution of the average catch per hook by Japanese longliners, averaged over 1952-1976, indicating the areas of relatively high density of large fish. Areas of high density of smaller fish are dependent upon oceanographic conditions in the surface layers, and can be identified by concentrations of surface fishing effort, *e.g.* historic surface fisheries (Figure 15). Otsu and Yoshida (1966) and Suzuki, Warashina, and Kishida (1977) show the distribution of catches of deep-caught albacore (Figure 2), indicative of relatively dense areas of deep swimming albacore at lower latitudes. Generally, the centers of density of all albacore occur between 25° and 40°N and 10° and 30°S (Kume, 1974).

4.3 Natality and recruitment

Suda (1959) discusses the possibility of "a situation where the physical and chemical environment at the time of spawning and immediately following the hatching of the eggs becomes an important factor affecting the success of hatching."

Recruitment is believed to take place in the northeastern Pacific surface fishery and in the higher latitudes of the south Pacific at 2 years of age. Bartoo and Weber (1979), making certain assumptions about mortality and age structure, estimated the recruitment for the age-2 fish of the north Pacific stock by cohort analysis for 1955-1974, and found it can vary by as much as a factor of four (Figure 16). The estimates for the birth years 1953-1972 varied from 3.3 to 14.5 million age-2 fish.

4.4 Mortality and morbidity

Suda (1963a and 1966a) and Murphy and Sakagawa (1977) estimated the mortality coefficients for albacore. The annual natural (M) and total (Z) mortality coefficients were estimated to be 0.20 and 0.40, respectively. These approximate Tauchi's (1940b) estimate of 0.66 for the annual survival rate, equivalent to an instantaneous total mortality rate of 0.4155.

The age-specific mortality of albacore was estimated from data on fish caught by Japanese longline vessels by Suda (1966a and 1970). He assigns instantaneous natural mortality rates of 0.20 to 6-year-old fish and 0.40, 0.60, and 0.80 to fish at the end of the sixth, seventh, and eighth years, respectively. Wetherall and Yong (1975), who reanalyzed the data, concluded that Suda's last three estimates were too high, and proposed values of 0.3, 0.4, and 0.5 for fish at the end of their sixth, seventh, and eighth years respectively.

Morbidity probably has relatively little effect upon total mortality, due to the high amount of fishing mortality.

4.5 Dynamics of the population

Albacore in the Pacific are believed to be divided into two populations, one in the north Pacific and one in the south Pacific. According to Sund, Blackburn, and Williams (1980), available data indicate that albacore do not migrate across the equator in any season, that the areas occupied in the two hemispheres are roughly symmetrical (Nakamura, 1969), and that there are separate spawning grounds and times in the two hemispheres.

Using the logistic form of the general production model of Pella and Tomlinson (1969), Shiohama (in Wetherall, 1979) estimated the maximum sustainable yield (MSY) from the north Pacific to be 100,000 to 120,000 metric tons of albacore. Wetherall and Yong (1975) judged that the yield per recruit of north Pacific albacore would be greater if the level of fishing mortality were increased relative to that during 1959-1975, and Bartoo and Weber (1979) state that the decline in yield per recruit in recent years suggests that the current harvest strategy does not permit maximum utilization of the resource. Some concern for the north Pacific albacore is warranted due to the expansion of the Japanese livebait fishery offshore into the Kuroshio Front area and the subsequent harvesting of younger fish (4 years old or less). The fishery, including that of the expanded area, produced 124,000 metric tons in 1976, as compared to 67,000 metric tons prior to expansion in 1970.

Skillman (1975) and Wetherall, Riggs, and Yong (1979) employed the general production model to estimate the MSY of albacore for the south Pacific and obtained estimates of 33,000 to 35,000 and 33,000 to 36,000 metric tons, respectively. These estimates are tentative however, as revised estimates of the catch for some years may alter them slightly (Bartoo, 1979).

Skillman (1978) observes that the CPUE corresponding to the MSY in the south Pacific is about 0.79 metric tons per day fished, and that the effort corresponding to this level was surpassed by the fishery in 1970. The relative abundance has since declined steeply, indicating that the albacore stock has been overfished, and he noted that the decline in the index of relative abundance in the southern winter fishery for small albacore may indicate that the adult stock has been reduced to levels sufficiently low as to reduce the recruitment.

4.6 The population in the community and the ecosystem

Albacore, like the other tunas, are apex predators in the pelagic environment of warm seas. Their feeding and schooling habits have been discussed in earlier sections. No specific, quantitative information on this subject was encountered.

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gears

Takayama (1963), Yoshida and Otsu (1963), and Yoshida (1966b) describe the gears employed to catch albacore and other tunas in the various Pacific Ocean fisheries, including longline, livebait, trolling, and purse seine. Minor modifications to these methods have been made over the years, and the significant ones are mentioned below. More detailed information concerning gear is found in June (1950), Shapiro (1950), Shimada (1951b), Otsu (1954), Mann (1955), Kanasashi (1960), Saito (1973), and Suzuki, Warashina, and Kishida (1977) for longline, Clemens (1955), Scofield (1956), de Buen (1958), Watkinson and Smith (1972), Roberts (1974), and Dotson (1979) for trolling, Godsil (1938), Cleaver and Shimada (1950), Muramatsu (1960), and Dotson (1979) for livebait fishing, and Clemens (1961) and Shaver (1962) for purse seining.

Hydraulic gurdy systems for hauling in hooked fish have been developed in recent years for the troll fishery (Dotson, 1979), and "automatic fishermen," which are lever systems which pull livebait-caught fish aboard without assistance from human fishermen, have been fabricated in Japan and the United States (Laurs 1979). Saito (1973) and Suzuki, Warashina, and Kishida (1977) describe "deep" longline gear, which fishes at greater depths than does standard gear.

5.12 Boats

The North American surface fishery has seen changes in vessel characteristics and fishing power since it was first described by Godsil (1938), Clemens (1955), and Scofield (1956). Trollers are larger now (up to 22 m) and are constructed of steel, fiberglass, or aluminum. Major changes in the fishing power of the vessels include increased refrigeration capacity and better communication systems, navigational aids, fish locating equipment, and hull design.

The New Zealand surface vessels are modified from vessels built for other fisheries, but have basically the same gear as the northeastern Pacific trollers.

Japanese livebait boats are described by Cleaver and Shimada (1950), Muramatsu (1960), Yoshida (1966b), and Webb (1972). These boats have also increased in size and bait holding capacities, which greatly increases the time they are able to spend at sea, and their range.

Longline vessels are described by June (1950) and Kanasashi (1960). They tend to be larger now, however, the average vessel being 300-500 gross tonnage and of steel construction.

A pictorial description of the different gears is found in Tomiyama (1975).

5.2 Fishing areas

5.21 and 5.22 General geographic distribution and ranges

The principal areas of albacore fishing in the Pacific Ocean are shown in Figure 15. Clemens (1961) states that albacore have been recorded from Clarion Island, Mexico, to the Gulf of Alaska, with the most productive fishing grounds being between central Baja California and the mouth of the Columbia River. The fishery has since expanded north to the Queen Charlotte Islands. The fishery has recently expanded westward along 35°N to 140°W during the early season. Van Campen (1960) describes the Japanese livebait fishery area as an arc averaging 200-300 miles in width extending from 30°N and 140°E to 32°-33°N and 160°-165°E. This fishery has expanded eastward along 40°N to approximately 170°W during the 1970's. The north Pacific Japanese longline fishery now takes place almost completely across the Pacific, having expanded eastward in recent years from the traditional area, which stopped at 170°W and was contained between about 20° and 45°N. The Hawaiian longline fishery, which takes incidental catches of albacore, is pursued within 20 miles of the islands (Otsu, 1954; Yoshida and Otsu, 1963).

The albacore longline fishing grounds in the south Pacific run from near the equator to 40°S and from 160°E to 80°W, although most of the effort is expended between 10° to 30°S and 160°E to 110°W (Wetherall, Riggs, and Yong, 1979). Roughley (1951) described the Australian surface fishery as occurring on the southeast coast from Port Macquarie to Westernport, on the east and south coast of Tasmania, and the south coast of Western Australia. Only incidental catches are made there now. The New Zealand fishery occurs along the west coasts of both islands and the east coast of North Island north of the Mahia Peninsula. Most of the catches are taken within 32 km of the land (Watkinson and Smith, 1972).

5.23 Depth ranges

Albacore have been caught at the surface by trolling or baitfishing off North America, east of Japan, and near Chile, Australia, and New Zealand (Yoshida and Otsu, 1963). Longline gear accounts for the fish taken at depths up to 140 m in the northwestern Pacific, near Hawaii, and in the south central Pacific. Murphy and Shomura (1953) report that albacore are generally caught on the deeper hooks of the longlines in the equatorial Pacific, but in the central north Pacific Shomura and Otsu (1956) report equal numbers from all depths fished. This is probably due to the differences in vertical thermal structure between the equatorial and northern areas. A modification called a "deep longline," used in areas where albacore are found at greater depths (up to 380 m), is described by Saito (1973) and Suzuki, Warashina, and Kishida (1977).

5.24 Conditions of the grounds

Water temperature is a major determinant of the fishing area in all the fisheries. In the northeastern Pacific, Clemens (1961) found a catch-temperature relationship, with the majority of the California catch coming from waters between 15.6° and 19.4°C. Roberts (1974) encountered albacore in New Zealand only in areas with sea-surface temperatures between 18.5° and 21.3°C. Laurs, Yuen, and Johnson (1977) found that albacore respond to temperature fronts and upwelling, and that the catch rates were highest within the boundaries of temperature and salinity known as the Transition Zone. The development of a certain pattern of surface temperatures off Japan caused by the progression of the Kuroshio Current northward in the spring results in isolated water masses with temperatures conducive to good fishing (Van Campen, 1960; Yoshida and Otsu, 1963).

5.3 Fishing seasons

Table 11 is a synopsis of information concerning the fishing seasons of the various Pacific fisheries.

5.4 Fishing operations and results

5.41 Effort and intensity

Although different authors have different definitions of the units, the fishing effort expended upon albacore is usually measured in days fishing or number of hook days, henceforth referred to as number of hooks. Standardization of effort among gears and among vessels of different fishing power is accomplished in various ways. Craig (1963) describes a standard format for United States west coast surface fishery logbooks, and Abramson (1963) and Laurs, Clemens, and Hreha (1976) provide a method for assessing the relative fishing powers of the vessels. The total fishing effort can vary due to such factors as changes in availability and abundance of the fish, number of vessels, and fishing power of the individual vessels.

An example of effort increasing with fleet expansion is shown in Figure 17, which illustrates the expansion of the longline fleet in American Samoa. The total effective effort for the north Pacific is estimated by Bartoo and Weber (1979) in Table 12 and for the south Pacific by Skillman (1975) and Wetherall, Riggs, and Yong (1979) in Tables 8 and 10.

The historic fishing areas of the Pacific defined in Figure 15 generally receive most of the total effort. Wetherall, Riggs, and Yong (1979) have estimated nominal effort by longliners of the Republic of Korea and the Republic of China by latitudinal band (Table 13).

5.42 Selectivity

Gear selectivity by size is shown in Figure 7, which indicates the sizes of fish taken by various gear types. In general, surface gear takes smaller fish and longline gear takes larger fish.

5.43 Catches

Tables 14 and 15 list the catches from the north and south Pacific by gear. Table 16 gives the weight of albacore caught by Japanese purse seiners, which is not included in the totals in Table 14.

6 PROTECTION AND MANAGEMENT

There are no management bodies regulating albacore effort. Suda (1973b) examines possible strategy for management of the albacore stocks, as well as those of other species, by regulation of longline effort, and Yoshida and Otsu (1963) give a short historical review of California regulations concerning albacore.

7 CULTURE

Inoue (1973) states that albacore have not been successfully raised nor held in captivity.

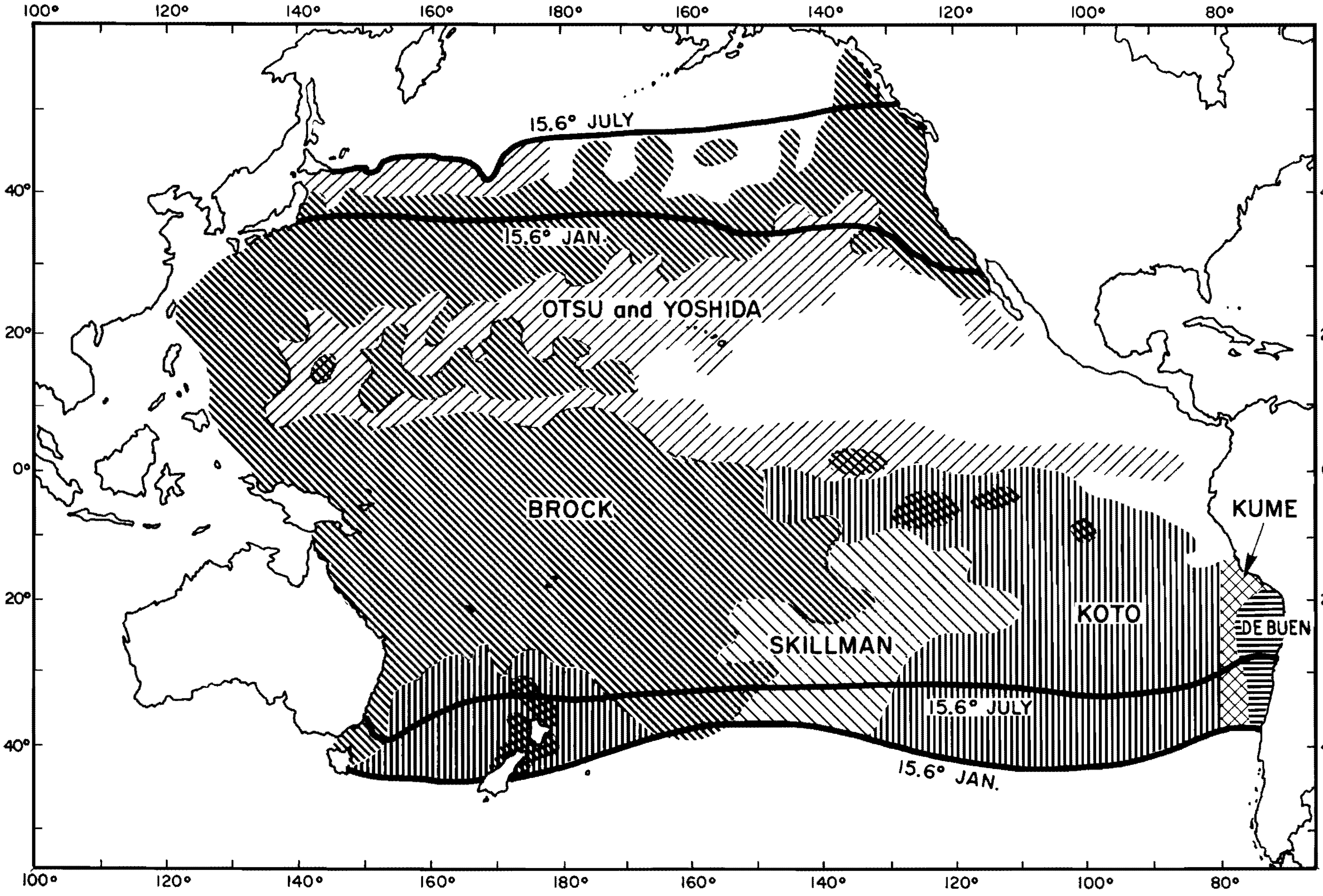


FIGURE 1. Distribution of albacore in the Pacific Ocean.

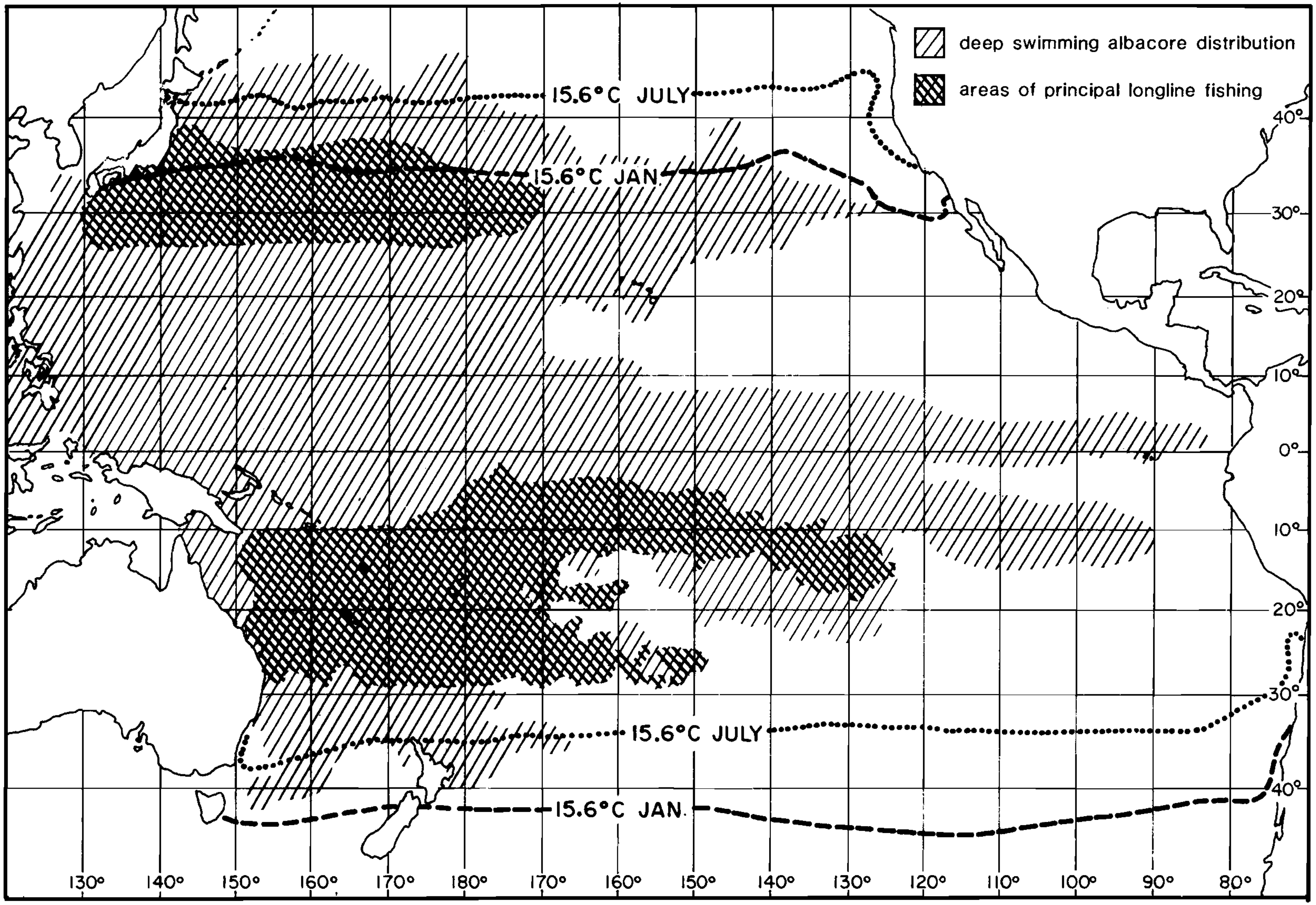


FIGURE 2. Distribution of deep-swimming albacore (hatching) and their principal fisheries (crosshatching) in the Pacific Ocean (from Otsu and Yoshida, 1966).

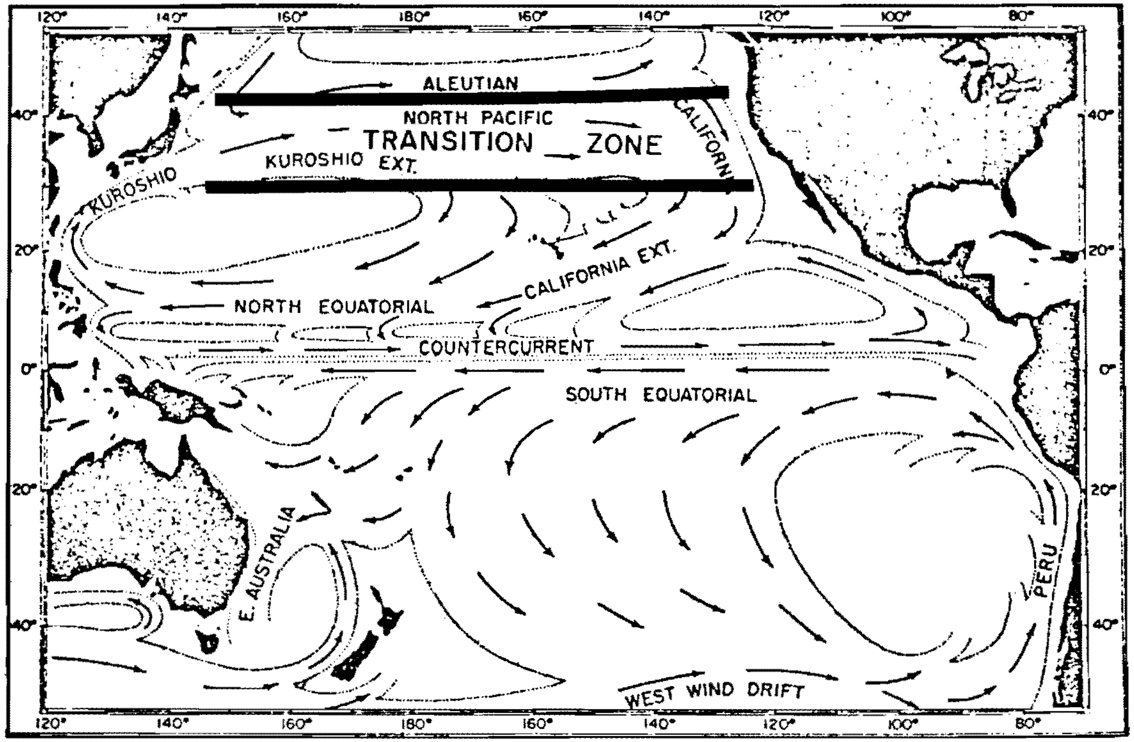


FIGURE 3. Pacific Ocean current systems (from Otsu and Yoshida (1966) and McGary, Graham, and Otsu (1958)).

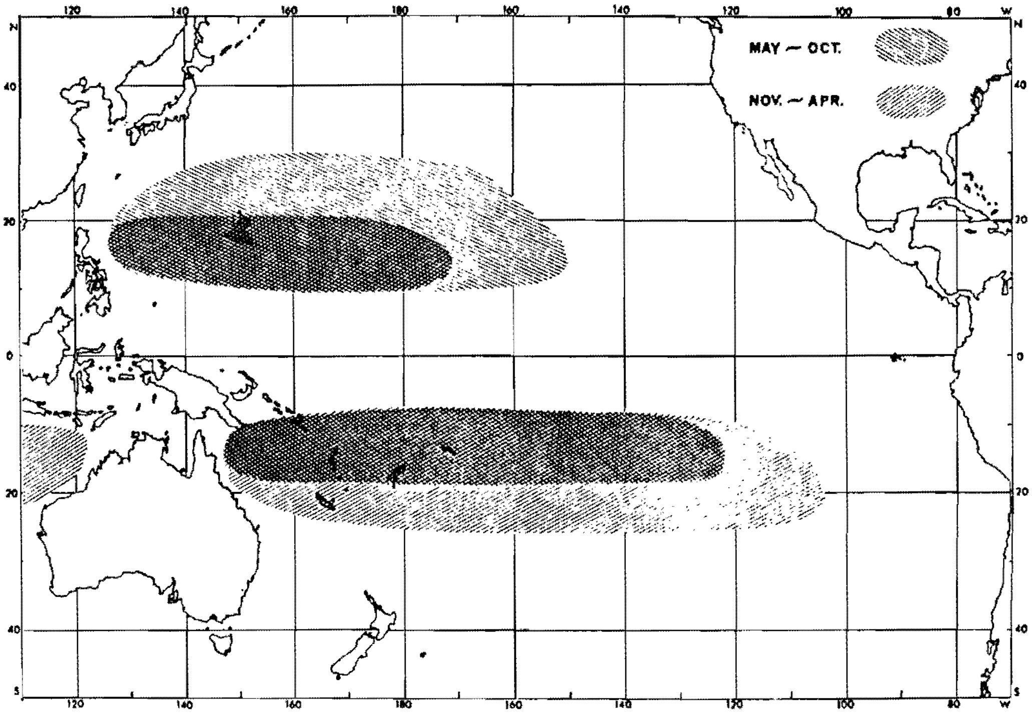


FIGURE 4. Distribution of albacore larvae in the Pacific Ocean (from Ueyanagi, 1969). The spawning areas are coincidental with larval distribution.

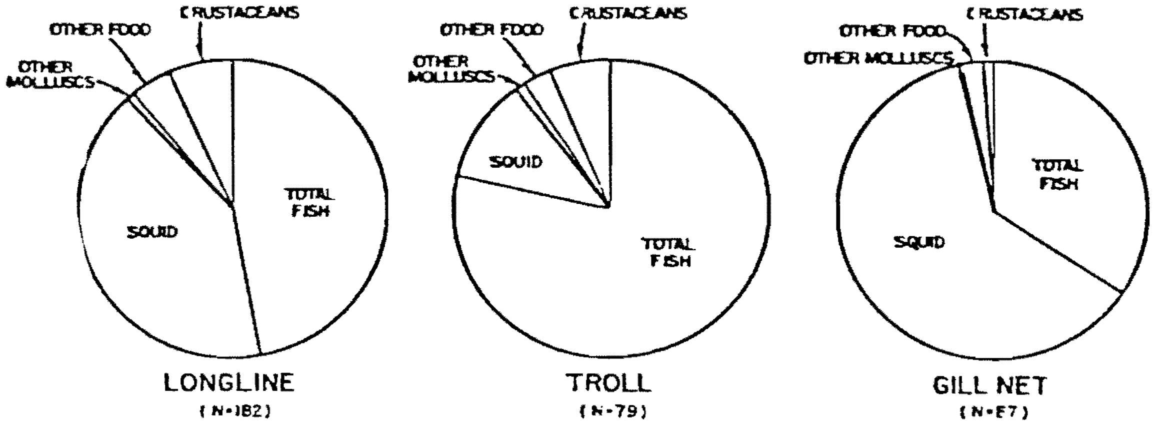


FIGURE 5. Comparative importance, by volume, of the major food elements found in 348 albacore stomachs (from Iversen, 1962).

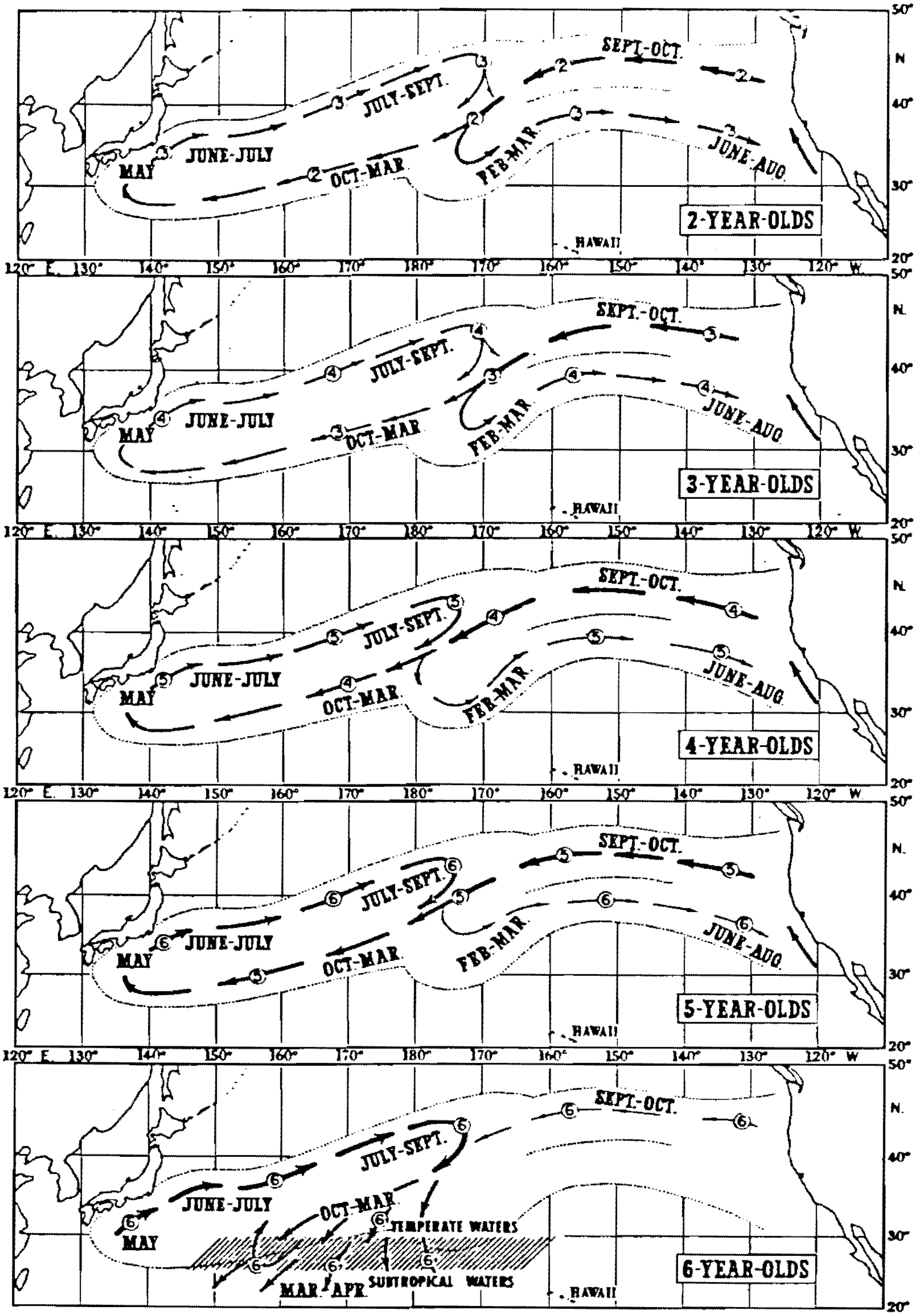


FIGURE 6. Model of albacore migration in the north Pacific Ocean, with age groups encircled (from Otsu and Uchida, 1963).

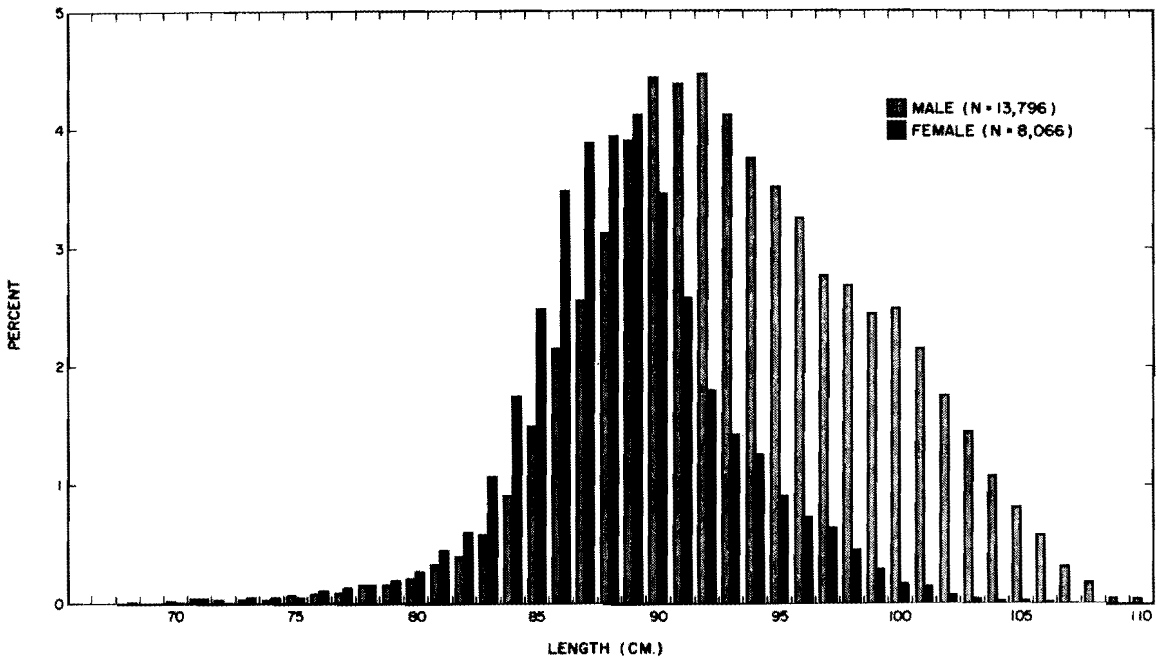


FIGURE 7. Composite length frequency distributions of male and female albacore landed by American Samoa-based longline vessels during 1965 (from Otsu and Sumida, 1968).

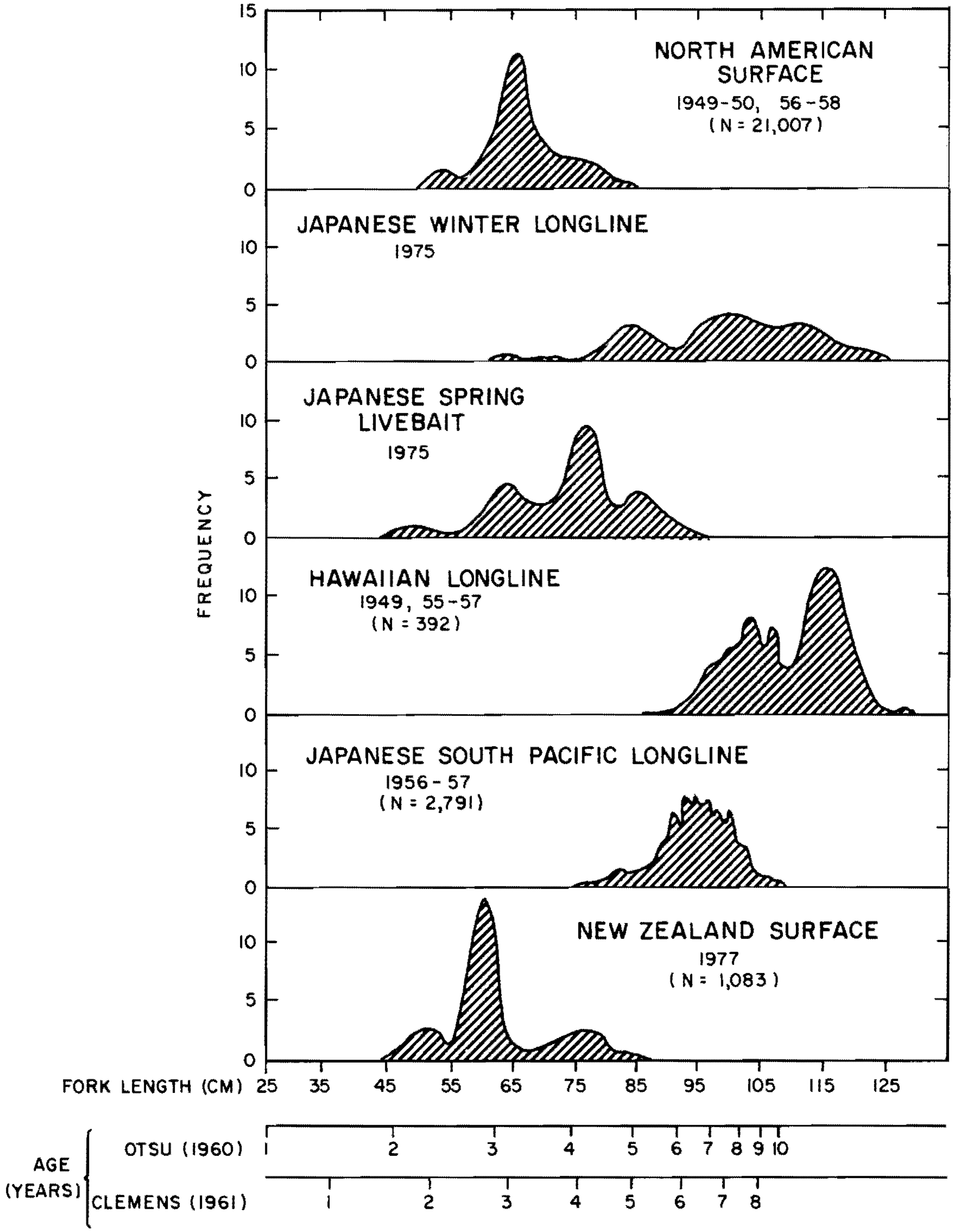


FIGURE 8. Length frequency distributions for the various albacore fisheries. The data are explained in Section 4.13.

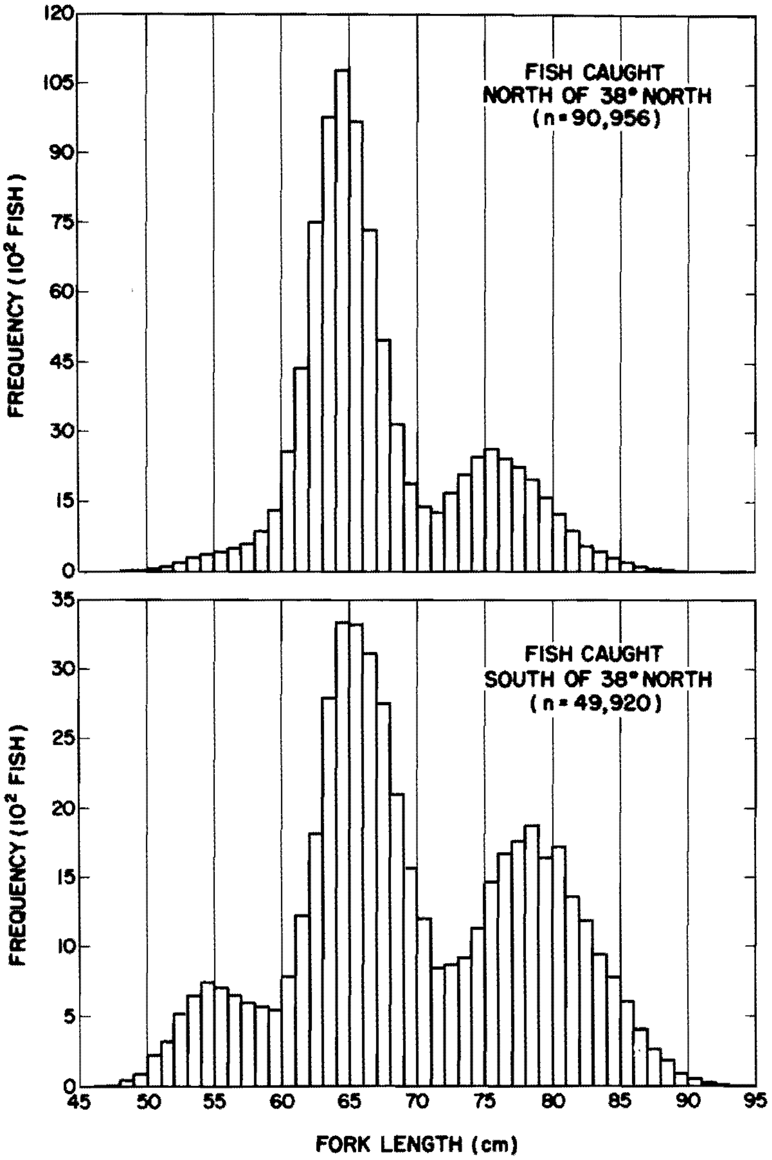


FIGURE 9. Composite length frequency distributions of north Pacific albacore caught north of 38°N and south of 38°N off the North American coast during the 1972-1975 fishing seasons (from Laurs and Wetherall, 1979).

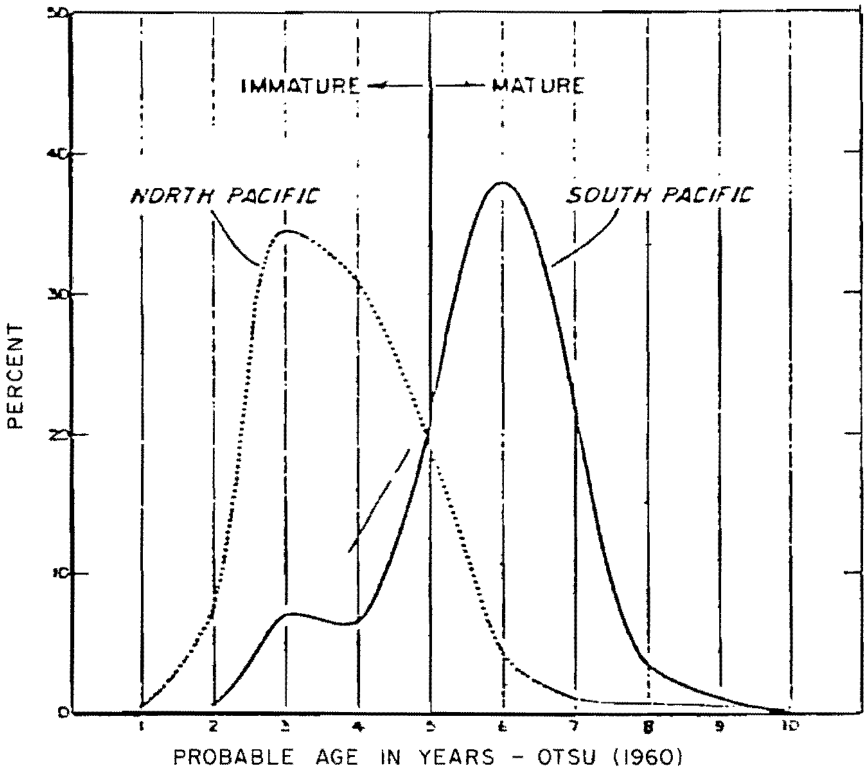


FIGURE 10. Comparison of the percentage age compositions of albacore taken in the north Pacific and south Pacific Ocean (5-year average, 1955-1959) (from Uchida and Otsu, 1961).

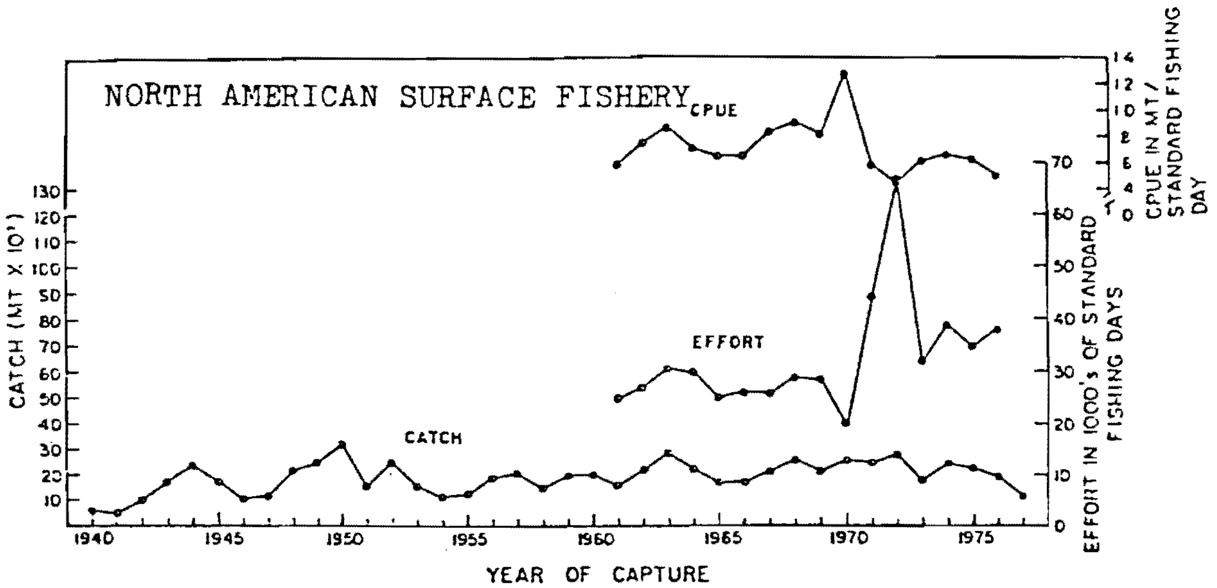


FIGURE 11. Relationship of catch, effort, and CPUE of albacore for the north Pacific fisheries, 1952-1977 (from Bartoo and Weber, 1979).

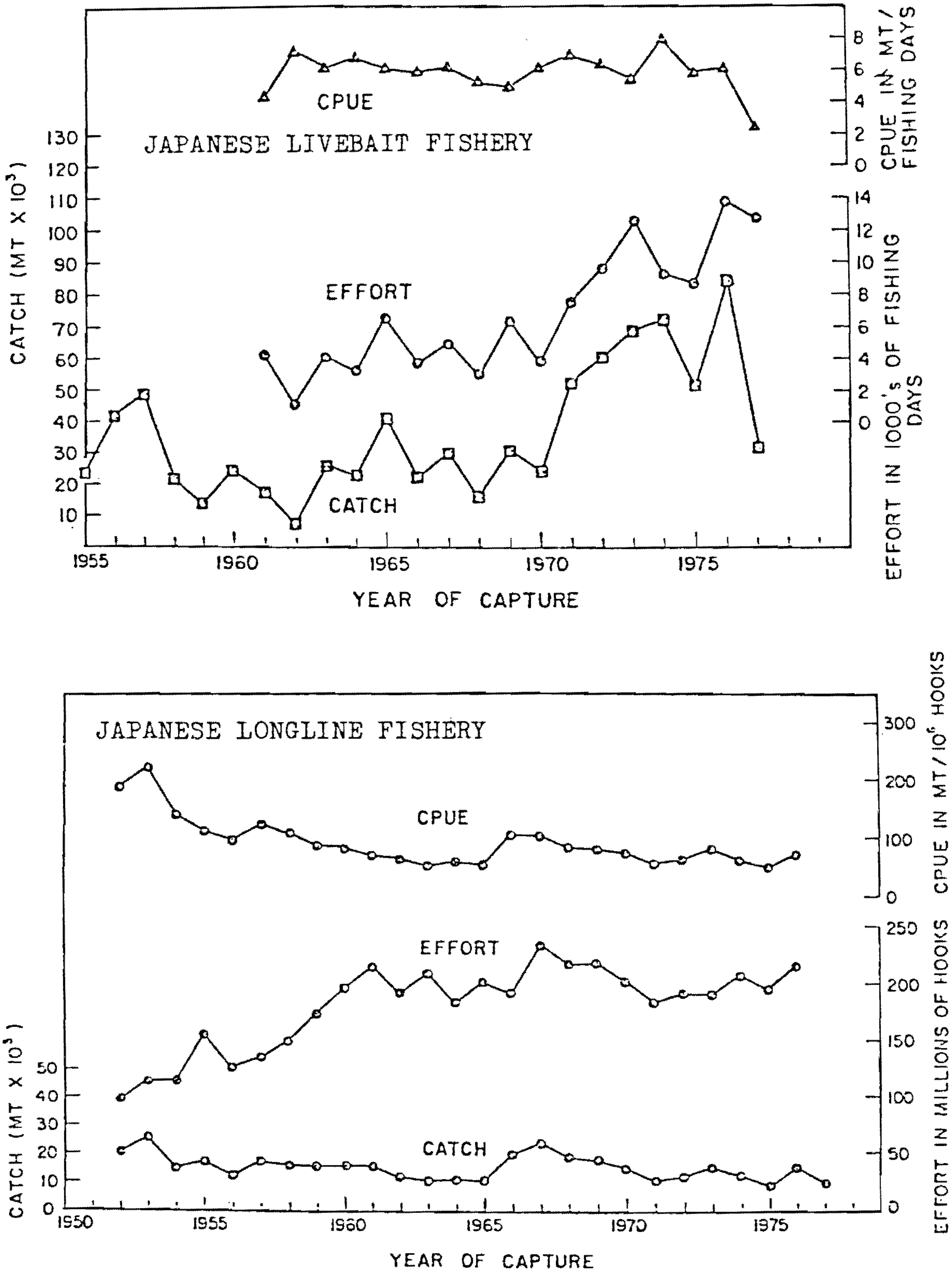


FIGURE 11. (continued)

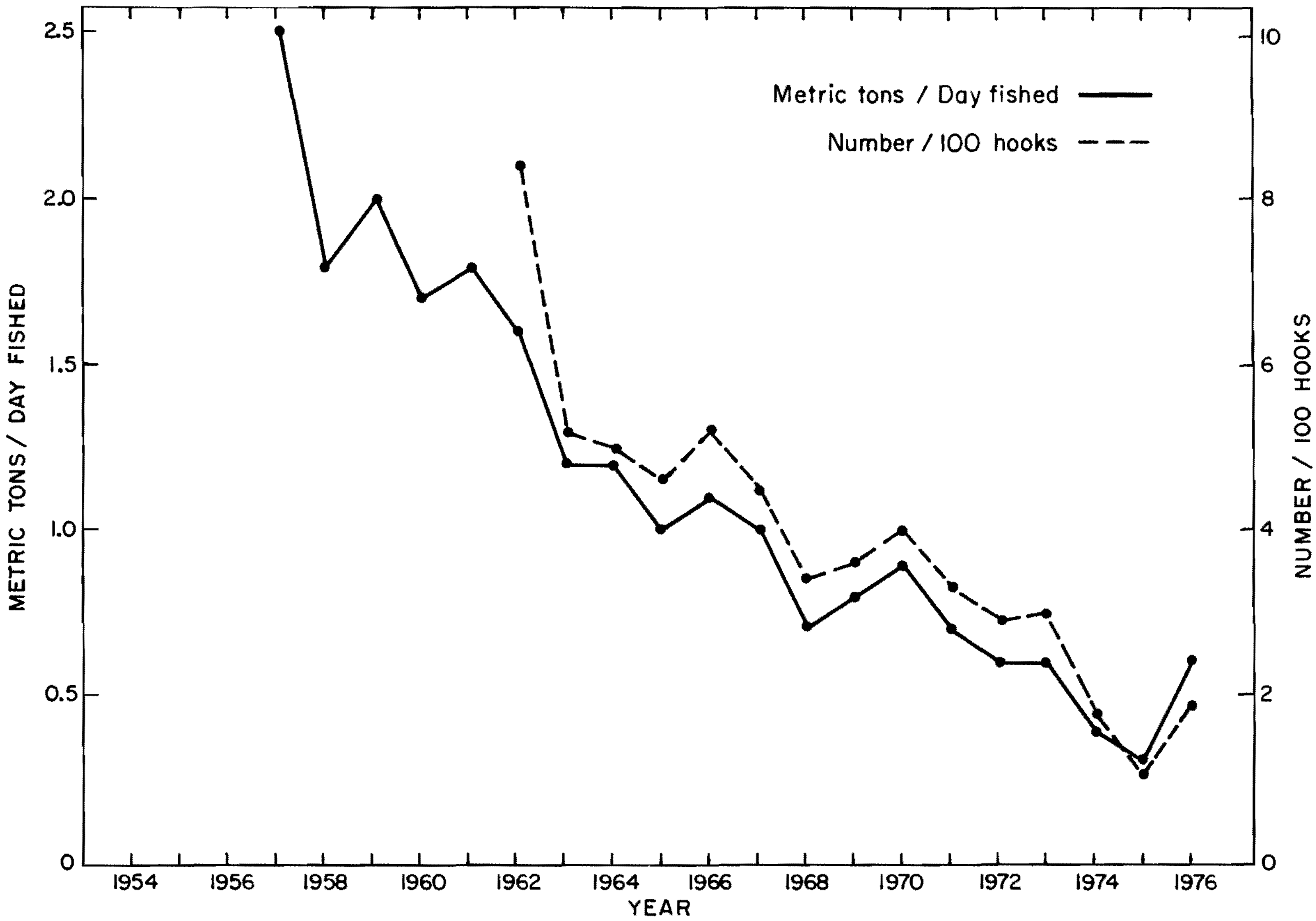


FIGURE 12. Indexes of relative abundance for the longline fishery based in American Samoa, for albacore, 1957-1976 (from Skillman, 1978).

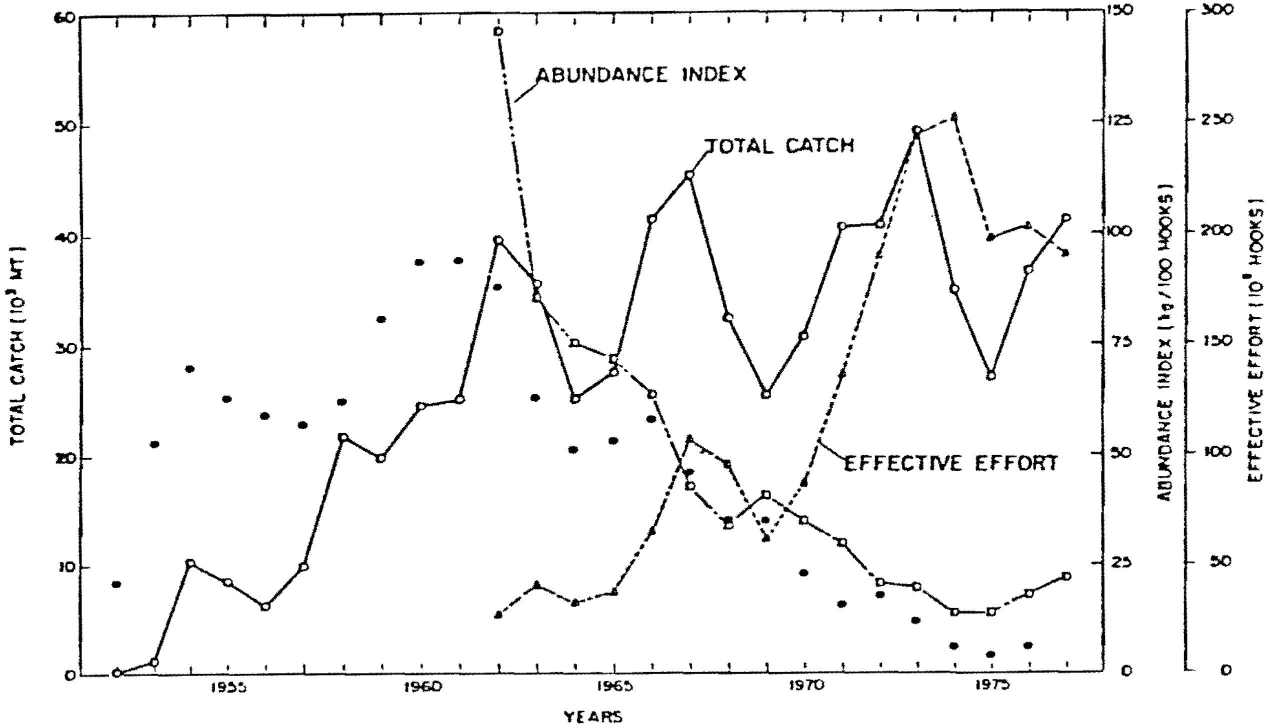


FIGURE 13. Estimated total catch (in thousands of metric tons), abundance index (in kg/100 hooks), and effective effort (in millions of hooks) for south Pacific albacore. The solid circles denote a second abundance index based on historical Japanese longline statistics (from Wetherall, Riggs, and Yong, 1979).

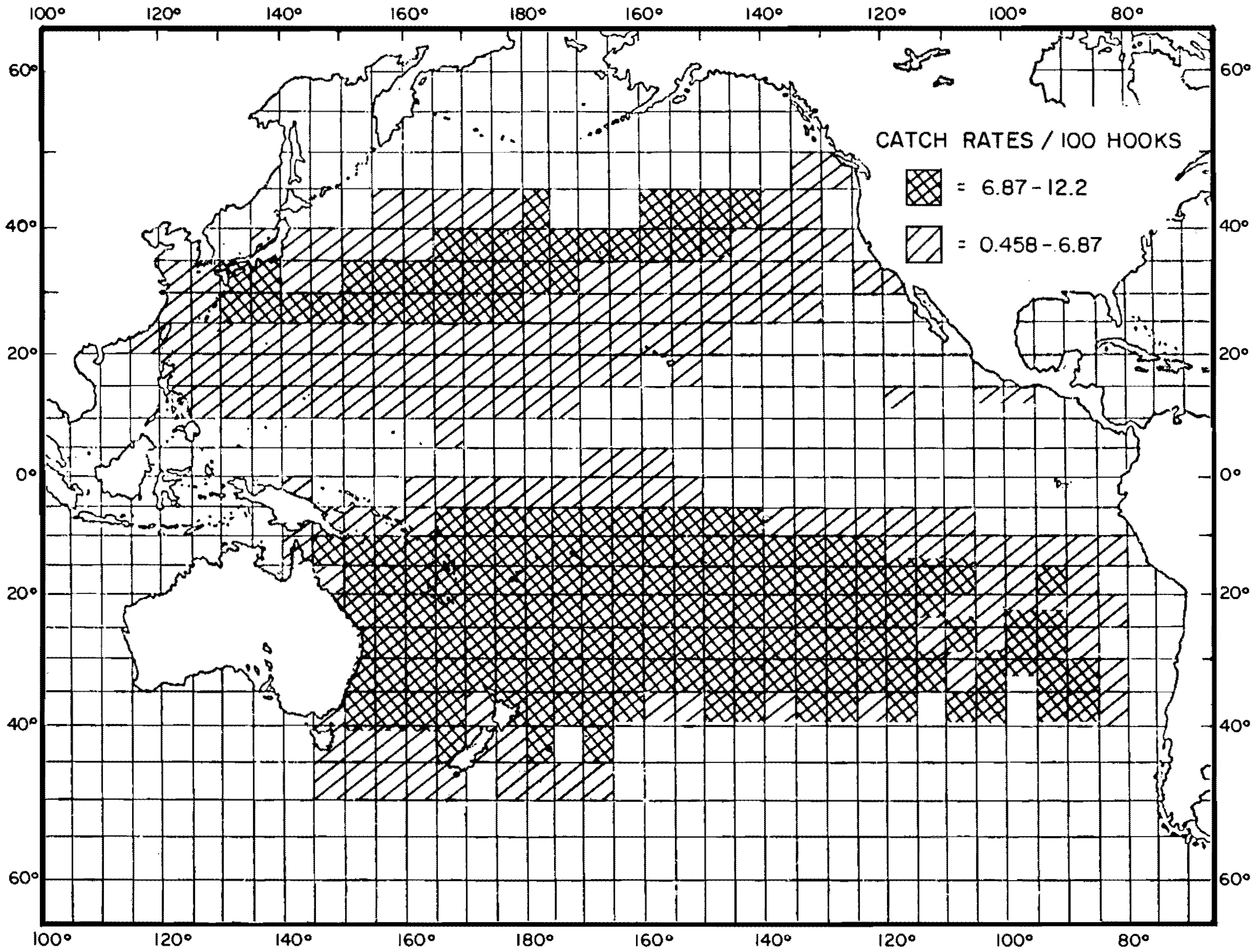


FIGURE 14. Distribution of average catch per hook for Pacific Ocean albacore taken by Japanese longliners, averaged over 1952-1976 (from Wetherall, Riggs, and Yong, 1979).

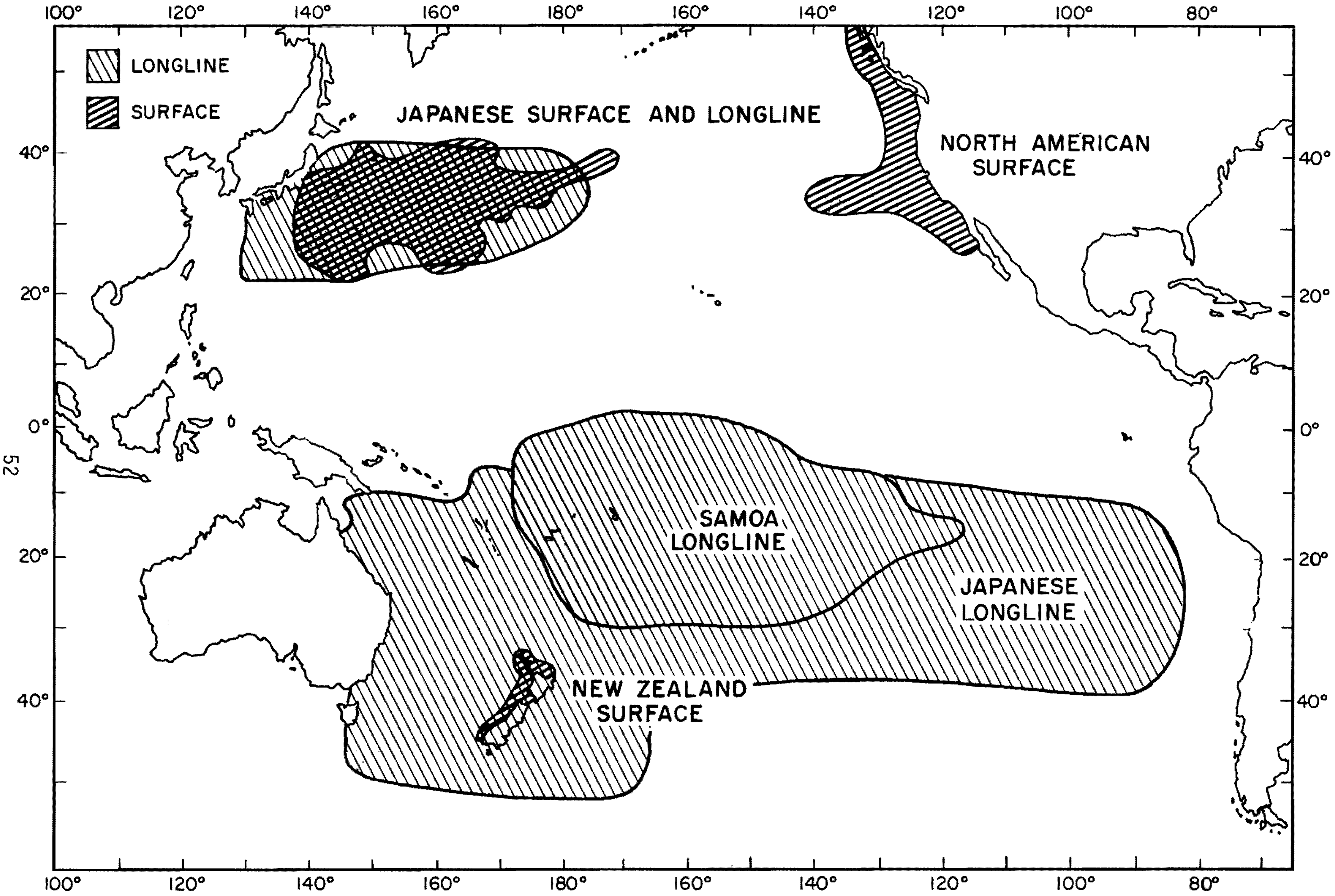


FIGURE 15. Major historical Pacific albacore fishery areas.

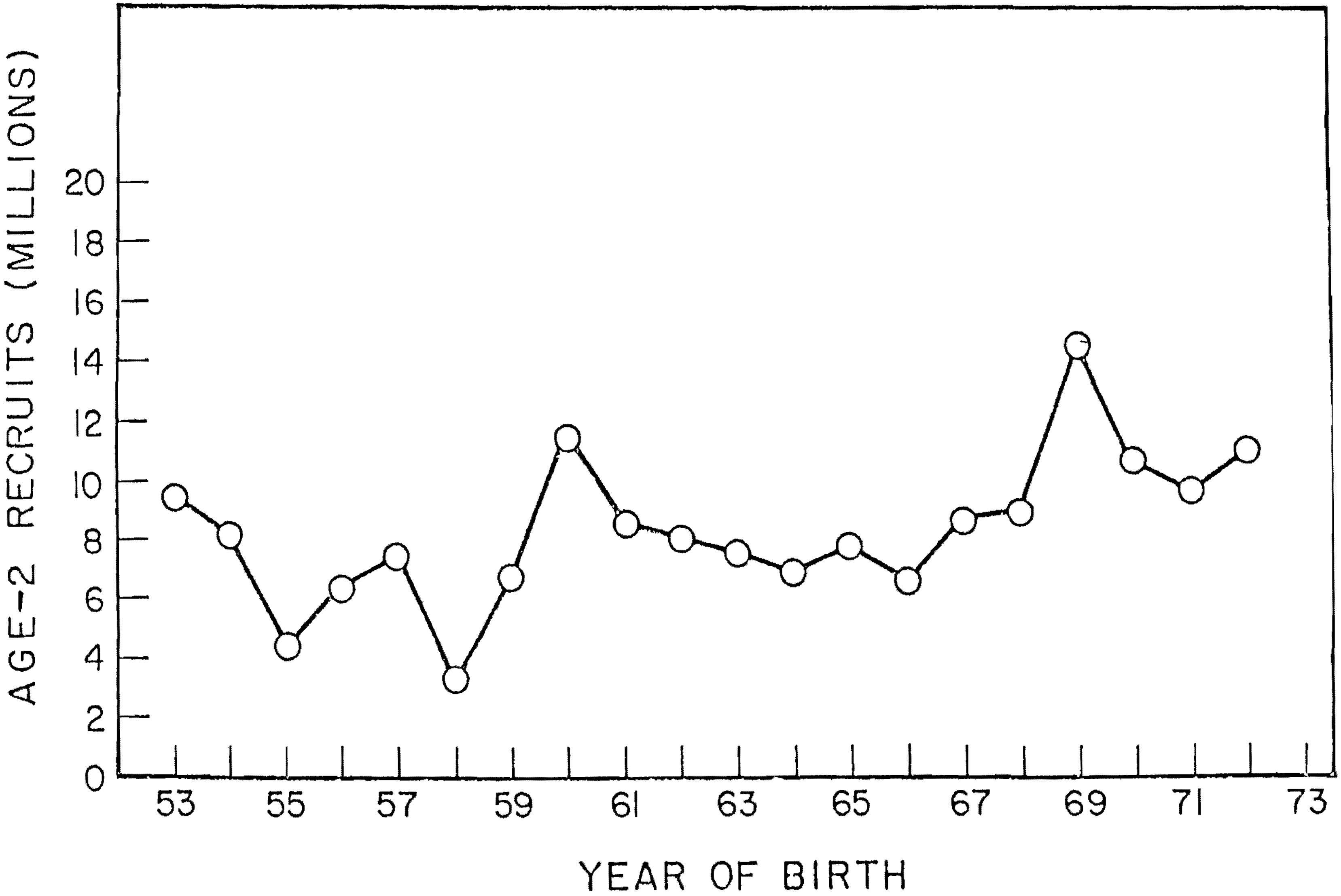


FIGURE 16. Recruitment of age-2 albacore for 1953-1972, estimated from cohort analysis for the north Pacific (from Bartoo and Weber, 1979).

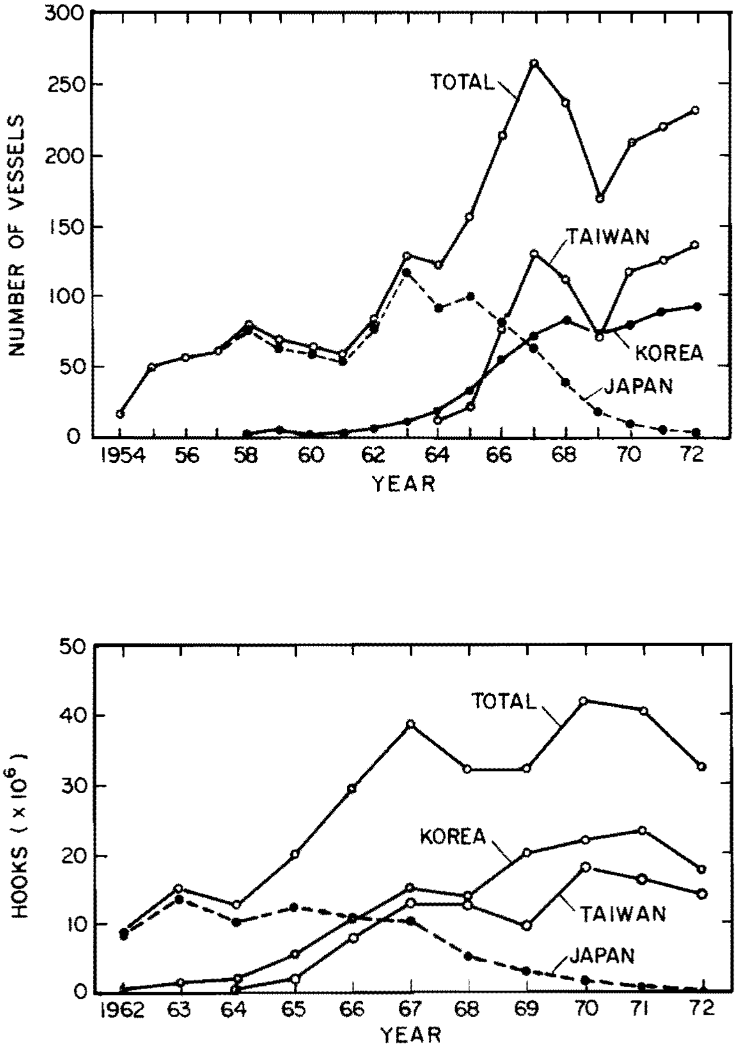


FIGURE 17. The relationship between effort and number of vessels in the American Samoa longline fleet, 1954-1972 (adapted from Skillman, 1975).

TABLE 1. Spawning seasons of albacore in different areas of the Pacific Ocean.

Area	Time of year	Peak	Reference
Western north Pacific, 20°-25°N	northern summer	June-July	Ueyanagi (1957)
Hawaiian Islands	northern summer	June-July	Otsu and Uchida (1959)
Hawaiian Islands	March-September	March-May	Yoshida (1968)
Central south Pacific, 10°-20°S	southern summer	December-January	Otsu and Hansen (1962)
Coral Sea	southern summer	January	Ishii and Inoue (1956)
New Caledonia	southern summer	December-January	Yoshida (1968)

TABLE 2. Estimates of the parameters of the von Bertalanffy growth equation for albacore.

Fishery	Method	L_∞ (cm)	K (annual)	t_0 (years)	Size range (cm)	Investigators	Comments
Western north Pacific	vertebrae	104.8	0.431	1.504	69-90	Uno (1936)	parameters calculated by Shomura (1966)
North Pacific	scales	114.4	0.308	0.818	65-120	Nose, Kawatsu, and Hiyama (1957)	parameters calculated by Shomura (1966) from 1952-1953 samples
"	"	145.3	0.159	-0.056	50-120	" "	parameters calculated by Shomura (1966) from 1953-1954 samples
Eastern north Pacific	"	108.8	0.2247	-2.2728	51-94	Bell (1962)	author's values
Western north Pacific	"	145.3	0.150	-0.396	40-95	Yabuta and Yukinawa (1963)	parameters calculated by Shomura (1966)
North Pacific longline, livebait, and troll	tagging	118.8	0.250	1.999	60-91	Otsu (1960)	parameters calculated by Shomura (1966)
"	"	135.6	0.17	-1.87	54-77	Clemens (1961)	author's values
Atlantic longline	length frequencies	140.0	0.141	-1.83	68-114	Beardsley (1971)	author's values

TABLE 3. Length at age, in centimeters, of albacore (from Yoshida and Otsu (1963) and Beardsley (1971)).

Age	Length frequencies		Scales		Tagging	
	Suda (1954)	Beardsley (1971)	Nose, Hiyama, and Kawatsu (1957)	Bell (1962)	Otsu (1960)	Clemens (1961)
1	57	44	38	57.3	-	52
2	67	55	49	65.7	-	65
3	78	64	59	77.4	26.3	76
4	89	75	68	83.7	46.8	85
5	100	87	78	87.8	62.7	93
6	111	95	86	-	75.1	100
7	-	100	96	-	84.8	105
8	-	104	105	-	92.3	-
9	-	108	-	-	98.2	-
10	-	112	-	-	102.7	-

TABLE 4. Sex ratios of albacore from various areas of the Pacific.

Area	Ratio male:female	Size range	Sample size	Reference
North Equatorial Current	2.64:1	>90 cm	408	Suda (1956)
North Pacific	1:1	50-112 cm	126	Otsu and Uchida (1959)
Southeastern Pacific	1.28:1	70-90 cm	373	Martinez F. (1974)
Central equatorial Pacific	0.76:1	83-104 cm	58	Murphy and Shomura (1953 and 1955)
"	0.63:1	89-106 cm	18	"
New Caledonia	2.66:1	80-109 cm	143	Legand (1961)
South Pacific	1.63:1	>90 cm	not given	Otsu and Sumida (1968)

TABLE 5. Age composition of the albacore catches in the Pacific Ocean, by fishery.

Fishery	Age (years)										Reference
	1	2	3	4	5	6	7	8	9	10	
North American surface		X	X	X	X						Bartoo and Weber (1979)
Japanese longline		X	X	X	X	X	X	X	X	X	Bartoo and Weber (1979)
Japanese surface		X	X	X	X	X	X				Bartoo and Weber (1979)
South Pacific longline (landed in American Samoa)			X	X	X	X	X	X			Otsu and Sumida (1968)
New Zealand surface	X	X	X	X	X						Habib and Cade (1972)

TABLE 6. Length-weight relationships of albacore. The lengths are expressed in centimeters and the weights in kilograms.

Area	Length range	a	b	Reference
Eastern Pacific	50.0-85.0	1.225×10^{-5}	3.13	Partlo (1955)
"	38.0-100.0	2.188×10^{-5}	2.99	Clemens (1961)
"	45.0-99.0	3.526×10^{-5}	2.9127	Dotson (1977)
Hawaii and north Pacific	49.6-127.6	2.5955×10^{-5}	2.9495	Nakamura and Uchiyama (1966)
South Pacific (American Samoa landings)	78.0-108.0	8.8406×10^{-5}	2.6822	Nakamura and Uchiyama (1966)
North Atlantic	44.0-112.0	6.303×10^{-6}	3.2825	Beardsley (1971)
South Africa (males)	-	2.3079×10^{-5}	2.98	de Jaeger (1963)
" (females)	-	1.40343×10^{-5}	3.09	de Jaeger (1963)
Western north Pacific	45-85	1.781×10^{-5}	3.053	Lee, Hue, and Kim (1978)

TABLE 7. CPUE statistics for the major north Pacific albacore fisheries, 1961–1978 (from Bartoo and Kikawa, 1979). Units: metric tons per boat per day for the Japanese livebait fishery; fish per boat per day for the United States troll fishery; fish per 100 hooks per day for the Japanese longline fishery. The "young" area extends from 25° to 45°N from October to March and from 30° to 45°N in September, the "adult" area extends from 0° to 25°N, and the total area extends from 0° to 45°N.

Year	Japanese livebait	United States troll	Japanese longline "Young" area	 "Adult" area	 Total area
1961	4.40	69.17	0.55	0.14	0.25
1962	7.22	124.59	0.67	0.14	0.30
1963	6.29	132.09	0.68	0.19	0.32
1964	6.86	97.61	0.90	0.19	0.40
1965	6.26	89.07	0.70	0.25	0.33
1966	5.94	90.45	1.20	0.27	0.54
1967	6.09	126.83	0.88	0.29	0.40
1968	5.34	135.23	0.84	0.29	0.38
1969	4.95	112.57	0.60	0.31	0.28
1970	6.13	127.39	0.66	0.27	0.31
1971	6.94	96.68	0.43	0.22	0.21
1972	6.25	61.08	0.63	0.30	0.30
1973	5.49	82.89	0.85	0.30	0.38
1974	7.81	105.17	0.64	0.30	0.34
1975	5.95	99.81	0.46	0.21	0.23
1976	6.13	69.22	0.66	0.21	0.30
1977	3.01	59.90	0.60	0.14	0.26
1978	3.58	86.80	-	-	-
Mean 1961–77	5.98	101.24	0.70	0.24	0.33

TABLE 8. Total catch, index of abundance, and estimated total effective effort for albacore in the south Pacific, 1962-1977 (from Wetherall, Riggs, and Yong, 1979).

Year	Total catch (metric tons)	Index of abundance (CPUE in kg per 100 hooks)	Estimated total effective effort (millions of hooks)
1962	39,479	146.00	27
1963	35,475	85.76	41
1964	24,975	75.39	33
1965	27,450	72.02	38
1966	41,387	63.66	65
1967	45,372	42.56	107
1968	32,355	33.76	96
1969	25,405	41.03	62
1970	30,672	35.42	87
1971	40,605	29.90	136
1972	40,753	21.45	190
1973	49,275	20.19	244
1974	34,911	13.86	252
1975	26,979	13.64	198
1976	36,534	18.00	203
1977	41,371	21.71	191

TABLE 9. Indexes of relative abundance of albacore for the longline fishery based in American Samoa, 1954-1976 (from Skillman, 1978).

Year	Metric tons per trip	Metric tons per day fished	Number of fish per 100 hooks
1954	5.5	-	-
1955	14.9	-	-
1956	14.1	-	-
1957	17.1	2.5	-
1958	22.3	1.8	-
1959	28.7	2.0	-
1960	39.3	1.7	-
1961	35.3	1.8	-
1962	36.0	1.6	8.44
1963	29.8	1.2	5.23
1964	28.5	1.2	4.96
1965	32.2	1.0	4.57
1966	35.1	1.1	5.20
1967	35.5	1.0	4.48
1968	30.5	0.7	3.43
1969	34.1	0.8	3.64
1970	37.2	0.9	3.98
1971	35.6	0.7	3.33
1972	31.8	0.6	2.87
1973	34.6	0.6	3.04
1974	21.9	0.4	1.82
1975	19.9	0.3	1.12
1976	37.2	0.6	1.89

TABLE 10. Total catch, CPUE, and estimated total effective effort for albacore in the south Pacific Ocean, 1962-1971 (from Skillman, 1975). The catches in parentheses were estimated from the 1970 catches and the 1971 average fish weights for Japan because the 1971 data were not available.

Year		Catch (metric tons)				CPUE (metric tons)		Estimated total effective effort	
		Japan	Rep. of Korea	Rep. of China	Total	per 10^3 hooks	per day	10^6 hooks	10^6 days
1962	Nation	28,352	-	298	28,650			19.267	17.517
	American Samoa				13,326	1.4870	1.6356	8.962	8.147
	Grand Total				41,976			28.229	25.664
1963	Nation	23,762	-	608	24,370			25.296	20.281
	American Samoa				14,650	0.9634	1.2016	15.207	12.192
	Grand Total				39,020			40.503	32.473
1964	Nation	14,136	-	73	14,209			16.857	12.671
	American Samoa				10,791	0.8429	1.1214	12.802	9.623
	Grand Total				25,000			29.659	22.294
1965	Nation	10,871	-	50	10,921			14.097	10.535
	American Samoa				15,459	0.7747	1.0366	19.955	14.913
	Grand Total				26,380			34.052	25.448
1966	Nation	16,534	0	0	16,534			18.918	15.512
	American Samoa				25,570	0.8740	1.0659	29.256	23.989
	Grand Total				42,104			48.174	39.501
1967	Nation	9,670	1,306	604	11,580			15.785	12.086
	American Samoa				28,320	0.7336	0.9581	38.591	29.548
	Grand Total				39,890			54.376	41.634
1968	Nation	5,413	1,262	4,206	10,881			19.719	15.321
	American Samoa				17,723	0.5518	0.7102	32.119	24.955
	Grand Total				28,604			51.838	40.276

TABLE 10. (continued)

Year		Catch (metric tons)				CPUE (metric tons)		Estimated total effective effort	
		Japan	Rep. of Korea	Rep. of China	Total	per 10^3 hooks	per day	10^6 hooks	10^6 days
1969	Nation	4,489	4,924	3,398	12,811			22.111	16.256
	American Samoa				18,731	0.5794	0.7881	32.328	23.767
	Grand Total				31,542			54.439	40.023
1970	Nation	5,598	4,673	3,707	13,978			24.570	16.206
	American Samoa				23,876	0.56889	0.8625	41.969	27.692
	Grand Total				37,854			66.539	43.888
1971	Nation	(6,437)	(4,673)	5,863	16,973			31.052	23.639
	American Samoa				22,193	0.5466	0.7180	40.602	30.909
	Grand Total				39,166			71.654	54.548

TABLE 11. Fishing seasons for the various albacore fisheries, and displacements of these fisheries (from Yoshida and Otsu (1963) and Watkinson and Smith (1972)).

Fishery	Range	Peak	Comments
Japanese livebait	March-July	June	originates south of Japan and develops offshore into area of Kuroshio Front; very complex; some fish captured all year (Van Campen, 1960)
Japanese longline	November-April	December-February	takes place across the north Pacific; sometimes taken all year (Van Campen, 1960)
North American surface	June-December (in the north) May-January (in the south)	August-September	commences east of 140° W; progresses north and east, depending on ocean conditions; in some years, fish are caught in the southern area (below 38° N) in December and January (Clemens, 1961)
South Pacific longline	all year	August-February	takes place north of 20°S from October to March, south of 20°S from April through September (Otsu and Sumida, 1968; Yoshida, 1975)
New Zealand surface	January-April	February	moves southward as season progresses (Watkinson and Smith, 1972)
Hawaii longline	—	—	albacore caught incidentally to other species

TABLE 12. Estimated effort by fishery for albacore in the north Pacific, 1961–1977. U.S. effort days are not equivalent to Japanese livebait days (from Bartoo and Weber, 1979).

Year	Japanese longline (hooks x 10^3)	Japanese livebait days	U.S. surface days
1961	3,260	4,235	25,255
1962	2,652	1,209	27,464
1963	2,927	4,200	31,456
1964	2,435	3,478	30,355
1965	2,825	6,628	24,945
1966	2,696	3,843	25,756
1967	3,262	5,005	26,453
1968	3,047	3,108	29,175
1969	4,005	6,447	28,528
1970	3,907	3,958	20,165
1971	3,791	7,631	44,015
1972	5,242	9,695	67,319
1973	4,588	12,685	32,031
1974	5,206	9,421	39,748
1975	5,080	8,766	35,449
1976	9,209	13,921	38,445
1977		12,825	

TABLE 13. Estimated percentages of total nominal effort by latitude for longliners of the Republic of China and the Republic of Korea based at American Samoa, 1964-1977 (from Wetherall, Riggs, and Yong, 1979).

Year	Nation	Latitude								Effort (10^3 hooks)
		0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	
1964	Rep. of China	0	16.9	76.1	5.1	1.3	0.6	0	0	611
	Rep. of Korea	0	45.9	53.9	0.2	0	0	0	0	1,280
1965	Rep. of China	2.7	62.8	21.7	8.7	0.3	3.8	0	0	1,881
	Rep. of Korea	0.2	54.4	34.5	6.3	1.5	3.1	0	0	4,708
1966	Rep. of China	0.4	36.7	36.8	9.5	4.4	12.2	0	0	7,708
	Rep. of Korea	0.4	44.2	28.4	13.3	0.5	10.1	3.1	0	10,061
1967	Rep. of China	1.0	33.2	27.4	14.0	3.1	17.2	4.0	0.1	13,373
	Rep. of Korea	2.2	31.8	27.5	19.5	2.1	7.1	9.5	0.3	15,378
1968	Rep. of China	2.8	52.3	20.3	9.9	3.6	8.7	2.4	0	12,219
	Rep. of Korea	10.3	41.8	15.6	15.3	1.3	10.0	5.7	0	14,276
1969	Rep. of China	4.8	53.1	29.8	6.6	1.4	3.1	1.2	0	9,554
	Rep. of Korea	12.7	40.5	19.0	10.7	1.5	13.8	1.8	0	20,681
1970	Rep. of China	3.6	45.0	29.5	11.0	2.4	6.3	2.2	0	13,746
	Rep. of Korea	9.5	27.1	16.9	15.6	1.6	16.6	10.8	1.9	20,405
1971	Rep. of China	7.4	31.5	21.9	16.0	4.8	10.2	7.5	0.7	12,891
	Rep. of Korea	6.3	17.4	16.8	21.8	6.3	14.5	13.0	3.9	21,994
1972	Rep. of China	5.8	37.7	25.7	12.0	4.9	10.9	2.6	0.5	12,885
	Rep. of Korea	10.2	21.8	19.2	14.4	2.9	13.7	5.4	12.4	21,603

TABLE 13. (continued)

Year	Nation	Latitude								Effort (10^3 hooks)
		0°-5°S	5°-10°S	10°-15°S	15°-20°S	20°-25°S	25°-30°S	30°-35°S	35°-40°S	
1973	Rep. of China	1.2	32.2	20.9	12.0	4.4	19.5	6.9	2.9	15,541
	Rep. of Korea	5.6	19.9	13.6	6.8	6.5	19.3	14.4	13.9	32,682
1974	Rep. of China	2.3	18.5	20.6	18.0	4.3	10.8	9.0	16.5	14,088
	Rep. of Korea	16.9	14.2	11.7	12.0	9.7	7.5	9.8	18.2	26,872
1975	Rep. of China	3.5	33.0	33.0	8.9	3.4	11.6	2.0	4.6	7,933
	Rep. of Korea	13.1	44.5	24.1	8.3	4.2	2.8	1.2	1.8	19,876
1976	Rep. of China	1.0	17.0	43.0	12.2	2.9	15.7	3.8	4.4	6,267
	Rep. of Korea	5.4	25.4	18.0	22.8	7.3	17.0	1.9	2.2	22,514
1977	Rep. of China	0.8	32.6	24.1	15.2	4.2	13.6	5.9	3.6	9,980
	Rep. of Korea	7.1	28.8	20.9	11.0	7.8	14.5	6.3	3.6	25,041

TABLE 14. Catches of albacore in the north Pacific Ocean, in metric tons, 1940-1978 (from Bartoo and Kikawa, 1979).

Year	Japan[1]				Rep. of China	United States[2]				Canada	Total[3]
	Live-bait	Long-line	Other gear	Total	Long-line	Live-bait	Troll	Sport[6]	Total	Troll	
1940							6,212		6,212	2	
1941							5,266		5,266	34	
1942							10,585		10,585	-	
1943							17,071		17,071	13	
1944							23,948		23,948	210	
1945							17,800		17,800	648	
1946							10,950		10,950	196	
1947							12,234	84	12,318	362	
1948							22,403	113	22,516	978	
1949							24,895	166	25,061	1,012	
1950							32,847	866	33,713	961	
1951	16,463						15,629	557	16,186	86	
1952	41,786						23,843	1,373	25,216	71	
1953	32,921						15,740	171	15,911	5	
1954	28,059						12,246	147	12,393	-	
1955	24,236						13,264	577	13,841	-	
1956	42,810						18,751	482	19,233	17	
1957	49,500						21,165	304	21,469	8	
1958	22,175						14,855	48	14,903	74	
1959	14,252						20,990	-	20,990	212	
1960	25,156						20,100	557	20,657	5	
1961	18,636	17,437	268	36,341		2,837	12,054	1,355	16,246	4	52,591
1962	8,729	15,764	191	24,684		1,085	19,753	1,681	22,519	1	47,204
1963	26,420	13,464	218	40,102		2,432	25,142	1,161	28,735	5	68,842
1964	23,858	15,458	319	39,635		3,411	18,389	824	22,624	3	62,262
1965	41,491	13,701	121	55,313		417	16,461	731	17,609	15	72,937

TABLE 14. (continued)

Year	Japan[1]				Rep. of China	United States[2]				Canada	Total[3]
	Live-bait	Long-line	Other gear	Total	Long-line	Live-bait	Troll	Sport[6]	Total	Troll	
1966	22,830	25,050	585	48,465		1,600	15,169	588	17,357	44	65,866
1967	30,481	28,869	520	59,870		4,113	17,814	707	22,634	161	82,655
1968	16,597	23,961	1,109	41,667		4,906	20,441	951	26,298	1,028	68,993
1969	31,912	18,006	1,675	51,593		2,996	18,826	358	22,180	1,365	75,138
1970	24,263	15,372	1,069	40,704		4,416	21,039	822	26,277	354	67,335
1971	52,957	10,915	1,623	65,495		2,071	22,196	1,175	25,442	1,587	92,524
1972	60,591	12,622	1,120	74,333		3,750	23,600	637	27,987	3,558	105,879
1973	69,640	16,000	2,152	87,792		2,236	15,652	72	17,960	1,720	107,472
1974	73,576	12,952	1,390	87,918		4,777	20,177	739	25,693	1,207	114,818
1975	52,157	9,931	697	62,785		3,243	18,926	1,243	23,412	101	86,298
1976	85,336	15,738	2,622	103,696		2,700	16,314	766	19,780	252	123,728
1977	31,934	15,512	1,952	49,398	524	1,479	10,012	619	12,128	53	61,579
1978[4]	62,000	-	-	-	-	950	15,700	-	16,650	23	-

1. Japanese longline catch for 1961-68 excludes minor amount taken by vessels under 20 gross tons. Longline catch in weight is estimated by multiplying annual number of fish caught by an average weight statistic.

2. United States livebait catch excludes minor amount taken by vessels not submitting logbooks to IATTC; this amount is included in the troll catch.

3. Omitted are unknown but minor catches by longline and livebait vessels of the Republics of Korea and China.

4. 1978 figures are preliminary.

5. All gears 1940-1960 added together.

6. Estimated minimum based on partial coverage rate.

TABLE 15. Catches of albacore in the south Pacific Ocean, in metric tons, 1952–1977 (from Wetherall, Riggs, and Yong, 1979).

Column	1	2	3	4	5	6	7
Year	Japan	Rep. of China	Japan and Rep. of China	R	Rep. of Korea	Others	Total
1952	210	-	210	-	-	-	210
1953	1,091	-	1,091	-	-	-	1,091
1954	10,200	-	10,200	-	-	-	10,200
1955	8,420	-	8,420	-	-	-	8,420
1956	6,220	-	6,220	-	-	-	6,220
1957	9,764	-	9,764	-	-	-	9,764
1958	21,558	-	21,558	-	146	-	21,704
1959	19,344	-	19,344	-	456	-	19,800
1960	23,756	-	23,756	-	610	-	24,366
1961	25,628	-	25,628	-	330	-	25,958
1962	38,880	0	38,880	0.0154	559	-	39,479
1963	33,500	608	34,108	0.0400	1,367	-	35,475
1964	21,435	629	22,064	0.1319	2,911	-	24,975
1965	19,305	1,640	20,945	0.3058	6,405	100	27,450
1966	23,401	6,669	30,070	0.3597	10,817	500	41,387
1967	16,640	14,910	31,550	0.4347	13,717	105	45,372
1968	7,707	14,496	22,203	0.4566	10,138	14	32,355
1969	5,559	9,883	15,442	0.6451	9,963	-	25,405
1970	6,560	12,463	19,023	0.6097	11,599	50	30,672
1971	4,339	21,584	25,923	0.5586	14,482	200	40,605
1972	2,796	23,050	25,846	0.5586	14,439	486	40,753
1973	2,381	28,858	31,239	0.5586	17,452	584	49,275
1974	1,847	19,980	21,827	0.5586	12,194	890	34,911
1975	1,045	15,092	16,137	0.5586	9,015	1,827	26,979
1976	1,906	19,954	21,860	0.5586	12,212	2,462	36,534
1977	2,240	21,345	23,585	0.5586	13,176	4,610	41,471

Comments:

Column 1:	Japanese longline catch courtesy of S. Ueyanagi, Far Seas Fisheries Research Laboratory.
Column 2:	Catch by Republic of China's high-seas longliners (over 50 gross tons) based at foreign ports estimated from published Republic of China catch statistics and average weights of albacore landed at Pago Pago.
Column 3:	Column 1 plus column 2.
Column 4:	R is the ratio of Republic of Korea's catch of south Pacific albacore to total catch of this species by Japan and Republic of China, estimated from data in Skillman (1975).
Column 5:	Column 3 x column 4, except for 1958-1961, which are from American Samoa cannery records.
Column 6:	Includes catch by Chile (from FAO statistics), Fiji (courtesy of Ian Brown), and New Zealand (from Habib and Cade, 1978).

TABLE 16. Catches of albacore in the Pacific Ocean by Japanese purse-seine vessels in metric tons, 1961-1974 (adapted from Honma and Suzuki, 1978).

Year	Catch
1961	7
1962	53
1963	59
1964	128
1965	11
1966	111
1967	89
1968	367
1969	521
1970	317
1971	902
1972	277
1973	1,353
1974	161

SYNOPSIS OF BIOLOGICAL DATA ON THE YELLOWFIN TUNA, *THUNNUS ALBACARES* (BONNATERRE, 1788), IN THE PACIFIC OCEAN

Jon S. Cole

Inter-American Tropical Tuna Commission
La Jolla, California
1980

CONTENTS

1 IDENTITY

The scientific name for the yellowfin tuna is *Thunnus albacares*.

2 DISTRIBUTION

2.1 Total area

Yellowfin are distributed worldwide, occurring in the tropical and subtropical waters of the Indian, Pacific, and Atlantic Oceans, and in each of the warm seas of the world except the Mediterranean Sea. The coastal limits of yellowfin distribution in the Pacific Ocean were documented by Rosa (1950). He reported that yellowfin range from Point Conception, California, to San Antonio or Talcahuano, Chile, along the eastern Pacific coastline, and from Hokkaido, Japan, through the Indonesian Archipelago, to Cape Howe, Australia, and New Zealand, along the western Pacific shoreline. Blackburn (1965) suggested that the longitudinal limits of yellowfin are about 35°N in the eastern north Pacific, 33°S in the eastern south Pacific, 40°N in the western north Pacific, and 35°S in the western south Pacific. Kamimura and Honma (1963) stated that yellowfin are distributed in practically every part of the Japanese longline fishing grounds, which at that time extended from about 40°N to about 40°S, and from the Asian coast eastward along the Equator to about 100°W. The longline fishery has since expanded further into the eastern Pacific, and recent catch records from this fishery and the purse-seine surface fishery (see Section 5.2 and Figures 8 and 11) indicate the relatively continuous distribution of yellowfin within its range, which extends across the Pacific and is roughly approximated by the 40°N and 40°S latitudes (Calkins and Chatwin, 1967 and 1971; Shingu *et al*., 1974; Calkins, 1975; Anonymous, 1974a, 1975a, 1976a, 1977a, and 1980a; Suzuki *et al*., 1978).

2.2 Differential distribution

2.21 Spawn, larvae, and juveniles

The distribution of yellowfin eggs has not been determined because it is not possible to differentiate these eggs from those of many other scombrids.

Yellowfin larvae distribution has been examined by Wade (1951), Sun' (1960), Yabe and Ueyanagi (1962), Ueyanagi *et al*. (1969a), and Mori (1970) for the western Pacific; by Matsumoto (1958), Strasburg (1960), Sun' (1960), and Nakamura and Matsumoto (1967) for the central Pacific; and by Mead (1951), Klawe (1963), and Klawe *et al*. (1970) for the eastern Pacific. Much of the data of these investigators has been incorporated into the works of Yabe *et* al. (1963), Matsumoto (1966a), Ueyanagi (1969b), Nishikawa et al. (1978), and Suzuki et al. (1978) in investigations of the distribution of yellowfin larvae in the entire Pacific Ocean. The studies on larvae distribution indicate that the larvae are trans-Pacific in occurrence, although their distribution is limited latitudinally to tropical and subtropical waters. Larvae occur year-round in equatorial waters, but there is a seasonal change in density in the subtropical waters of the western Pacific. Seasonal peaks in density of larvae occur in the Kuroshio Current area during May to June and in the East Australian Current during November to December. In the eastern Pacific the range of yellowfin larvae is compressed somewhat during winter of the northern hemisphere by cold water converging toward the equator from the north and south. Although data are not available for an entire year, there appears to be a peak in density of larvae from April to June off Central America (Figure 1).

Klawe (1963) examined the vertical distribution of yellowfin larvae in the eastern Pacific. He found no evidence of occurrence of larvae below the thermocline. Information on the vertical distribution of yellowfin larvae in the central Pacific has been provided by Matsumoto (1958) and Strasburg (1960) and in the Indo-Pacific by Ueyanagi (1969b). These investigators indicated that yellowfin larvae are probably restricted to the upper 50 or 60 meters of the ocean.

Higgins (1967) summarized the published accounts on the capture of juvenile yellowfin. He reported that juveniles have been collected in the western Pacific as far north as approximately 31°N near the coast of Japan and as far south as 23°S. In the central Pacific the northernmost record is 23°N near the Hawaiian Islands, and the southernmost record is 23°S. In the eastern Pacific juvenile yellowfin have been recorded from approximately 24°N off Baja California to approximately 2°S, just off the coast of Ecuador. Higgins (1967) found no records of juvenile yellowfin in the area bounded by 150° and 112°W. He attributed this hiatus to insufficient sampling in this area.

Higgins (1970) examined the distribution of juvenile tunas in Hawaiian waters from July to September, 1967. Although skipjack was the dominant species encountered, he found that juvenile yellowfin were more abundant offshore than inshore, and that they exhibited no extensive vertical migrations.

2.22 Adults

Areas of occurrence and seasonal and annual variations in the distribution of adult yellowfin are discussed in Sections 2.1 and 5.3, respectively.

2.3 Determinants of distribution changes

Temperature is an important determinant of the horizontal distribution of yellowfin, particularly at the northern and southern limits of its range in the eastern Pacific. There have been two reports of yellowfin occurrence in surface waters as cool as 15°C (Bini, 1952; Uda, 1957); however, Laevastu and Rosa (1963) and Blackburn (1965) suggested that the thermal boundaries of yellowfin occurrence were 18° and 31°C. Laevastu and Rosa (1963) and Broadhead and Barrett (1964) noted that commercial concentrations of yellowfin occurred between 20° and 28°C, but Blackburn (1965) stated that the upper limiting temperature for fishable abundance was at least 30°C, not 28°C. In a later study made off Baja California, Blackburn (1969) verified, despite one exception when fish entered 17°C water to feed because warmer water areas were scarce and had limited food supply, that yellowfin prefer to congregate in areas of plentiful food where the surface temperatures are 20°C or greater. Yellowfin have been observed to exhibit movements in conjunction with changes in the position of the 20° and 21°C isotherms off North America (Radovich, 1961 and 1963; Blackburn and associates, 1962; Broadhead and Barrett, 1964), and were found to be limited to the northern boundary of the Peru Current off South America during non-El Nino conditions (Broadhead and Barrett, 1964; Sandoval T., 1970). West of 150°W, however, thermal boundaries do not restrict the latitudinal distribution of yellowfin as much as in the eastern Pacific because of the larger north-south temperature variations.

The vertical thermal structure of the ocean appears to influence the vertical distribution of yellowfin. Brock (1959) noted that purse-seine surface fishing in the eastern Pacific is usually restricted to areas where there is a relatively shallow mixed layer. Similarly, Suzuki et al. (1977) compared catches of regular versus deep longline gear in the western and central equatorial Pacific and found that the catches of yellowfin by the regular gear were relatively higher in areas where the thermocline was shallower. Green (1967), Sharp (1978), and Miller and Evans (1979) have demonstrated a high correlation between the yellowfin's vulnerability to capture by purse seines, the depth of the mixed layer, and the strength of the temperature gradient within the thermocline. Strong thermocline gradients and dissolved oxygen concentrations less than 2 ml/l found below the thermocline appear to present a barrier which yellowfin are reluctant to cross, making it more susceptible to capture in situations where the minimum depth of the net extends past the depth of the thermocline.

As Blackburn (1969) noted, the availability of forage organisms in areas of optimum temperature is an important factor in determining where yellowfin tend to aggregate. Areas of high phytoplankton productivity and high standing crops of zooplankton are produced, in part, by upwelling, doming, and converging surface waters of different densities. Yellowfin conceivably are drawn to these areas to feed on forage organisms also gathered there. In this respect, yellowfin distribution has been found to coincide with areas of upwelling and ocean frontal boundaries between the Equatorial Countercurrent(s) and the South Equatorial Current (Blackburn, 1965; Murphy and Shomura, 1972; Uda, 1973; Yamanaka, 1978).

2.4 Hybridization

No information is available on this subject.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Yellowfin are heterosexual, but exhibit no externally visible sexual dimorphism.

3.12 Maturity

Yellowfin inhabiting coastal areas or waters close to islands attain sexual maturity at a different size than do those found in offshore waters of the Pacific. Wade (1950a) found a sexually mature male 525 mm in length near the Philippine Islands, and Buñag (1956) encountered a mature female with a length of 567 mm in the same area. Orange (1961) found the minimum size of mature female yellowfin along the coast of Central America to be 50 cm; in this area 20 percent of the females in the 50- to 60-cm size class were found to be mature. In the central equatorial Pacific, on the other hand, a few yellowfin reach maturity at around 70 to 80 cm, but the majority do not mature until they reach 120 cm (Yuen and June, 1957). Similarly, Kikawa (1962) reported female yellowfin attain first maturity at more than 110 cm in the western and central Pacific longline grounds, although a few individuals were found to be mature at lengths between 80 to 110 cm. In the eastern Pacific longline grounds (areas east of 130°W), Shingu et al. (1974) found the minimum size at first spawning for both sexes to be between 91 and 100 cm; however, their data also indicate that a high percentage of fish reached first maturity at lengths above 120 cm.

Kikawa (1966) postulated that the spawning potential of small (<100 cm) yellowfin likely to be distributed in open areas of the western Pacific had been underestimated. A recent study (Suzuki et al., 1978) points out that such may also be the case in the eastern Pacific. Significantly higher percentages of sexually mature yellowfin under 120 cm in length were found in samples taken from purse-seine surface catches than in samples gathered from longline catches made in the same area and month. Hisada (1973) has also reported differences in sexual maturity of yellowfin sampled from surface hand-line and longline catches in the Coral Sea. These results seem to imply that longline gear may be an inappropriate sampling gear for maturation studies. It is possible that a re-evaluation of the spawning potential of yellowfin of smaller size groups, as suggested by Kikawa (1966) and Suzuki et al. (1978), will show that a higher proportion of fish under 120 cm in open waters of the Pacific are mature than was previously thought.

In light of the apparent size range at which yellowfin have been found to reach sexual maturity, the age at first maturity, on the basis of the length-age relationship established for yellowfin (Table 3), is about 2 or 3 years (Ueyanagi, 1966a).

3.13 Mating

The spawning of yellowfin has not been observed, but the mating is presumably promiscuous.

3.14 Fertilization

The fertilization of the eggs takes place externally.

3.15 Gonads

Kikawa (1966) calculated the following equations for the relationships between body length and ovary weight (both ovaries combined) for yellowfin in the tropical central and western Pacific Ocean:

fish under 160 cm: $Y = (9.596 \times 10^{-5})\ X^{3.436}$;

fish over 160 cm: $Y = 2760 + 5.318X$;

where Y = ovary weight in grams and X = fork length in centimeters. Fecundity studies have been carried out by June (1953) and Joseph (1963) for yellowfin in the central and eastern Pacific, respectively. The relationship between the length and the number of maturing ova is expressed by:

$$Y = (8.955 \times 10^{-9}) X^{2.791};$$

where Y = millions of ova in the most advanced mode and X = total length (to the cartilaginous median part of the caudal fork) in millimeters (Joseph, 1963).

3.16 Spawning

Yellowfin spawning in the western and central regions of the Pacific Ocean takes place in the northern latitudes during spring and summer of the Northern Hemisphere, and in the southern latitudes during spring and summer of the Southern Hemisphere (Table 1). In the equatorial waters of the western and central Pacific spawning occurs throughout the year. In the eastern Pacific spawning takes place year-round in northern equatorial waters; however, in southern equatorial waters yellowfin spawn mostly during the first half of the year, with minimal spawning during the second half because of the intrusion of water cooler than 26°C into the area. Ueyanagi (1969b and 1978) stated that this temperature is probably the lower limit for spawning. Off the coasts of Mexico and Central America yellowfin spawn throughout the year, but the peaks of spawning occur at different times in different areas. Spawning appears to be more sporadic and shorter in duration in the coastal spawning areas than in northern equatorial waters.

By identifying the recruitment cohorts present on the spawning grounds, Knudsen (1977) was able to show that yellowfin spawn at least twice a year off southern Mexico and Central America. The periods of spawning vary in length and time of occurrence from year to year.

Yellowfin eggs were artificially fertilized successfully on board a purse seiner off Japan in 1970 (Mori _et_ _al_., 1971) and again in 1971 and 1976 (Ueyanagi, 1978). The fertlized eggs were transferred to a laboratory, and the resultant larvae were reared in large-volume tanks. The most successful culture occurred in the 1976 experiment, where the larvae reached 4 cm total length in 4 weeks. On this occasion one larva survived 38 days, reaching juvenile stage, and attained a length of 5.3 cm and a weight of 1.33 g (Ueyanagi, 1978).

3.17 Spawn

A description of the development of the ova of yellowfin is given by June (1953).

3.2 Pre-adult phase

The general development from pre-larval to post-larval phase of the yellowfin larvae hatched from artificially fertilized eggs has been described by Mori *et al*. (1971). Descriptions of larval and post-larval yellowfin collected at sea are given by Mead (1951), Wade (1951), Matsumoto (1958 and 1962), Sun' (1960), Ueyanagi (1966b and 1969b), and Matsumoto *et al*. (1972). The internal anatomy of the yellowfin larva has been described by Richards and Dove (1971). The juvenile forms have been described by Schaefer and Marr (1948), Wade (1950b), Yabe *et al*. (1958), and Matsumoto (1961).

3.3 Adult phase

3.31 Longevity

The longevity of yellowfin has not been accurately determined. The largest yellowfin captured with sport gear had a fork length of 209 cm (Olson, 1980) and weighed 176.35 kg (Anonymous, 1980c).

3.32 Hardiness

Tester (1952) discussed the difficulties in transporting live yellowfin and subsequent attempts to establish yellowfin in various ponds and fish tanks. In regard to resistance to the stresses encountered during tagging and handling, Clemens (1961) ranked yellowfin fourth in hardiness behind albacore, *Thunnus alalunga*, northern bluefin, *T. thynnus*, and bigeye, *T. obesus*.

3.33 Competitors

There is no doubt that many large carnivorous fish and marine mammals occupying the same domain as yellowfin compete with it for certain food items. From a limited sample of the stomach contents of longline-caught yellowfin and bigeye, Juhl (1955) related that the food preferences of these tunas did not differ. Waldron and King (1963) noted that squids were common in the diet of yellowfin, bigeye, and skipjack, *Katsuwonus pelamis*. Perrin *et al*. (1973) found that an ommastrephid squid, which they suspected to be *Dosidicus gigas*, was a prominent food item of yellowfin, the spotted dolphin, *Stenella attenuata*, and the spinner dolphin, *S. longirostris*.

3.34 Predators

Yabe *et al*. (1958) reported finding young yellowfin in the stomachs of larger yellowfin, shortbill spearfish, *Tetrapturus angustirostris*, white marlin, *T. albidus*, and black marlin, *Makaira indica*. Strasburg (1969) reported the capture of a 1500-pound (680-kg) black marlin in the central Pacific that had a 157-pound (71-kg) yellowfin in its stomach which it apparently had speared twice before eating. Sivasubramaniam (1966) stated that predation by sharks in the Pacific or Indian Ocean damaged 11 percent of the longline catch of tunas. He determined that damage to the longline catch of tunas tended to coincide with high densities on the fishing grounds of the oceanic whitetip shark, Carcharhinus longimanus, and another requiem shark, C. brachyurus. Attacks by these sharks on yellowfin restrained by longline hooks, of course, does not necessarily indicate that these particular sharks prey on yellowfin under normal conditions. Sivasubramanian (1966) further reported that killer whales may account for damage to over 3 percent of the total longline catch of tuna in the Pacific Ocean.

3.35 Parasites and diseases

Shiino (1959b), Ward (1962), Schaefer et al. (1963), Silas (1967), Kabata (1970), Chen and Yang (1973), Love and Moser (1977), and Cressey and Cressey (1980) provide data on parasites which are known to infest yellowfin.

3.36 Physiology and biochemistry

Yellowfin, like all tunas, are warm-bodied, possessing retia mirabila ("wonderful nets") which act as countercurrent heat exchangers in retaining the heat produced through metabolism. The retia are systems of closely packed parallel arterioles and venules; heat is retained through the cooling of warm venous blood on its way to the gills and the warming of cool arterial blood on its way to body tissues (Carey and Teal, 1966; Carey et al., 1971; Carey, 1973). Yellowfin have been found to be less warm-bodied than some other tunas, having muscle temperatures averaging about 1° to 5°C higher than the ambient sea water (Barrett and Hester, 1964; Carey et al., 1971; Carey, 1973; Graham, 1975).

Linthicum and Carey (1972) described the carotid retia which conserve the heat produced in the eyes and brain in the genus Thunnus. These retia are located on the ventral surface of the prootic bone, dorsal and anterior to the first efferent branchial arteries. They found the carotid retia of the yellowfin to be less developed than those of the northern bluefin. Graham (1975) determined the thermal profile of the red muscle of yellowfin and described the structure of the central and cutaneous retial systems. The central rete is situated in the haemal arch on either side of the aorta and cardinal vein. The cutaneous retial system consists of four pairs of lateral exchangers, two epaxial and two hypaxial, each adjoined to a longitudinal cutaneous artery and vein. Graham also found differences in the retia of yellowfin and northern bluefin and determined that the skipjack tunas (Euthynnus and Katsuwonus) have much more developed central heat exchangers than yellowfin.

Several arguments have been postulated for the adaptive benefits tunas derive from having elevated body temperatures. Linthicum and Carey (1972) propose that having warm eyes and brains enhances the tunas' vision and response to prey. Carey et al. (1971) suggested that elevated muscle temperatures increase the power of the swimming muscles, thereby promoting the fast swimming speeds which have been demonstrated for scombrids (Walters and Fierstine, 1964; Yuen, 1966; Magnuson, 1978b). Stevens and Neill (1978), who have given a thorough review of the body temperature relations of tunas, stated that being warm enables tunas to recover rapidly after rigorous exercise, making it possible for more frequent feeding frenzies.

Another adaptive advantage of heat exchangers is that they provide tunas with a large thermal inertia, which probably allows them to move freely from the upper mixed layer into the thermocline despite rapid changes in water temperature (Graham, 1975; Neill et al., 1976), and may enable them to sense weak temperaure gradients (Neill et al., 1976). Dizon et al. (1977) found that yellowfin swam more slowly as the water temperature decreased, but that changes in swimming speed did not keep pace with changes in water temperature. They credited this effect to the yellowfin's thermal inertia.

Stevens and Neill (1978) and Dizon and Brill (1979a and 1979b) reviewed investigations implying thermoregulation in tunas and discussed several thermoregulatory options available to tunas. In laboratory experiments the latter investigators found no relationship between red-muscle temperature and swimming speed in yellowfin despite the fact that heat produced through metabolism is directly linked to swimming speed. They observed both direct and indirect relationships between muscle temperature and metabolic heat production, and proposed that yellowfin are capable of some type of physiological thermoregulation mediated through the central nervous system.

Sidwell et al. (1974) surveyed the world literature on the chemical composition of the edible portion of 153 species of fish. They provide the following values for the protein, fat, moisture, and ash content in yellowfin:

	Protein	Fat	Moisture (gm per 100 gm)	Ash
1)	24.3 ± 0.2	2.2 ± 0.5	73.2 ± 0.5	1.5 ± 0.3
2)	22.9--25.8	0.1--9.5	67.3--77.1	1.3--1.9
3)	26	25	27	25

where: 1) = mean and standard error of the mean; 2) = range; and 3) = number of averages used to compute the overall average.

Sharp and Pirages (1978) examined the distribution of the red and white muscle and electrophoretically assayed the enzymes of red, white, and heart muscle of yellowfin. On the basis of similarities observed in the electrophoretic mobilities of major proteins, they were able to diagram the phylogeny of the genus Thunnus. They found that the yellowfin was the least divergent of the eight species examined, occupying the central position in the Thunnus phylogeny.

Magnuson (1973) determined the influence of the gas bladder on the density of yellowfin and the corresponding influence on lift by the pectoral fins required to maintain neutral bouyancy. The gas bladder of the yellowfin grows allometrically, and as it grows the density of the fish becomes less. He found that as density becomes less the lift required to keep a yellowfin from sinking increases only slightly. However, in the case of the skipjack, which has no gas bladder and whose density remains roughly the same over its entire size range, the lift necessary for maintaining neutral bouyancy increases in direct proportion to the increase in mass. Magnuson reasoned that differences in the density, fish size, and lifting area of the pectorals would significantly influence the swimming velocity necessary to maintain hydrostatic equilibrium. Species with greater mass, higher density, and smaller pectorals should demonstrate greater minimum swimming velocities. Magnuson was able to show this using a model he devised in an earlier study (Magnuson, 1970) which predicted the minimum speed required to maintain hydrostatic equilibrium. His results have aided other investigators (Sharp and Francis, 1976; Sharp and Vlymen, 1978) in determining the swimming energetics of yellowfin.

3.4 Nutrition and growth

3.41 Feeding

Yellowfin apparently eat any forage organism from the three major marine groups comprising their diet, fish, cephalopods, and crustaceans, which they can catch and swallow, as determined by gill raker gap and maximum distensibility of the oesophagus (Magnuson and Heitz, 1971). "Feeding occurs during the daylight hours and principally in the surface layers of the open oceans" (Schaefer et al., 1963).

3.42 Food

Watanabe (1958) reported the occurrence of 37 families of fish and 8 orders of invertebrates in the stomachs of yellowfin examined from the western equatorial Pacific. In a later study (1960) he showed that the diet of yellowfin from several regions in the western Pacific and the Indian Ocean was quite varied. Volumetric food composition studies carried out in the central Pacific (Reintjes and King, 1953; King and Ikehara, 1956) and the eastern Pacific (Blunt, 1960; Alverson, 1963; Anonymous, 1979a and 1980a) also show that the diet of yellowfin is diverse. These studies indicate that although yellowfin consume a variety of food organisms, only a few organisms of the three major categories, fish, cephalopods, and crustaceans, appear as dominant components. The major food items found in yellowfin stomachs in central and eastern Pacific waters are shown in Table 2.

3.43 Growth rate

The age and growth of yellowfin have been studied through analysis of rings on scales and vertebrae (Aikawa and Kato, 1938; Nose *et al*., 1957; Yabuta *et al*., 1960; Tan *et al*., 1965; Yang *et al*., 1969), modal progression of length frequencies (Moore, 1951; Yabuta and Yukinawa, 1957 and 1959; Hennemuth, 1961a; Davidoff, 1963), incremental growth (Diaz, 1963), and data from tagging experiments (Blunt and Messersmith, 1960; Schaefer *et al*., 1961; Bayliff, 1973). In addition, there have been recent attempts to age yellowfin by counting growth increments deposited on the otoliths; (Uchiyama and Struhsaker, 1979; Anonymous, 1980a, Wild and Foreman, 1980). None of the direct aging methods, *i*. *e*. counting marks on hard tissue, have proven reliable for aging individual fish. All of the methods, however, have provided comparable estimates on the rate of growth of yellowfin.

Growth determinations by the scales and vertebrae, length frequencies, and incremental growth methods have been reviewed by Shomura (1966) and Suzuki (1971). These authors note that there is general agreement among the various investigators that yellowfin grow rapidly in early life and at a similar rate in the major regions of the Pacific Ocean. The estimates of the parameters of the von Bertalanffy growth equation realized in the various studies are given in Table 3.

3.44 Metabolism

Yellowfin, as do all tunas, have a high metabolic rate, although actual measurements of metabolic rate in yellowfin are yet to be made. Much of the knowledge regarding metabolism in tunas, including yellowfin, is inferred from experiments carried out on skipjack (Gordon, 1968; Stevens, 1972; Sharp and

Dizon, 1978; Brill, 1979; Gooding et al., no date; Forsbergh, 1980).

3.5 Behavior

3.51 Migrations and local movements

Suzuki et al. (1978) have summarized what is known about the extent of yellowfin migration in the Pacific Ocean:

"Tagging experiments of yellowfin exploited by the surface fisheries in the eastern Pacific have been conducted for many years. Analysis of data for fish recovered up to 1965 indicated that yellowfin tuna migrate on a large scale along the coastal regions of the CYRA [Figure 16] (Fink and Bayliff, 1970). The extent of inshore-offshore (east-west) migration was not revealed by these experiments, however, because until about the middle 1960's the surface fleets had been fishing only near coastal areas and a few offshore islands. However, since no tag recoveries were made outside the CYRA by the Japanese longliners that were operating over offshore areas contiguous to and partly overlapping the surface fishing grounds it was believed that there were no large-scale inshore-offshore movements (Schaefer et al., 1961; Joseph et al., 1964).

"The results of the analysis of more recent tag recovery data (Bayliff and Rothschild, 1974; IATTC, 1977 [= Anonymous, 1977b; see also Bayliff, 1979]) indicate that there is not a strong tendency for yellowfin to move offshore as they get older. However, this can be verified only by obtaining more tag return data and by a more even geographical and temporal distribution of fishing effort...

"In the western and central Pacific, very few yellowfin tagging experiments have been carried out so far, mainly due to the inadequacy of longline gear (the major fishing method for yellowfin in this region) for this purpose. Experimental tagging cruises have been conducted, taking advantage of handline fishing on banks in the tropical western Pacific. However, tagged fish were recaptured close to the release points, and all within one year after their release (Kikawa, 1971). As Schaefer et al. (1961) have pointed out, tuna tagged near fishing banks tend to disperse very slowly. Thus these tagging experiments appear to be inadequate for detecting the extent of migration. However, unpublished data from the Tohoku Regional Fisheries Research Laboratory indicate that a yellowfin tagged at 9°56'N, 137°30'E was recaptured at 32°57'N, 136°40'E, and unpublished data from the Far Seas Fisheries Research Laboratory indicate that a yellowfin tagged at 26°25'S, 154°15'E was recaptured at 36°26'S, 150°13'E. These long-distance movements partially support the hypothesis of yellowfin migration along the Kuroshio and the East Australian Currents..., as suggested from the distribution of the longline catch rates."

A selection of long-range movements that have been exhibited by tagged yellowfin in the western and eastern Pacific is shown in Figure 2.

3.52 Schooling

Yellowfin generally school at the surface with individuals of the same species and the same size; the tendency to school by size seems to be stronger than the tendency to school by species (Orange _et_ _al_., 1957; Orange and Broadhead, 1960; Calkins, 1965). Mixed schools of yellowfin and skipjack are often encountered by fishing vessels, but Yuen (1963) has presented evidence which suggests that such mixed schools are actually separate single-species schools which have been aggregated together by a common stimulus such as food.

Yellowfin frequently school in association with dolphins, principally the spotted dolphin, the spinner dolphin, and the common dolphin, _Delphinus delphis_. Fish in such schools are generally larger and less homogeneous in size than those in schools which are not associated with dolphins. About 85 percent of the yellowfin captured by fishing on schools not associated with dolphins are less than 85 cm in length (approximately 12 kg), while about 70 percent of the yellowfin taken by fishing on schools associated with dolphins are greater than 85 cm (Anonymous, 1975b).

Yellowfin also associate with inanimate floating objects such as logs, dead whales, patches of grass, or other debris. The catch per set of yellowfin and other tunas in co-association with flotsam by purse seiners has increased in recent years (Greenblatt, 1979), but the reasons for the attraction of tunas and other fish to floating objects have not been fully substantiated. Several hypotheses have been proposed to explain this association: (1) fish are attracted to the object to feed on co-associated forage organisms, algae, or decaying matter; (2) fish seek shade under the object; (3) the object provides shelter from predators; (4) the object is used as a substrate on which fish lay their eggs; and (5) the object functions as a cleaning station where pelagic fishes congregate to have their parasites removed by other fishes. Gooding and Magnuson (1967) and Hunter and Mitchell (1967) examined these hypotheses. The former investigators concluded that shelter from predation was probably the most significant drawing force in attracting fish to a floating object. The latter investigators, on the other hand, found no evidence to support any of the hypotheses, and suggested the following alternative mechanisms: (1) fishes associate with floating objects because the object serves as a schooling companion, and (2) in the case of non-pelagic species and others undergoing a change from pelagic to other modes of existence the object may function as a substitute for a reef or some other type of substrate.

The schooling behavior of yellowfin which inhabit deeper waters is less known. Mimura _et al_. (1963) concluded that yellowfin inhabiting subsurface layers of the Indian Ocean tend to scatter and do not form schools of high density.

3.53 Responses to stimuli

The response of yellowfin to stimuli, such as extracts of tuna and other fish flesh and various chemical compounds, has been documented by Tester _et al_. (1954 and 1955). Experiments have also been conducted on the reaction of yellowfin to light (Hsiao, 1952), sound (Miyake, 1952; Iversen, 1967), and electrical stimuli (Miyake and Steiger, 1967). Dizon (1977) and Dizon _et al_. (1978) have examined the swimming behavior of yellowfin with respect to changes in environmental conditions, such as salinity, oxygen, and temperature.

4 POPULATION

4.1 Structure

4.11 Sex ratio

The sex ratio of yellowfin exploited from the Pacific Ocean is about 1:1, or moderately in favor of males, until a length of about 120 to 140 cm is reached. At lengths above this range the proportion of males greatly exceeds that of females (Nakamura, 1949; Murphy and Shomura, 1955; Shomura and Murphy, 1955; Schaefer and Orange, 1956; Orange, 1961; Suda and Schaefer, 1965b; Kikawa, 1966; Murphy and Shomura, 1972; Lenarz and Zweifel, 1979).

Kikawa (1966) sampled yellowfin from eight areas of the longline fishery in the western and central Pacific Ocean and found little seasonal variation in the sex ratio. In the southwestern Pacific area (12^{o}-28^{o}S, 140^{o}E-180^{o}), it appeared to him that, at the time when the percentage of mature fish (gonad indices >3.1) was high, the percentage of females dropped somewhat; however, no such relationship was recognized in any of the other areas sampled.

4.12 Age composition

The estimated age composition of yellowfin captured by Japanese longliners in western and central equatorial waters, west of 120°W, during 1955 to 1964 is shown in Table 4. In the western region of the fishery 2- and 3-year-olds predominated, while in the central portion 3- and 4-year-olds were the major components of the catch. Comparable age composition estimates have been made for the western Pacific longline fishery for 1968 through 1974 (Honma and Suzuki, 1978). These investigators showed that 2- and 3-year-old yellowfin continued to support the longline fishery in this region. For the eastern Pacific longline fishery the age composition was examined by Suda and Schaefer (1965), Kume and Schaefer (1966), Kume and Joseph (1969), and Shingu et al. (1974) for 1964 to 1970. These investigators reported that 3- and 4-year-olds were the principal age groups being exploited by the longline fishery in that area.

Yellowfin in the eastern Pacific surface fishery are thought to belong to two groups which are recruited to the fishery at separate times in each year. The first group (X) enters the fishery during the first half of the year and the second group (Y) during the second half of the year (Hennemuth, 1961a; Davidoff, 1963; Anonymous, 1980a). In Figure 3 are shown the estimated weights of fish of different ages belonging to these two groups caught during the first and second quarters of 1968 through 1979. It is apparent from the figure that 2- and 3-year-old fish comprised the bulk of the catch for 1968-1972 and 1975-1977. In 1973, 1974, 1978, and 1979, however, large catches of 1-year-old fish, which came almost totally from the Y group (except in 1978 and 1979), were made. The high catch of 1-year-old fish in 1973 has been attributed to increased vulnerability of these fish to the fishing gear, while that in 1974 was apparently a result of a combination of above-average recruitment and increased vulnerability (Anonymous, 1979a). In the 1979 fishery the 1978 cohort made a significant contribution to the catch as 2-year-olds, suggesting that this year class was recruited to the fishery in above-average numbers (Anonymous, 1980a).

The age composition of yellowfin captured by the baitboat and purse-seine fisheries in the western Pacific was estimated by Honma and Suzuki (1978) for 1968 through 1974. They found that the catches from the tropical areas of the fishery were composed primarily of 1-year-old fish and under. The temperate purse-seine fishery, on the other hand, exploited principally 2- and 3-year-old fish, as did the longline fishery.

4.13 Size composition

In Figure 4 are shown quarterly length composition data of longline-caught yellowfin for 1966-1972. The data are grouped into three major areas, northern (10°-25°N), middle (10°N-5°S), and southern (5°-25°S), and 10-degree longitude intervals for all areas east of 130°E. The data are also combined for nine major areas as shown in Figure 5. In their analysis of these data Suzuki et al. (1978) report: "Though there are yearly variations in areal patterns of the length-composition, it can be noted that there is a consistent tendency for large individuals to become increasingly dominant from west to east in the three major areas" (Figure 4). "In the northern and southern areas, large fish are generally more dominant than in the middle area for areas of the same longitude, except for the areas east of 130°W" (Figure 5). They noted that their results confirm the progressive longitudinal change in length composition of yellowfin caught by longline gear reported by Yabuta et al. (1958) and Kamimura and Honma (1963). Suzuki et al. (1978) considered the gradual size increase from west to east to be a consistent phenomenon, although occasional appearances of small (80-100 cm) fish in the central and eastern Pacific, seemingly not mentioned in the earlier studies, were apparent in some years (areas east of about 160°W, their Appendix Table 1; southern area east of 120°W, third quarter, Figure 4 of this synopsis).

Two different interpretations of the west-east cline observed in longline length-composition data have been postulated: (1) Yellowfin migrate from the western Pacific (inshore) to the central Pacific (offshore) as they grow (Kamimura and Honma, 1963); and (2) Since morphometric and other evidence of lack of rapid migration and mixing of yellowfin along the equator are not available (Royce, 1964), the cline is attributed to differential selectivity of the longline gear to the size of the fish in relation to the depth of the thermocline. This interpretion is based on the belief that "all sizes of yellowfin occur throughout the upper mixed layer and perhaps the upper part of the thermocline, but ... larger fish may be relatively more prevalent nearer the bottom of the mixed layer and in the upper part of the thermocline" (Suda and Schaefer, 1965b). Thus, larger fish gradually become more available to longline gear fished at a constant depth from the western Pacific to the eastern Pacific as the upper mixed layer becomes thinner in an eastward direction.

Suzuki et al. (1978) appraised these two interpretations and hypothesized that both are plausible, but in respect to different areas. That is, the cline evident in the central and western Pacific is perhaps an artifact caused by differential size selectivity in relation to the thermocline topography as proposed by Suda and Schaefer, while the western Pacific cline is better explained by Kamimura and Honma's theory of size-specific movement of yellowfin from coastal to offshore areas.

The average weights of yellowfin from the longline catches made in the nine major areas investigated by Suzuki et al. (1978) are also shown in Figure 5.

The length-frequency distribution of yellowfin captured by the eastern Pacific surface fishery within the Inter-American Tropical Tuna Commission's Yellowfin Regulatory Area (CYRA) (Figure 16) for 1969-1979 are shown in Figure 6. For all the years except 1974, 1978, and 1979 the average weight of yellowfin in the CYRA ranged from a low of 27.7 pounds (12.6 kg) in 1971 to a high of 37.8 pounds (16.7 kg) in 1972. During 1974, 1978, and 1979, however, the average weight dropped sharply, owing to the large catches of small yellowfin of the entering year class. In 1973 large numbers of small fish in the 60-cm size group were also captured, but the average weight did not drop as much as it did during 1974, 1978, and 1979 because greater numbers of older, larger individuals, which were recruited during previous years, were also caught.

The yellowfin captured between the CYRA boundary and 150°W longitude (Figure 7) are much larger, on the average, than those taken within the CYRA. The average weight of yellowfin caught outside the CYRA was more than double that of yellowfin caught in the CYRA for all years except 1969, 1974, and 1977. There is a tendency for the proportion of larger individuals to increase in the catches as they are made from inshore areas to offshore areas in the CYRA and, to a lesser extent, outside the CYRA (Anonymous, 1974b; Suzuki et al., 1978). Since available tagging data indicate little offshore movement of small yellowfin as they grow older, this longitudinal gradient in length-frequency is possibly a reflection of size selectivity in the purse-seine fishery (Suzuki et al., 1978; Bayliff, 1979).

Chatwin (1959) calculated the length-weight relationship of yellowfin from the eastern Pacific Ocean. He determined that the equation $Y = (3.894 \times 10^{-8})X^{3.020}$, where Y is the weight in pounds and X is the length in millimeters, adequately described this relationship in all of the areas he sampled.

4.14 Subpopulations

Most of the inferences about the subpopulation structure of the yellowfin inhabiting the Pacific Ocean have come from indirect sources such as morphometric comparisons (Godsil, 1948; Godsil and Greenhood, 1951; Schaefer, 1952 and 1955; Royce, 1953 and 1964; Kurogane and Hiyama, 1957b; Broadhead, 1959; Yang, 1971), length-frequency and catch-and-effort analyses (Yabuta et al., 1958; Kamimura and Honma, 1963), tagging experiments (Section 3.51), spawning studies (Section 3.16), and other studies dealing with aspects of the life history of yellowfin. A considerable amount of genetic research has been carried out in an attempt to develop a direct method to discriminate yellowfin subpopulations (Suzuki, 1962b; Barrett and Tsuyuki, 1967; Sprague, 1967, Fujino and Kang, 1968a and 1968b; Fujino, 1970; Anonymous, 1971a, 1972a, 1973, 1974b, 1975b, 1976b, 1977b, 1978a, 1979a, and 1980a). Some of these studies have produced inferences contradictory to those obtained from the indirect sources; however, due to sampling difficulties, limited geographical coverage, and the need for further systematic follow-up investigations they are still considered to be preliminary in nature (Suzuki et al., 1978; Anonymous, 1980a). Thus, determination of the existence, or non-existence, of subpopulations of Pacific yellowfin is yet to be made.

On the basis of the available indirect data, nevertheless, the following conclusions were reached by the most recent comprehensive investigation on the subject (Suzuki et al., 1978):

1) Although no definite geographical break in the continuity of yellowfin distribution across the Pacific is indicated, the extent of migration appears to be insufficient for there to be much intermingling among yellowfin of the eastern and central Pacific and probably of the western and central Pacific as well.

2) Three stocks, which are more or less independent, are envisioned: a western Pacific stock, which inhabits the area between about 120°E and 170°W; an eastern Pacific stock, inhabiting the area bounded more or less by the CYRA (Figure 16); and a central Pacific stock, inhabiting the area between the western and eastern Pacific stocks. (Suzuki et al. defined stock to mean "an exploitable subset of the population existing in a particular area and having some uniqueness relative to exploitation.")

3) The three stocks may well be composed of subpopulations which will have to be discriminated by more direct methods. Should the existence of

subpopulations be established, however, it is possible that even direct genetic studies will not demarcate their spatiotemporal boundaries.

4.2 Abundance and density

The relative abundance of yellowfin is measured in terms of the catch per unit of fishing effort (CPUE). The CPUE in the Japanese longline fishery is generally expressed as numbers of fish caught per day per 100 hooks set. In the eastern Pacific surface fishery the CPUE is normally expressed as the weight of fish caught per standard day's fishing (CPSDF). In this fishery the overall purse-seine effort is standardized to the fishing power of a Class-3 purse seiner (101-200 short tons capacity) by the method of Shimada and Schaefer (1956). The CPUE data from both fisheries are usually stratified on the basis of time and area to provide indices of the relative abundance and/or density for the various strata.

The distribution of the monthly average longline catch rates shown in Figure 8 indicates that the equatorial western Pacific, which was the major longline fishing ground for yellowfin in the early 1960's (Rothschild and Uchida, 1968), continues to be the area of greatest relative abundance of yellowfin. However, the relative abundance of yellowfin in this region, as well as on the fishing grounds to the east which were exploited in later years, has declined as a result of increased fishing effort (Honma et al., 1971; Suda, 1971; Suzuki et al., 1978). Honma (1974), as cited by Suzuki et al. (1978), has shown that a two-fold increase in longline fishing effort from the early 1960's to the early 1970's has resulted in only moderate increases, or in some years decreases, in the catch of yellowfin.

The values of the CPSDF for yellowfin in the CYRA (Figure 16) for 1960 to 1979 are shown in Figure 9. For the years since 1966, when regulations were first put into effect, only data obtained from the logbooks of vessels making unregulated fishing trips were used to compute the CPSDF. Since 1962 the CPSDF has been adjusted for changes in portions of sets which were successful to adjust for changes in gear efficiency. The relative abundance of yellowfin was highest in 1960. Increased fishing effort resulted in a decline in abundance starting in mid-1961, and the annual CPSDF continued to be low through 1965, although there was a slight increase in 1964. In 1966 and 1967, due to the expansion of the fishery offshore, the CPSDF climbed and the annual CPSDF remained level at about 6 tons from 1968 through 1970. In 1971, when skipjack were abundant and a considerable portion of the effort was directed toward that species, a decline in CPSDF was registered. In the following year, 1972, the CPSDF rose to the 1968-1970 level, but since then the relative abundance of yellowfin has been declining almost steadily.

4.3 Natality and recruitment

4.31 Reproduction rates

Assuming an instantaneous survival rate for adults of approximately $e^{-0.8}$ (45 percent) on an annual basis, Sharp and Francis (1976) calculated that 6.67 x 10^7 postlarval yellowfin would need to survive annually to maintain at equilibrium a hypothetical unexploited yellowfin population in the CYRA (Figure 16) consisting of individuals from 40 to 140 cm fork length and a biomass of 600,000 metric tons. They estimated that approximately 9.13 x 10^4 postlarval yellowfin entered the system each day, which is the equivalent of nearly 1-percent reproductive success of either one 155-cm female or five 87-cm females. Estimating that 7 x 10^6 reproductive females were present in this unexploited population, and using the fecundity estimate of Joseph (1963), Sharp and Francis (1976) proposed that 1.79 x 10^{13} eggs were produced annually.

4.32 Factors affecting reproduction

Because of thermal and energetic requirements, yellowfin between larval and juvenile stages are likely to be narrowly distributed in the water column. Their relative immobility makes the survival of larval yellowfin extremely dependent on the availability of food resources (Sharp and Francis, 1976).

4.33 Recruitment

According to Suzuki et al. (1978), in the western equatorial Pacific (130°E-180°) during 1966 to 1972 yellowfin began to be recruited to the longline fishery at around 80 cm in length and were substantially recruited at about 110 cm. In the central equatorial Pacific (180°-120°W) fishery, on the other hand, yellowfin were not substantially recruited until about 125 cm was reached (Figure 4). Honma et al. (1971) examined data for an earlier series of years (1955 to 1964) and, similarly, showed that yellowfin were recruited to the western equatorial Pacific fishery at age 2 and to the central equatorial Pacific fishery at age 3. Suda and Schaefer (1965b) reported that during 1958-1962 most of the recruitment of yellowfin to the longline fishery in the eastern Pacific consisted of fish between 110 and 130 cm. In a later study, Shingu et al. (1974) determined that most of the recruitment to this fishery consisted of fish between 90 and 120 cm.

Recruitment of yellowfin to the western equatorial Pacific surface fisheries occurs during the first year of life at lengths between 40 and 50 cm (Kikawa and Warashina, 1972; Honma and Suzuki, 1978). The size at recruitment of yellowfin to the eastern Pacific surface fishery changed during the course of the development of the fishery. During the early years, when baitboats were the principal gear and fishing was basically confined to inshore waters, primarily small yellowfin were recruited. Then, with the transfer from baitboat to purse-seine gear and the expansion of the fishery to offshore areas of the CYRA (Figure 16) with concomitant catches of yellowfin associated with dolphins, much larger yellowfin began to be recruited. This has led to a wide range in recruitment sizes (from less than 40 to 80 cm). It is pertinent to note, however, that for some recent years (1973, 1974, 1978, and 1979) mostly small fish have been recruited (Figure 6). Since 1973, the amount of recruitment of yellowfin to this fishery has apparently become more variable (Anonymous, 1979a and 1980a).

4.4 Mortality and morbidity

Various estimates of the natural mortality rate of Pacific yellowfin are provided in Table 5.

Hennemuth (1961b) analyzed length-frequency data to obtain an estimate of 1.72 for the total annual instantaneous mortality rate of yellowfin in the eastern Pacific for 1954-1959. Using the coefficient of catchability estimated by Schaefer (1957) and the available estimate of fishing effort, he estimated an annual instantaneous fishing mortality rate of 0.95 and an annual instantaneous natural mortality rate of 0.77 with 95-percent confidence limits of 0.64 to 0.90. Hennemuth regarded 0.80 as the most probable value of the natural mortality rate and 0.60 and 1.00 as the "extreme possible" values. Schaefer (1967), however, considered the lowest and highest probable values to be 0.55 and 1.05, respectively. Murphy and Sakagawa (1977) evaluated the published estimates of natural mortality rates and concluded that the values around 0.80 were the "best" estimates. Francis (1977), however, on the basis of computer simulation modeling of the dynamics of the eastern Pacific surface fishery, suggested that the estimate of 0.80 as the natural mortality rate was too high. He employed this estimate and Hennemuth's (1961b) lowest value of the natural mortality rate (0.60) as input parameters to modified versions of a computer simulation model developed earlier (Francis, 1974) and found that the lower estimate of the natural mortality rate was a better parameter in validating versions of the model which best mimicked the fishery.

Honma et al. (1971), as cited by Suda (1971), employed an annual instantaneous natural mortality rate of 0.8 to estimate the annual instantaneous fishing mortality rate of yellowfin exploited by longline gear in the central and western Pacific during 1963 and 1964. They estimated the annual instantaneous fishing mortality rates for those years to be 1.6 and 1.2, respectively.

Estimates on the annual instantaneous rates of total and fishing mortality of yellowfin for several years in the eastern Pacific on the basis of tag recovery data were made by Fink (1965) and Bayliff (1971 and 1974).

4.5 Dynamics of the population

Much of the work which is currently being done on the population dynamics of tunas was pioneered by the Inter-American Tropical Tuna Commission. The results of these investigations are applicable to studies of exploited populations of many other animals, and hence have attracted world-wide attention among specialists in this field, including many working with animals other than fish. Two general types of models have been employed, production models and age-structured models.

Schaefer (1954 and 1957) developed the logistic model, a special type of production model, using catch, effort, and catch-per-unit-of-effort (CPUE) data for yellowfin for 1934-1955. The effort was standardized to Class-4 baitboat units (vessels of 201 to 300 short tons capacity). He assumed that the equilibrium relationship between CPUE and effort is linear, i. e. $C/f = a + bf$, where C = catch and f = effort. Accordingly, the equilibrium relationship between catch and effort would be parabolic, i. e. $C = af + bf^2$. From the data available at that time he estimated that the annual average maximum sustained yield (AMSY) of yellowfin in the eastern Pacific was about 95 to 100 thousand short tons (86 to 91 thousand metric tons), and that this could be taken with an effort of about 35 thousand standard days of fishing (Figure 12).

During 1959 and 1960 most of the vessels of the eastern Pacific tuna fleet were converted from baitboats to purse seiners, making it impossible to continue Schaefer's series of baitboat data. Broadhead (1962), however, devised a method for converting purse-seine effort in Class-3 days (vessels of 101 to 200 short tons capacity) to Class-4 baitboat units, and for several years thereafter converted purse-seine effort data were used with those for baitboat effort to estimate the parameters of the model. Eventually, however, when data for enough years during which purse-seine fishing predominated had accumulated, the data for the baitboat era were dropped, and the parameters were estimated only from data for the purse-seine era.

During the mid-1960's the fishery expanded much further offshore, and annual catches in excess of 100 thousand short tons were taken. It was obvious that the AMSY for the expanded area was greater than that for the area in which fishing took place during the years studied by Schaefer. Accordingly, to estimate the AMSY for the expanded area as quickly as possible, an "experimental overfishing program" was initiated in 1969. The object of this program was to catch amounts of fish somewhat in excess of the current estimate of the AMSY each year until a revised estimate of the AMSY which was thought to be nearly correct was obtained. As a safeguard, however, it was specified that fishing would be curtailed immediately if the CPUE dropped to 3 short tons (2.7 metric tons) per standard day (Class-3 purse-seine) of fishing. This program is still in effect. The current estimate of the AMSY for the CYRA (Figure 16) is about 175 thousand short tons (159 thousand metric tons) (Figure 13) (Anonymous, 1980a).

Pella and Tomlinson (1969) developed a more general production model in which the equilibrium relationship between CPUE and effort is not necessarily linear, i. e. $C/f = (a + bf)^{1/(m - 1)}$, and that between catch and effort is not necessarily parabolic, i. e. $C = (af^{m - 1} + bf^{m})^{1/(m - 1)}$. If m is less than 2 the dome-shaped curve analogous to the parabola of Schaefer is skewed to the right, whereas if m is greater than 2 it is skewed to the left. This model has not been used in recent years because there is no evidence from the data available that the relationship between CPUE and effort is nonlinear.

Hennemuth (1961b) first applied the yield-per-recruit model of Beverton and Holt (1957), a type of age-structured model, to data for yellowfin. Using estimates of the parameters of growth and natural mortality obtained from other studies, he produced isopleths of yield per recruit obtainable with various combinations of fishing mortality and age at recruitment into the fishery (Figure 14). Hennemuth's results indicated that the yield per recruit could be increased if the age at entry were increased. Purse seiners, on the average, catch larger fish than do baitboats, so, if the recruitment has remained the same, the current catches should exceed those made during the baitboat era. Such has been the case, but the relative contributions of offshore expansion of the fishery and increased age of recruitment to the increased catches of recent years are not known. The yield-per-recruit approach is still employed by the Tuna Commission (Anonymous, 1980a), but the rigid model of Beverton and Holt has now been discarded in favor of the flexible model of Ricker (1958 and 1975) (Figure 15).

Schaefer (1967) compared the results obtained with the logistic and yield-per-recruit models, and found that they complimented one another. This approach is still employed by the staff of the Tuna Commission (Anonymous, 1980a).

The dynamics of the yellowfin stock exploited by the Japanese longline fishery in the Pacific Ocean have been investigated by Kamimura (1965), Honma *et al*. (1971), and Honma (1974). The last investigator indicated that the AMSY of the stock available to this fishery is about 60,000 metric tons.

4.6 The population in the community and the ecosystem

Yellowfin are nektonic apex predators, and are members of the oceanic community during their entire life span. They are essentially confined to the upper 100 meters or so of the ocean (Sharp, 1976), feeding on smaller fish, cephalopods, and crustaceans. They are in turn preyed upon by larger tunas, sharks, spearfishes, and probably small whales.

Yellowfin frequently associate with dolphins of the genera *Stenella* and *Delphinus*. The association of these two distinct animals is quite strong, a fact which has enabled purse-seine fishermen to capture large yellowfin that are normally found below the surface (Perrin, 1968 and 1969). The reasons for this association are unknown. Perrin *et al*. (1973) analyzed the stomach contents of yellowfin and two dolphin species (*Stenella attenuata* and *S. longirostris*) captured in the same purse-seine sets, and determined that although the animals' diets overlap to a large degree, they do not necessarily consume the same food items at similar times and depths. If the dolphin-tuna relationship is food based, they reasoned that ommastrephid squids would be the principal binding force, since these cephalopods were found to be the most important overlapping forage organism. Other hypotheses formulated to explain this association are that dolphins shelter the yellowfin from predation by sharks, or that yellowfin school under pods of dolphins as an aid to orient themselves spatially in the optical void common to their enviroment (Perrin, 1968, in reference to the research of Hunter and Mitchell, 1967).

5 EXPLOITATION

5.1 Fishing equipment

Yellowfin schooling at the surface are exploited primarily by purse-seine and pole-and-line fishing. Trolling, gillnetting , and surface handlining are also employed, but catches of yellowfin by these gears are minimal. The subsurface fishery for yellowfin is carried out almost exclusively by the use of longlines.

The purse-seining method of catching tuna is accomplished by (1) encircling a school with the net, (2) closing up the bottom of the net underneath the school, (3) hauling aboard the net until the catch is confined in a small area, and (4) transferring the catch into the vessel with a brailer. In the eastern Pacific purse seining for tropical tunas was carried out with marginal success until the late 1950's when improved brine refrigeration methods (Orange and Broadhead, 1959), the Puretic power block (Schmidt, 1959), and all-nylon nets (Anonymous, 1959) were introduced. These technological advances made it possible for purse-seine fishermen to make longer trips, catch more fish, complete sets in less time, and spend less time replacing and repairing their nets. As a consequence there followed a rapid conversion of most of the larger vessels of the predominantly baitboat fleet to purse-seine gear (McNeely, 1961; Green, Perrin, and Petrich, 1971). In 1962, the year following the near completion of this mass conversion, the eastern Pacific surface fleet numbered 119 purse-seiners, 90 baitboats, and 26 other vessels, with a combined carrying capacity of 40,638 short tons (36,891 metric tons) (Calkins and Chatwin, 1971). Most of the fleet at that time operated under the U. S. flag. By comparison, the 1979 surface fleet consisted of 259 purse-seiners, 45 baitboats, and 17 other vessels, from a total of 16 nations. The carrying capacity of this fleet amounted to 186,329 short tons (169,149 metric tons) (Anonymous, 1980a).

McNeely (1961) has described the typical tuna purse seine in use during the early 1960's. Some improvements have been made since then (Ben-Yami and Green, 1968; Petrich, 1968; Green, Jurkovich, and Perrin, 1971; Green, Perrin, and Petrich, 1971). The most significant change in the net has been its size. The typical purse seine employed by a modern seiner today may measure as much as 700 to 800 fathoms (1,280 to 1,460 m) long by 12 to 14 strips deep (one strip is approximately 6 fathoms (11 m) in depth), as compared to the 425-fathom (780- m) by 7-strip net described by McNeely (1961). The capacity of the vessels using this size of net may range from about 1,000 to 1,800 metric tons. Descriptions of a modern purse-seiner and the equipment and gear it carries are provided by De Fever (1968) and Green, Perrin, and Petrich (1971).

Purse seines are also fished in the western Pacific, and catch yellowfin incidental to skipjack and bluefin. The Japanese purse-seine fishery in the western Pacific is conducted with both single and double boats, although the latter have declined in number in recent years. A brief description of the vessels and nets used in these operations is given by Anonymous (1965a) and Tomiyama (1975). The double-boat seiners range in size from about 30 to 200 gross metric tons, while the single-boat seiners range from 50 to nearly 1,000 gross metric tons (Honma and Suzuki, 1978).

Pole-and-line fishing for tropical tunas has become less important in the eastern Pacific; however, it continues to be an important fishing method in use in the central and western Pacific fisheries. Skipjack is the principal species exploited in these fisheries, but yellowfin constitute a part of the incidental catch. Pole-and-line fishing utilizes bait which is maintained alive in tanks aboard the vessel. When a school of tuna is sighted the live bait is thrown overboard to attract the tuna, which are then captured with fishing poles and lines with barbless hooks or jigs. The gear used in the pole-and-line fishing method, as described by Godsil (1938), Cleaver and Shimada (1950), Shimada and Schaefer (1956), Muramatsu (1960), Takayama (1963), and Yoshida (1966b), has not changed much over the years. The Japanese baitboats in the western Pacific range from coastal vessels of 10 gross metric tons or less to vessels greater than 200 gross metric tons (Ishida, 1975). The size range of the eastern Pacific baitboat fleet in 1960 (the year preceeding the near completion of conversions of baitboats to purse-seine vessels) was 10 to 732 gross metric tons; the 1980 baitboat fleet size range is currently 39 to 467 gross metric tons (Orange, 1980).

The longline is the major gear used by fishermen of Japan, the Republic of China, and the Republic of Korea to catch deep-swimming tunas in the Pacific Ocean. The gear is made up of units called "baskets," which consist of a main horizontal line buoyed at the surface between two floats. From this main line are suspended four to six branch lines, each of which terminates in a "sekiyama" (a line consisting of a center core of either linen, hemp, or steel wire with an outer wrapping of cotton or synthetic thread), a wire leader, and a hook (June, 1950; Shapiro, 1950; Shimada, 1951b; Anonymous, 1965a). Mann (1955 and 1957) reported on improvements made on the conventional longline, and Saito (1973) has described an experimental longline designed to fish twice as deep. A typical longliner set is composed of 400 baskets connected together, carrying a total of 2,000 hooks, and if stretched out this line would have a total length of 120 kilometers (Rothschild and Uchida, 1968). The Japanese longline fleet consists of vessels ranging in size from 70 to 1,300 gross metric tons (Anonymous, 1965a). Descriptions of the layout of a typical Japanese longliner are provided by Kanasashi (1960) and Yoshida (1966b). Most vessels of the Republic of China's fleet range in size from 100 to 200 gross metric tons (Yang, 1979). No data are available on the size of vessels operated by the Korean fleet.

5.2 and 5.3 Fishing areas and seasons

The distribution of yellowfin captured by the Japanese longline fishery is well documented. Although this fishery exploits yellowfin through virtually the entire extent of its range, the equatorial waters of the Pacific produce the largest catches (Figure 8). In an analysis of the distribution of yellowfin caught by the Japanese longline fishery, Suzuki <u>et al</u>. (1978) have delineated three major fishing grounds based on the catch rates (number of yellowfin caught per 100 hooks) for 1967 through 1972. The first fishing ground is the west central equatorial region, which is defined as the area between about 5°N and 10°S and west of 140°W. The width of this ground narrows to the area between 5°N and 5°S, however, east of 180°. The second longline ground is the northeastern region, defined as the area between 5° and 10°N and east of 140°W. The third fishing ground, in the southeastern sector of the fishery, is the area east of 140°W lying close to the equator in its western part and extending diagonally southeast to as far south as 20°S in its easternmost part. The longline fleets from the Republics of China and Korea operate chiefly south of the equator, concentrating on more temperate tunas such as albacore and southern bluefin (Bour and Galenon, 1979; Yang, 1979).

In Figure 8 is shown the distribution of the average catch rate of yellowfin by month and 1-degree area. On the basis of this figure Suzuki <u>et al</u>. (1978) describe the seasonal changes in catch rates for the three major longline fishing grounds as follows:

1) <u>West central equatorial region</u>

"There are few seasonal changes in the distribution of catch rates in this region, except that rates between 170°E and 140°W decrease from about

August to December. Moderately high catch rates extend from the western part of this region up along the Kuroshio Current and curving down along the East Australian Current in accordance with the seasonal strength of these currents, although local patches of high catch rates off Sydney, Australia, seem to persist nearly all year."

2) Northeastern region

"There are two zonal areas of high catch rates in this region. The western area, located between 130°W and 140°W, had high rates from April to July. On the other hand, the eastern area, which appears along 10°N and between 85°W and 110°W, had high rates during December-June; however, the effort in this area was sparse during the other months."

3) Southeastern region

"The area with the highest rates is found in the eastern part of this region between about 85°W and 95°W. The area of high catch rates seems to shift its position southward from July to October."

Honma and Suzuki (1978) reviewed the Japanese purse-seine fishery for tunas in the western Pacific, and showed that this fishery operates in two geographically distinct fishing grounds. These grounds are the temperate fishing ground, which is concentrated mainly off the coast of Japan, and the tropical fishing ground, which is concentrated in the region of the Caroline Islands south to Papua New Guinea. This fishery exploits, in order of importance, skipjack, yellowfin, bluefin, albacore, and bigeye. In Figure 10 are shown the average catches per set of yellowfin in the western Pacific fishing grounds by month and 1-degree area for 1968 to 1974. As indicated by this figure, yellowfin are exploited primarily in the temperate fishing grounds from May to September and in the tropical grounds from October to March.

For the eastern Pacific purse-seine fishery a definitive evaluation of the geographical distribution of yellowfin tuna catches and seasonal variations in catch within fishing areas is difficult. This is due primarily to fishing regulations in effect since 1966 which have prevented most tuna vessels from fishing for yellowfin within the CYRA (Figure 16) during the latter half (approximately) of the year. Upon closure of the fishery the captains of the vessels which are subject to regulation who wish to fish for yellowfin in the Pacific Ocean may do so only outside the CYRA. The geographical distribution of the yellowfin catches by quarter from unregulated and regulated trips for 1963-1974 is given by Calkins and Chatwin (1967 and 1971) and

Calkins (1975). Suzuki et al. (1978) have analyzed the data for unregulated trips for 1965 to 1973 (Figure 11), and report the following on the distribution of yellowfin catch by purse seiners:

"The seiner fishing grounds in the first quarter covered almost the entire CYRA north of the equator. (Recently, however, yellowfin fishing has expanded into areas as far south as 10°S.) Good catches were made off central and southern Mexico, off Costa Rica and in the vicinity of the Gulf of Guayaquil. During the years covered in this study (1965-1973) the yellowfin catch by seiners in the Panama Bight was poor except in 1973.

"In the second quarter good fishing areas within the CYRA were roughly the same as in the first quarter, except that they expanded north off the coast of southern Baja California.

"Since 1967, due to regulations the third quarter catch has come mainly from outside the CYRA. Most fishing in this area occurs along 10°N as far west as 145°W. Inside the CYRA, yellowfin seem to be captured off southern Baja California and off southern Mexico, although almost no third quarter data were available except for 1965.

"The catch from outside the CYRA along 10°N in the fourth quarter appears to be slightly lower than that of the third quarter. Good catches are also reported from the areas along 5°N just outside the CYRA and along 3°N (northern boundary of one of the experimental areas which was opened in 1973 (IATTC, 1974) [= Anonymous, 1974b]). Within the CYRA fishing seems to occur along 10°N from the coastal area to farther offshore.

"Throughout the years of this study there has been virtually no fishing effort immediately to the east of the CYRA boundary. Therefore, very little can be inferred about whether yellowfin tuna are accessible to surface fisheries in this area. There are no apparent environmental barriers to the capture of yellowfin here."

5.4 Fishing operations and results

5.41 Effort and intensity

Information on this subject is given in Sections 4.2 and 4.5.

5.42 Selectivity

Information on this subject is given in Section 4.13.

5.43 Catches

The annual catches of yellowfin in the entire Pacific Ocean by the major longlining countries and by the surface fisheries in the western and eastern

Pacific are shown in Table 6. The data were obtained from Honma (1971), Anonymous (1974e, 1975f, 1975g, 1976e, 1977e, and 1980a), Honma and Suzuki (1978), Suzuki et al. (1978), Yang (1979), and Orange (1980). Except for 1966, the yellowfin catch by the Japanese longline fleet has been declining since 1961; catches by longline vessels from the Republic of China have been decreasing since 1972.

6 PROTECTION AND MANAGEMENT

Research concerning stock assessment of yellowfin in the eastern Pacific is carried out by the Inter-American Tropical Tuna Commission (IATTC) (Joseph, 1970 and 1973b; Bayliff, 1975). The IATTC staff makes recommendations for the scientific management of this species to the member governments, and these are discussed by representatives of those governments and other governments whose flag vessels participate in the fishery. For each year of the 1966-1979 period resolutions calling for regulations governing the fishery for yellowfin in the eastern Pacific were adopted. These resolutions are printed in the IATTC's annual reports and summarized in Table 7. The resolutions consist, essentially, of an overall catch quota, to be taken on a first-come-first-served basis, for yellowfin in the Commission's Yellowfin Regulatory Area (CYRA) (Figure 16) and special allocations, primarily for small vessels and vessels of developing nations. The special allocations provided for in the resolutions, however, were not recommended by the IATTC staff because involvement in these questions is outside its province. Also, in some cases the quotas adopted in the resolutions were slightly higher than those recommended by the IATTC staff. Commencing in 1973, various experimental areas inside the CYRA were opened to unregulated fishing on a yearly basis. The boundaries of these areas are shown in Figure 16.

The IATTC is presently carrying out a program started in 1969 to determine empirically the average maximum sustainable yield by setting the catch quota each year at a level higher than the theoretical maximum estimated by present knowledge (Section 4.5). After establishing the quota for a given year, the catch is closely monitored, and if it appears that the stock will not be damaged, the quota may be increased by one or more increments; otherwise, the fishery inside the CYRA is closed to unrestricted yellowfin fishing when it appears that the quota will be reached by the end of the year (see below). However, regardless of whether or not it appears that the quota will be reached, if the catch per standard day's fishing falls below 3 short tons

(2.7 metric tons) at any time during the year, unrestricted fishing for yellowfin in the CYRA is to be curtailed immediately so as to safeguard the resource.

Because the fishery in the CYRA operates also on species other than yellowfin, a specified allowance is made for the incidental catch of yellowfin by vessels subject to regulation whose captains choose to fish in the CYRA.

The closure date of the fishery in the CYRA is established at the time when the quantity of yellowfin already caught, plus the expected catch of yellowfin by vessels which are at sea on unrestricted fishing trips and by vessels expected to depart on unrestricted trips within the grace period (Table 7) reaches the yearly established quota, less the portion reserved for the incidental catch of yellowfin and any special allocations granted during the year.

Thus far, no regulatory measures have been implemented for fisheries for yellowfin in other areas of the Pacific Ocean. Suda (1973b) has examined some of the possible problems that might be encountered should a catch quota or limited entry system be established as a means to regulate the longline fishery.

7 CULTURE

The results of experiments carried out on the rearing of yellowfin larvae were summarized by Ueyanagi _et_ _al_. (1973) and Ueyanagi (1978). Inoue (1973) reviewed the studies investigating the possibilites of artificial propagation of tropical Pacific tunas and noted: (1) preservation of tuna sperm via quick freezing techniques appears feasible; (2) artificial fertilization of tuna eggs can be accomplished easily; and (3) food sources for tuna larvae can be mass produced. He proposed that a pilot propagation farm be established on a tropical island in the Pacific having a natural lagoon. Tuna larvae, hatched from eggs removed from captured females and artificially fertilized by thawed viable sperm, would be raised in the lagoon until the resulting juveniles reached a length of 25 cm or more, at which time they would be released into the open sea. Citing investigators who have shown that predators of yellowfin do not generally prey on fish larger than 25 cm, Inoue (1973) reasoned that allowing the young tunas to reach this size before releasing them would increase their chances of survival.

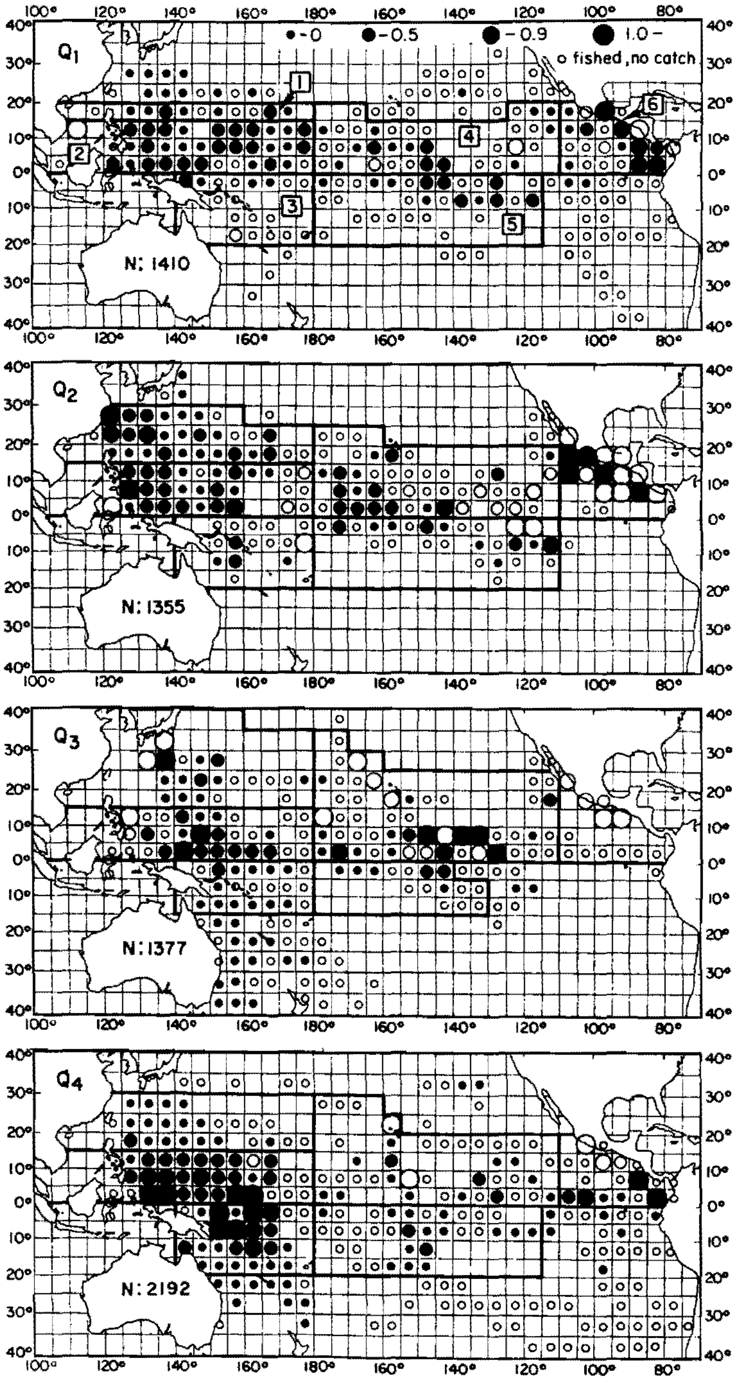


FIGURE 1. Quarterly density distributions of larval yellowfin sampled by surface horizontal tows (from Suzuki et al., 1978). Solid and open circles denote the densities in 5-degree areas calculated from five or more tows and less than five tows, respectively. N indicates the number of nominal tows and the numerals represent areas (shown surrounded by heavy lines) for examining seasonal changes of density in them.

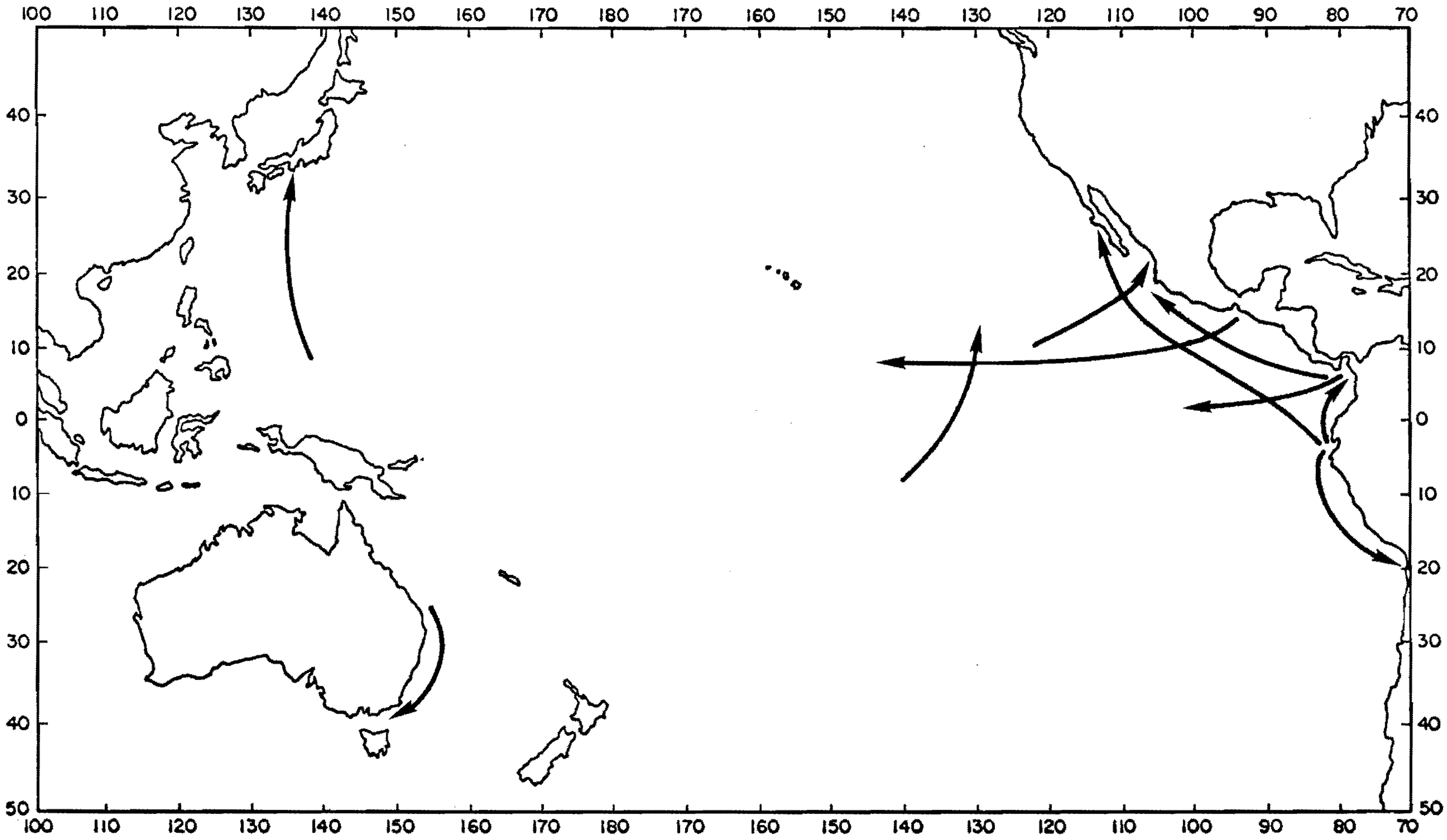


FIGURE 2. Long-range migrations exhibited by yellowfin tagged in the western Pacific (after Suzuki et al., 1978) and the eastern Pacific (after Fink and Bayliff, 1970, Anonymous, 1973 and 1980a, and Bayliff, 1979).

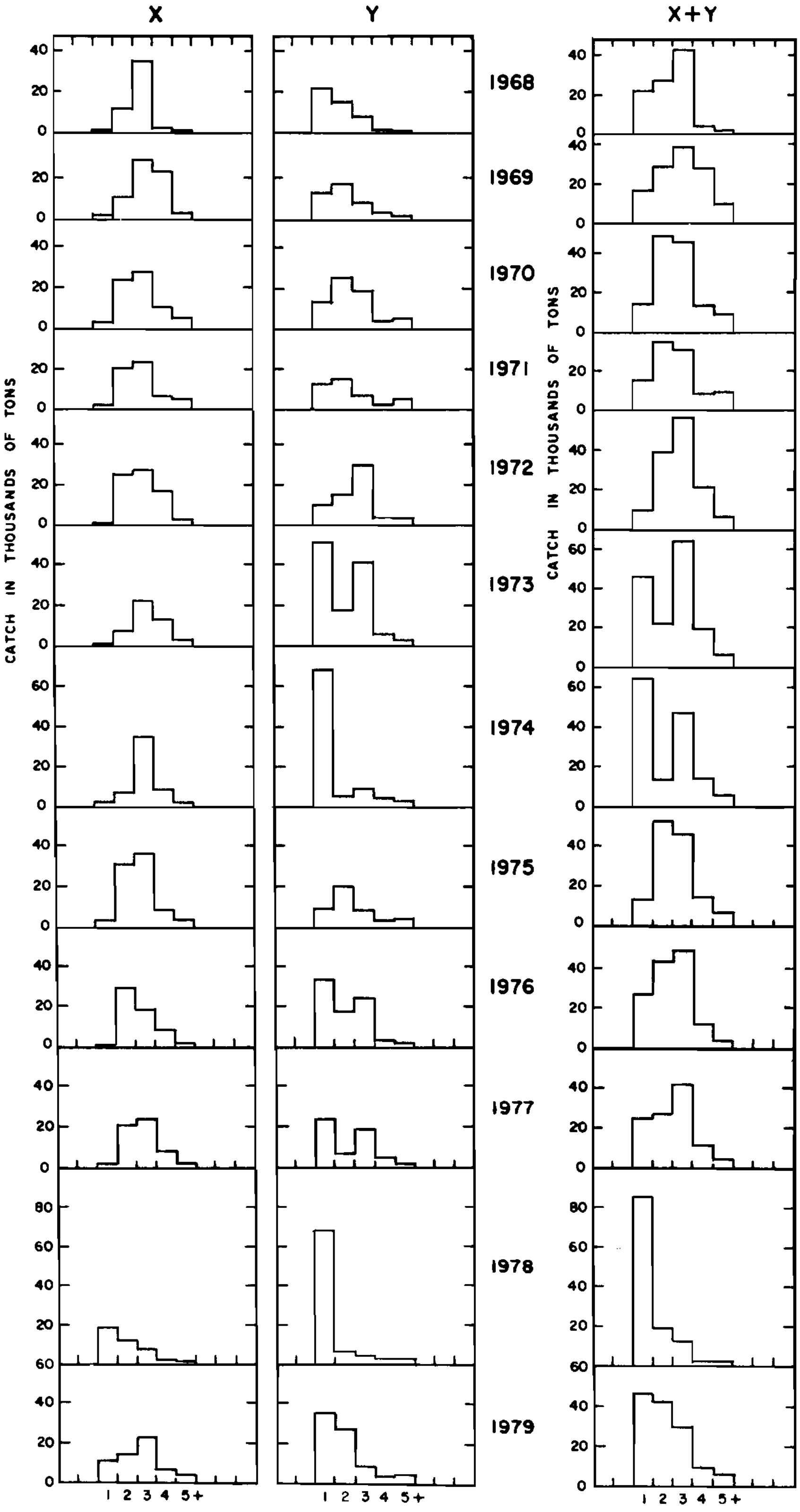


FIGURE 3. Estimated weights of yellowfin of ages 1 through 5+ in the first- and second-quarter purse-seine catches in the eastern Pacific from 1968 through 1979 (from Anonymous, 1980a).

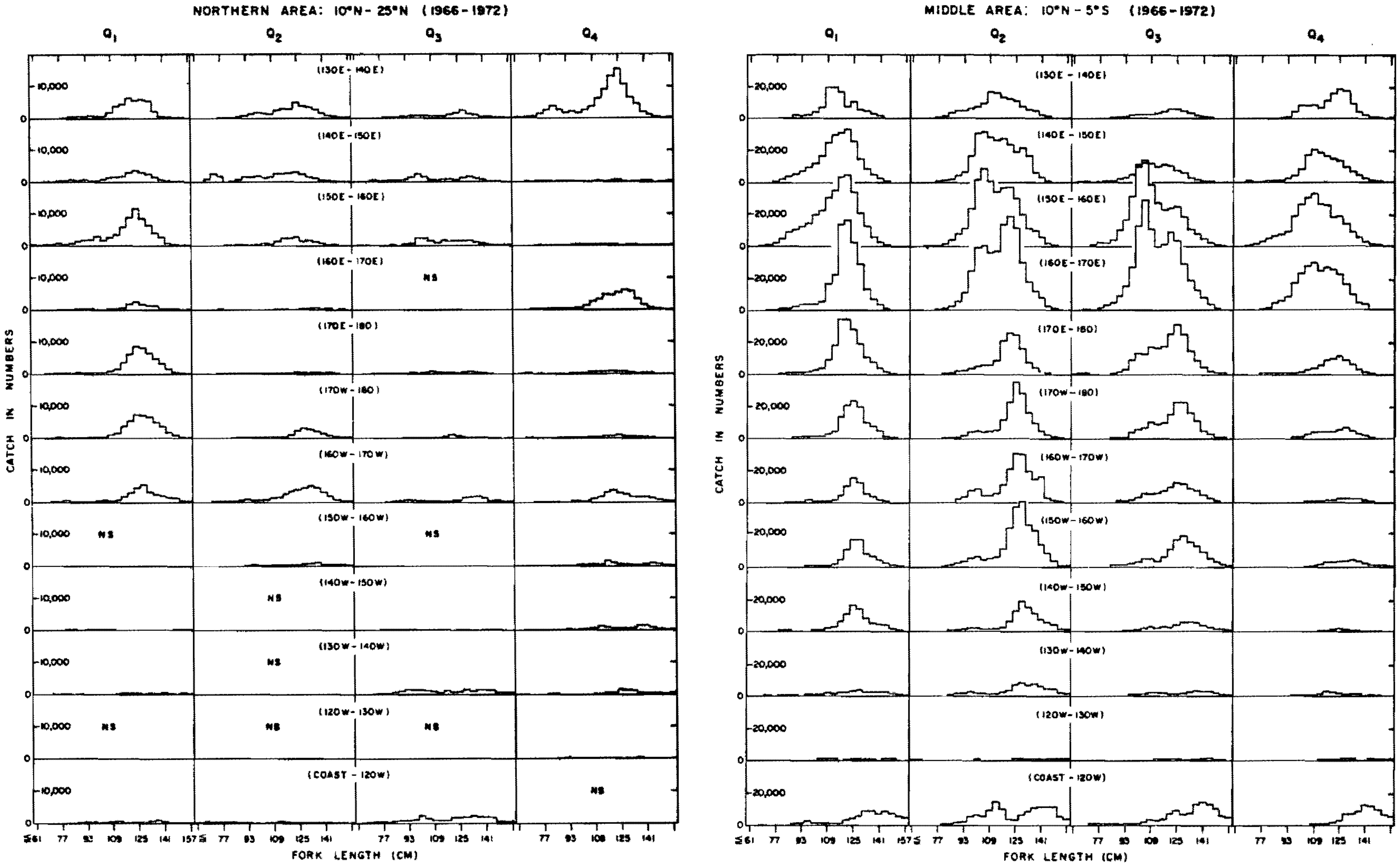
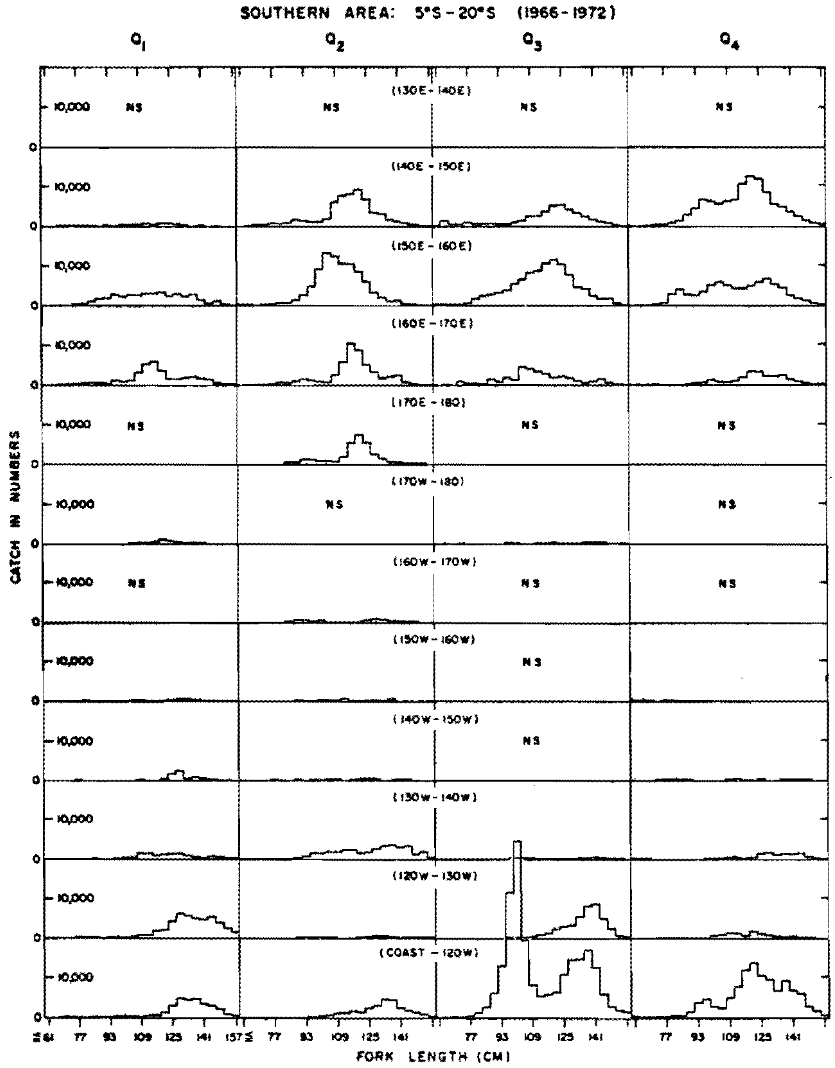


FIGURE 4. Quarterly length frequencies of longline-caught yellowfin in three major areas of the Pacific (northern, middle, and southern) for 1966-1972 combined, by 10-degree longitudinal strips (from Suzuki et al., 1978). NS denotes no samples.



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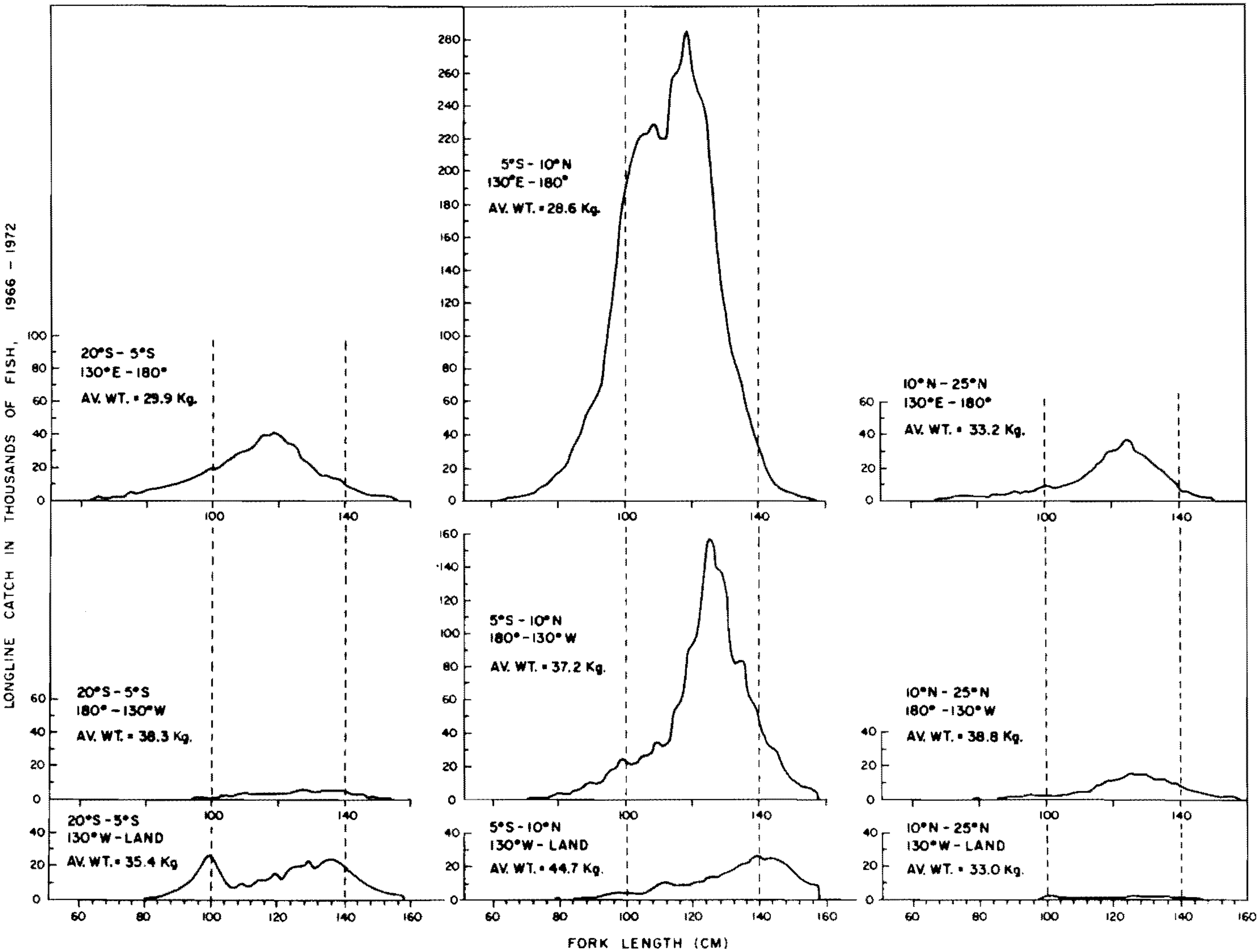


FIGURE 5. Length frequencies of longline-caught yellowfin for 1966-1972 combined, for nine major areas of the Pacific (from Suzuki et al., 1978).

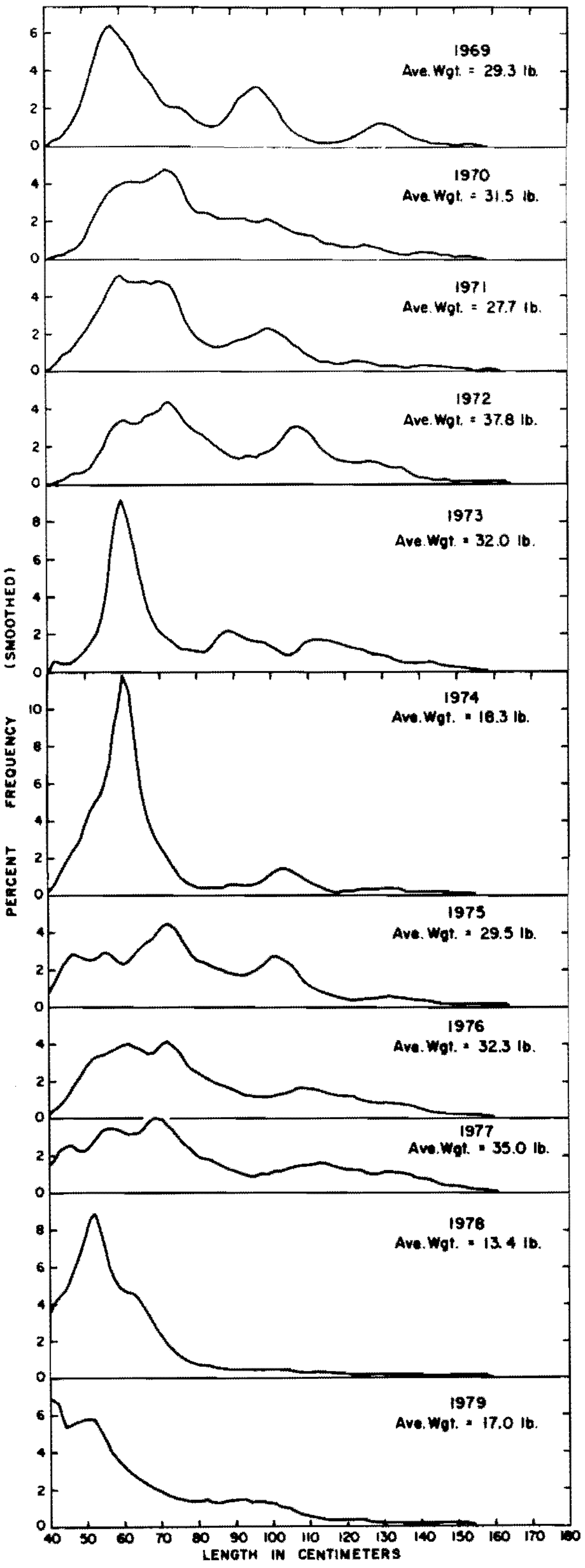


FIGURE 6. Length frequencies of yellowfin caught by surface gear in the CYRA (Figure 16), 1969-1979 (from Anonymous, 1974b and 1980a).

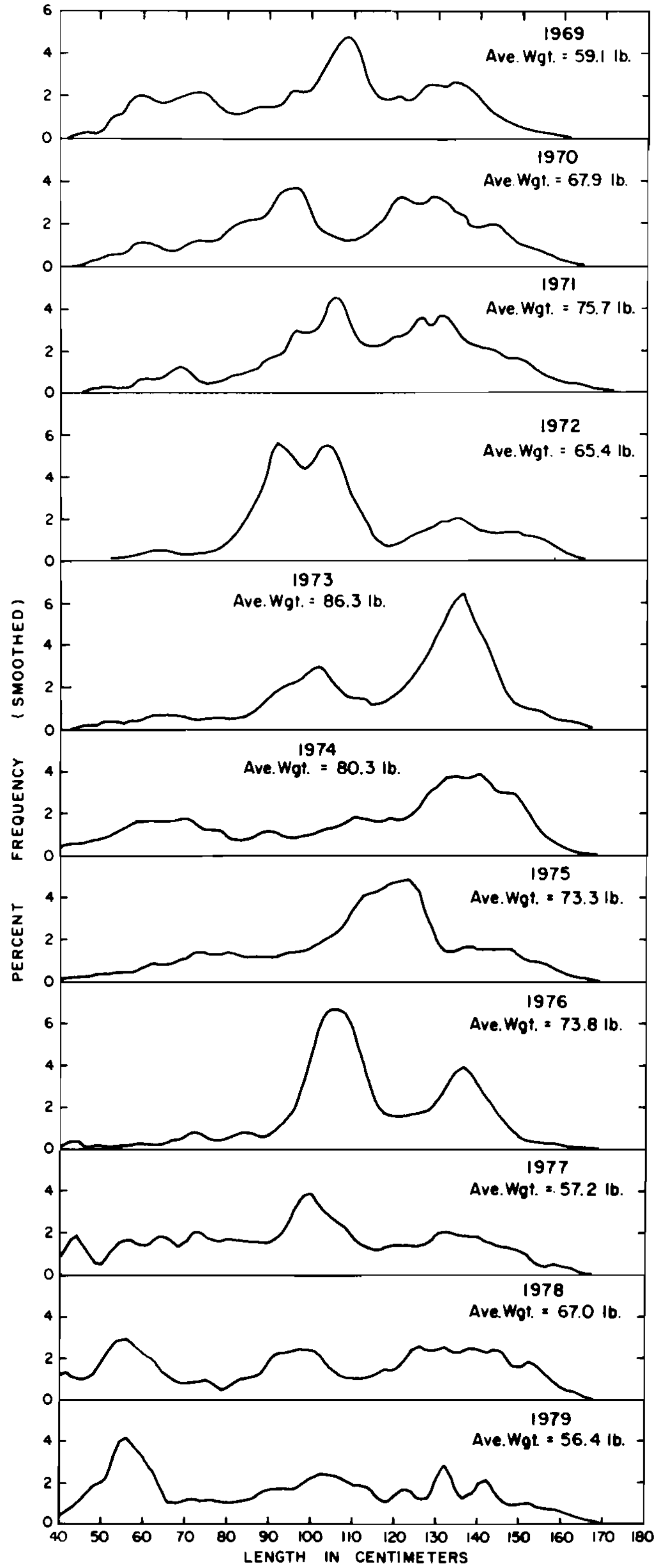


FIGURE 7. Length frequencies of yellowfin caught by surface gear between the CYRA boundary (Figure 16) and 150°W, 1969-1979 (from Anonymous, 1970d, 1976b, and 1980a).

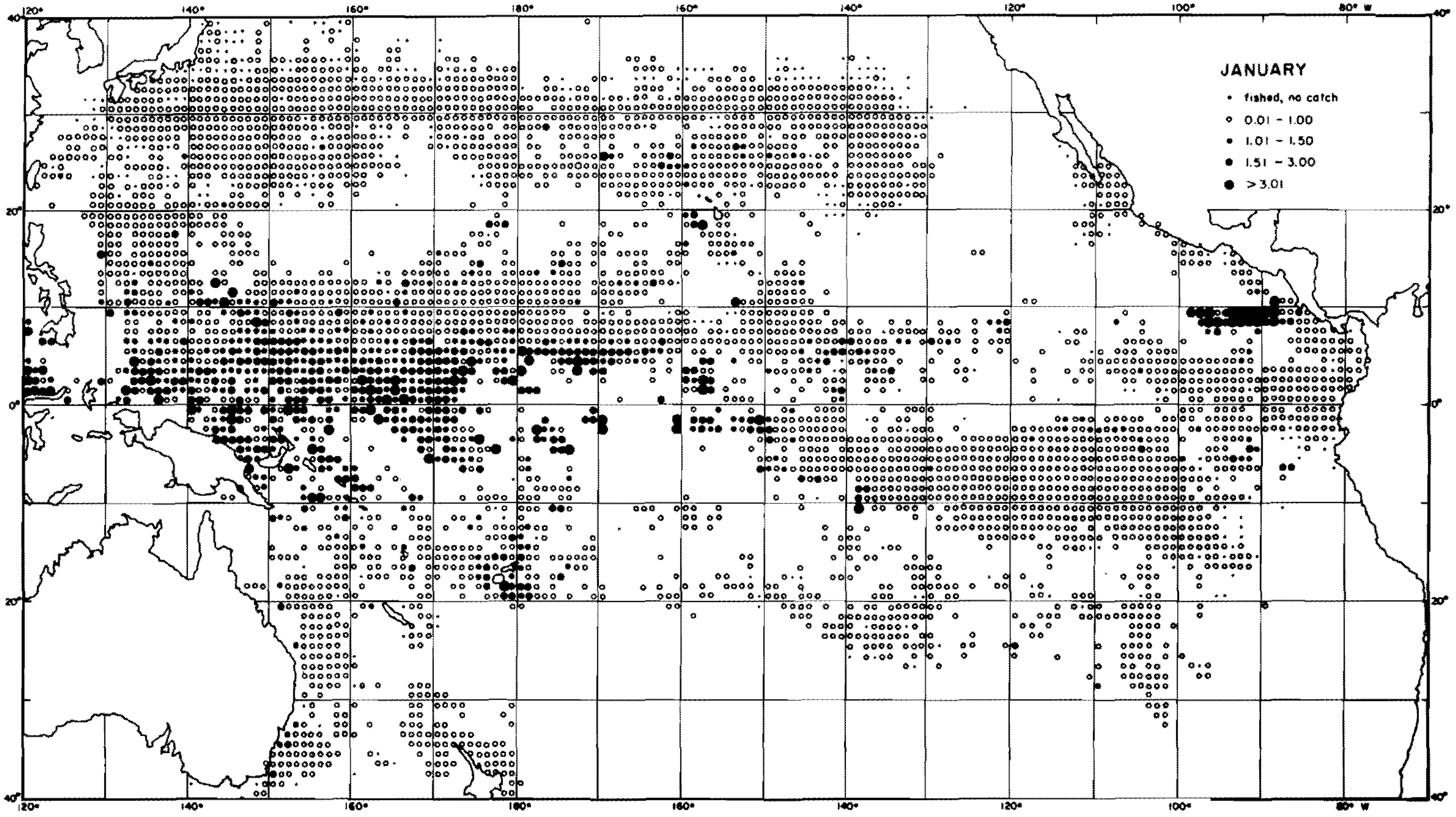
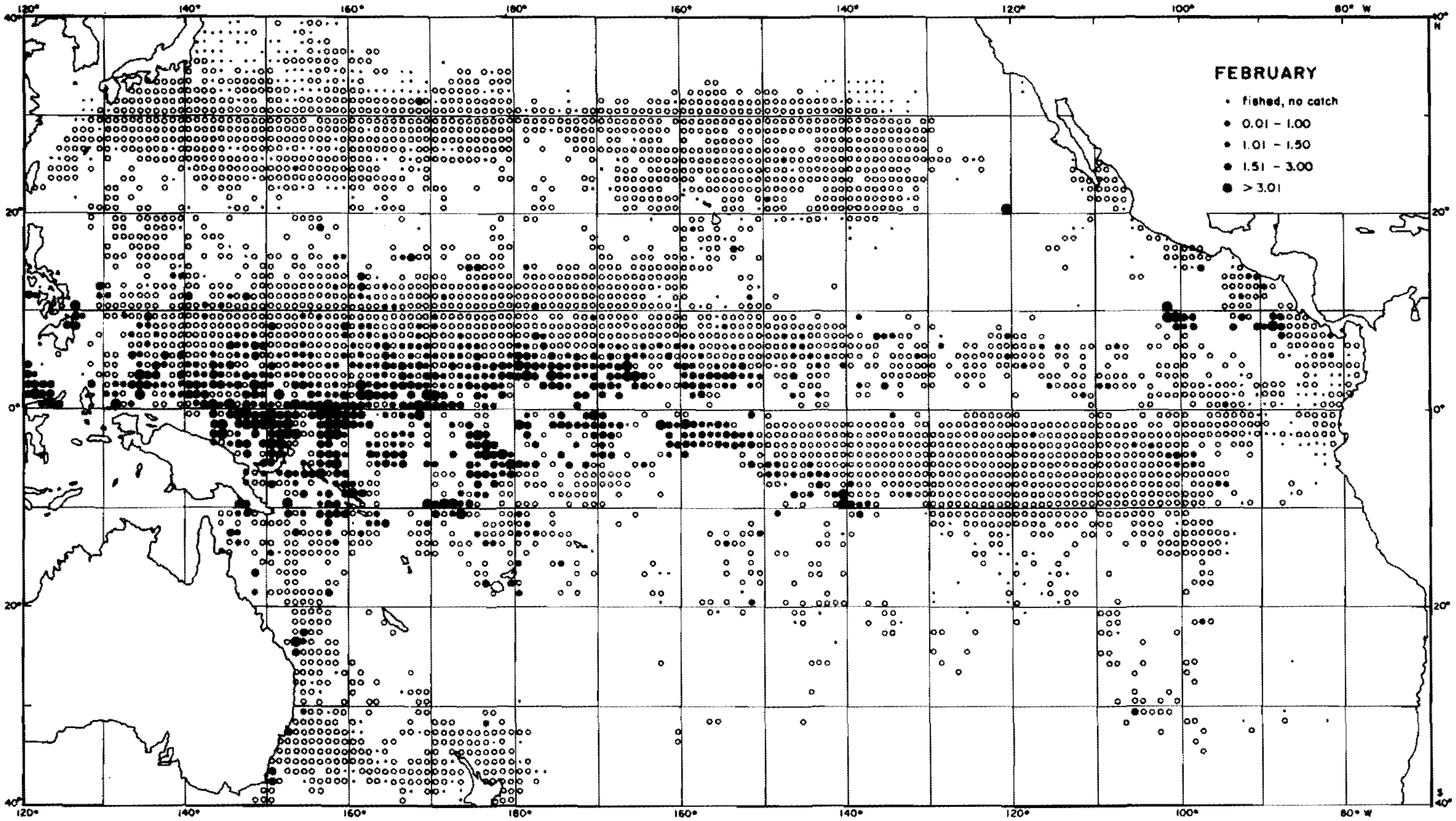


FIGURE 8. Monthly distributions of average catch rates for yellowfin caught by Japanese longline boats, for 1967-1972 combined (from Suzuki et al., 1978).



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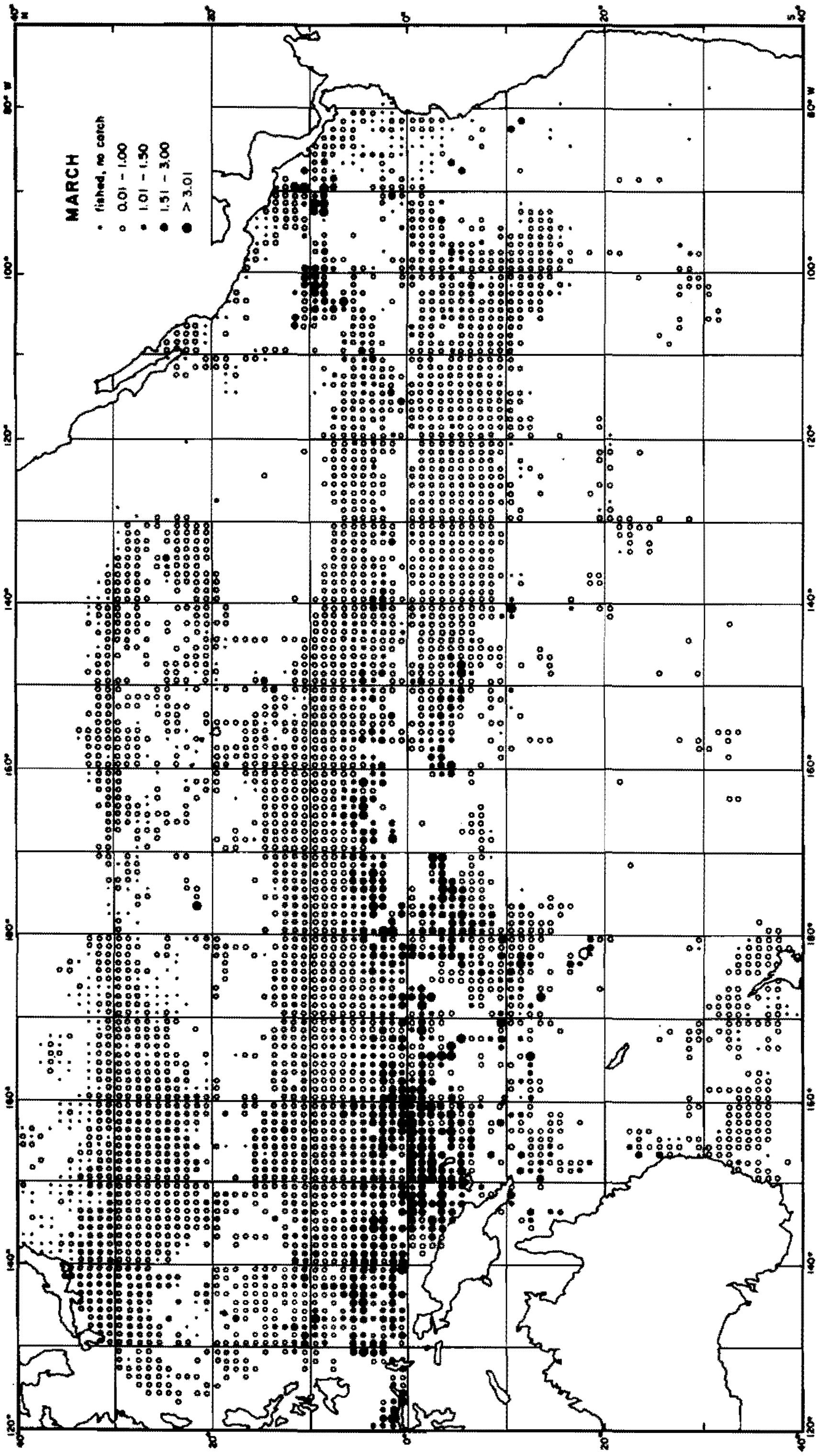

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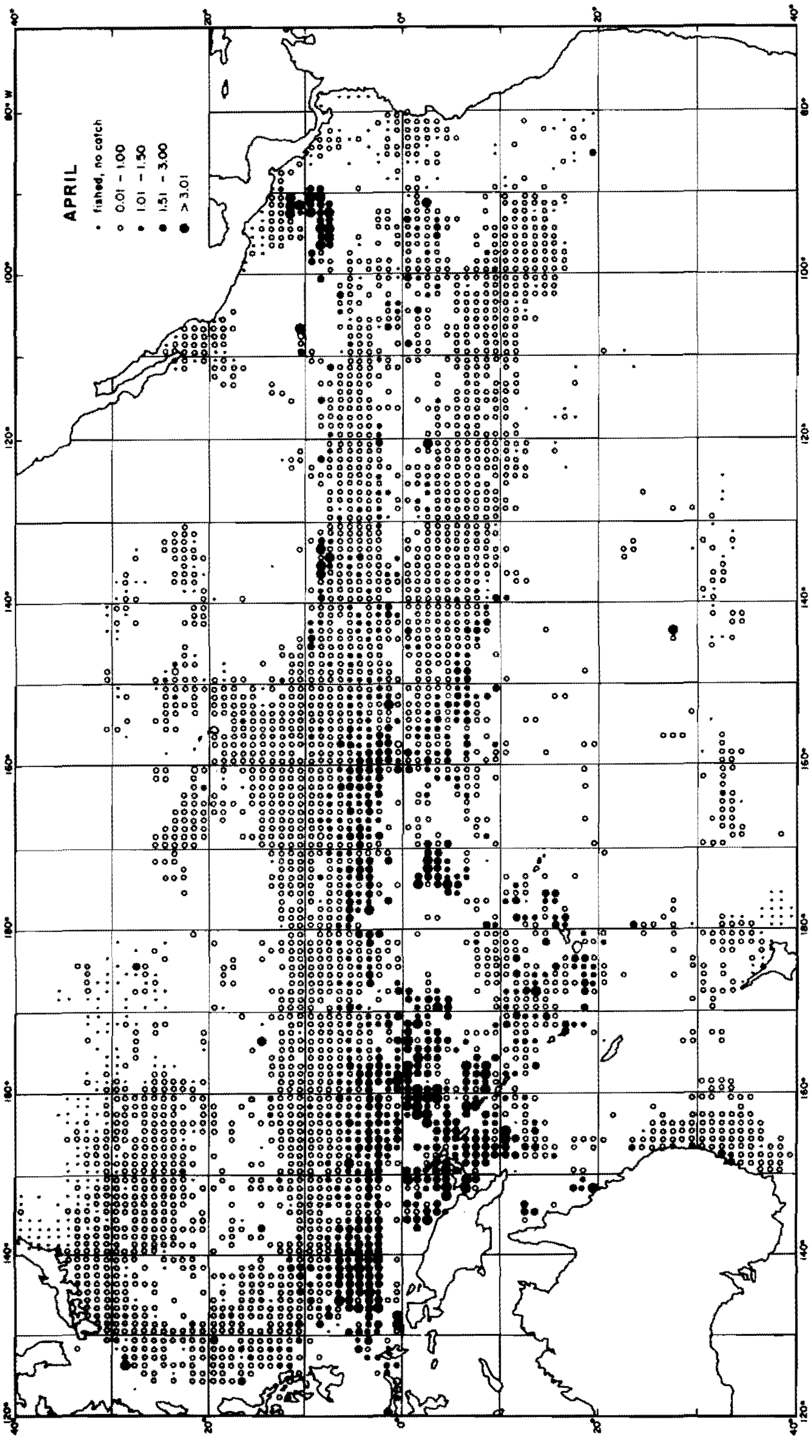

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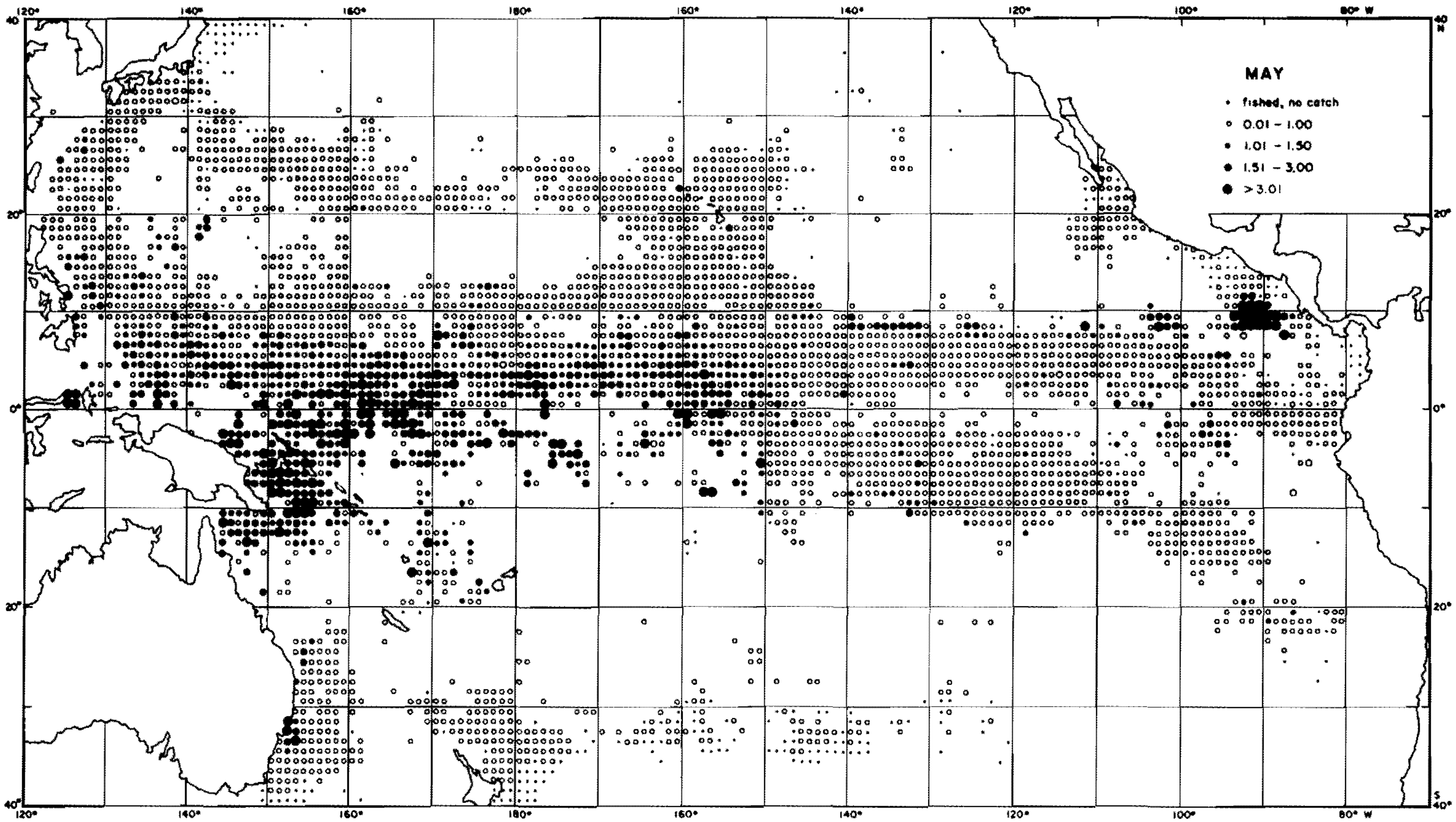

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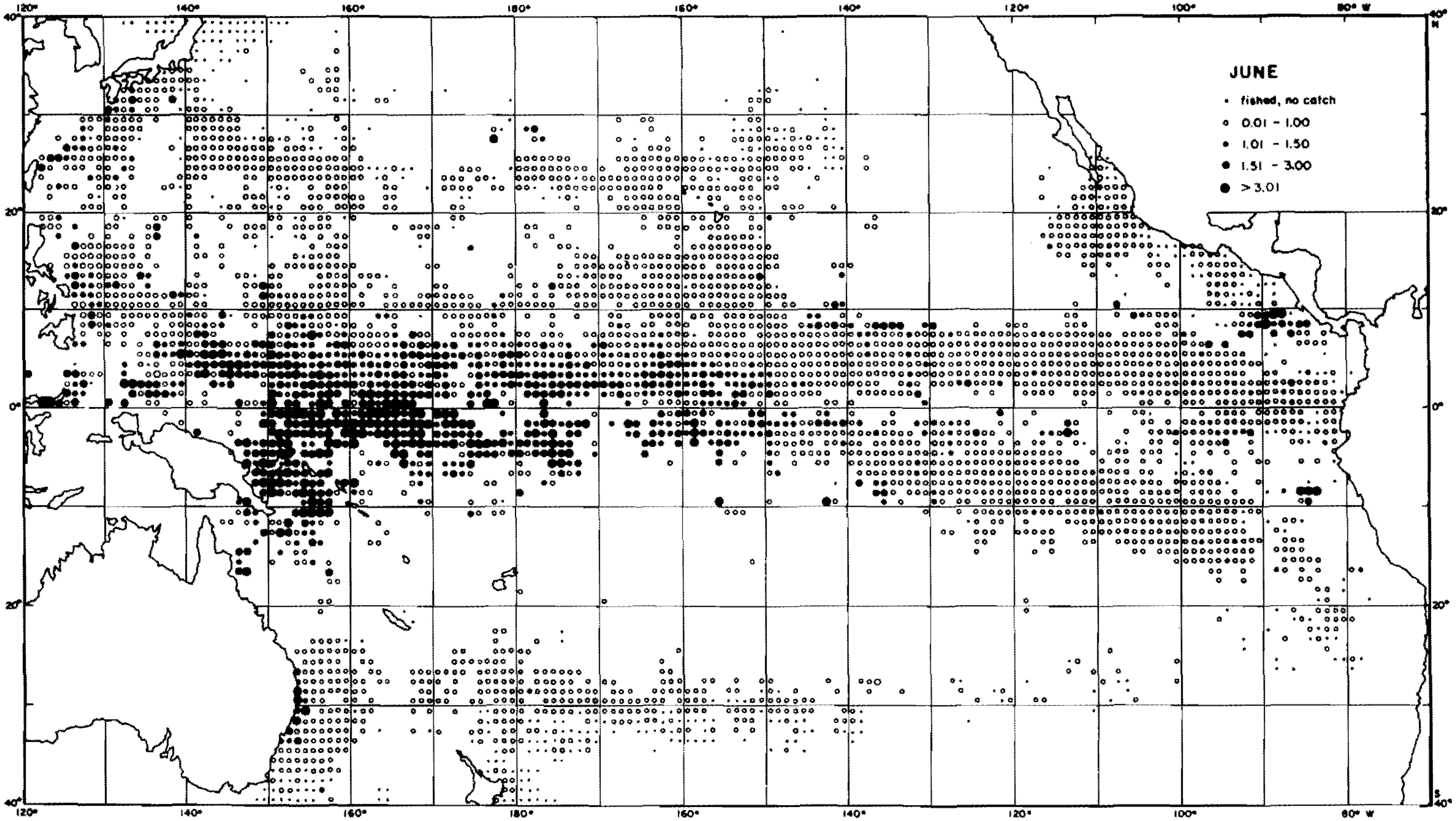

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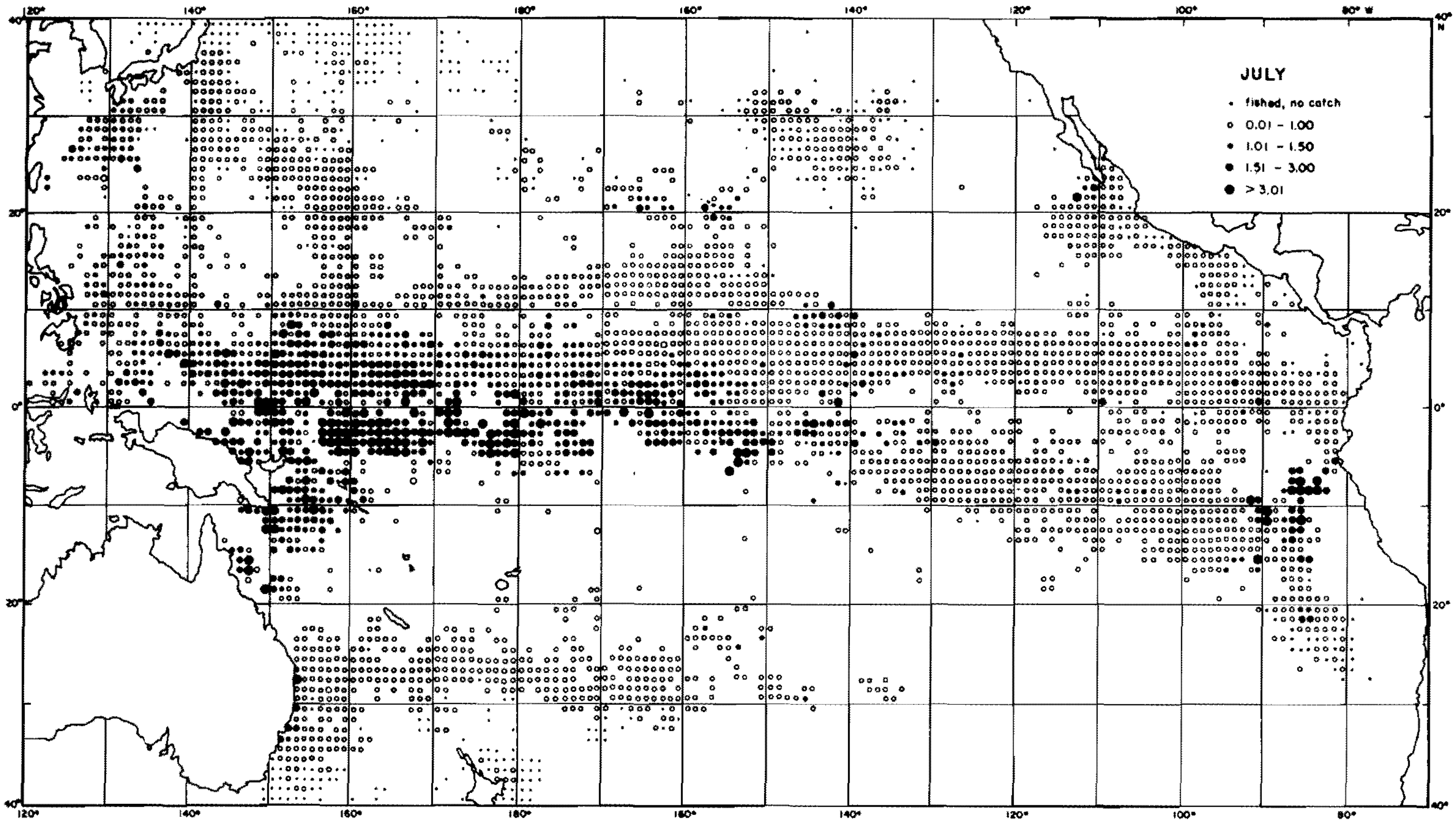

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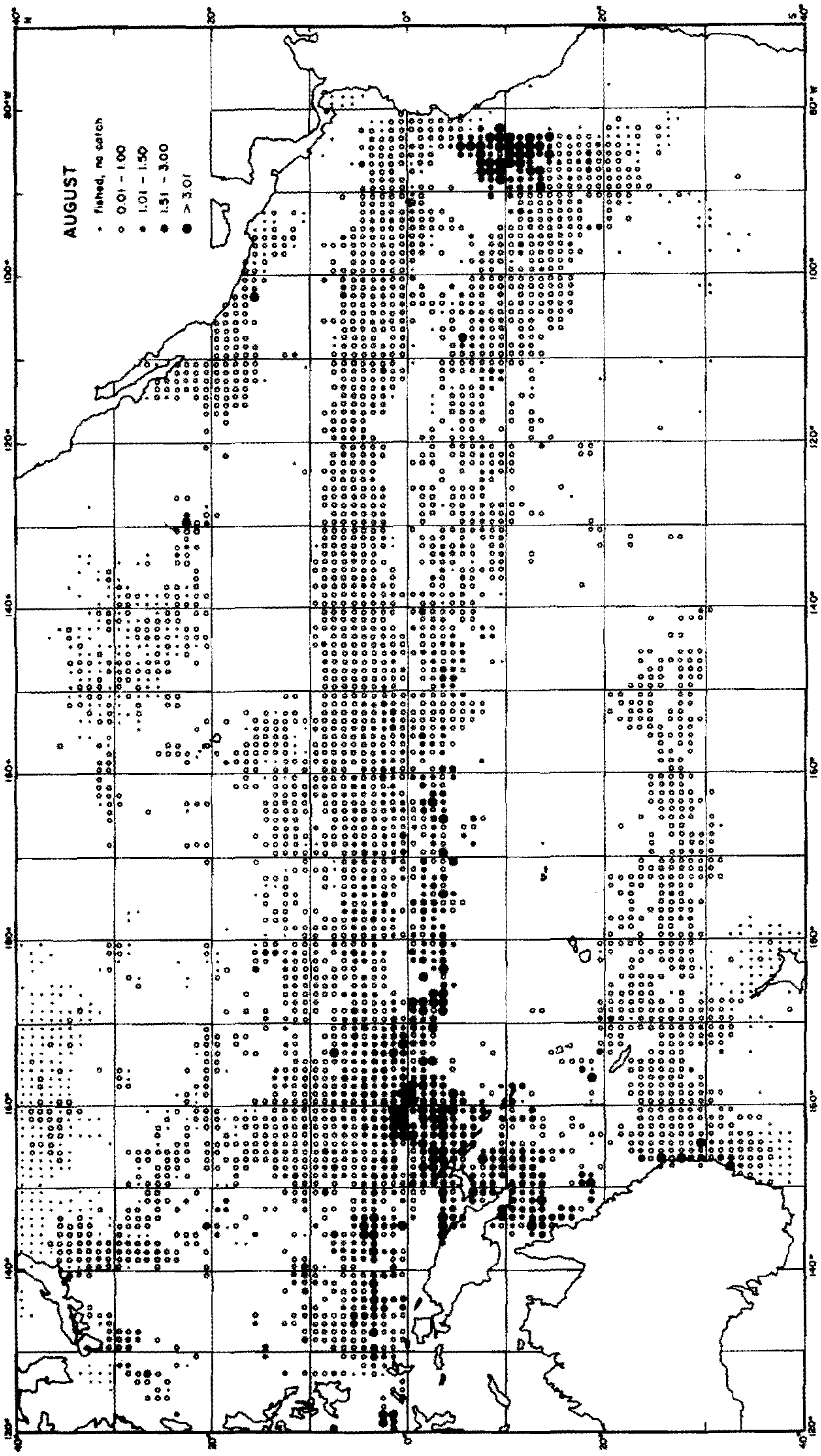

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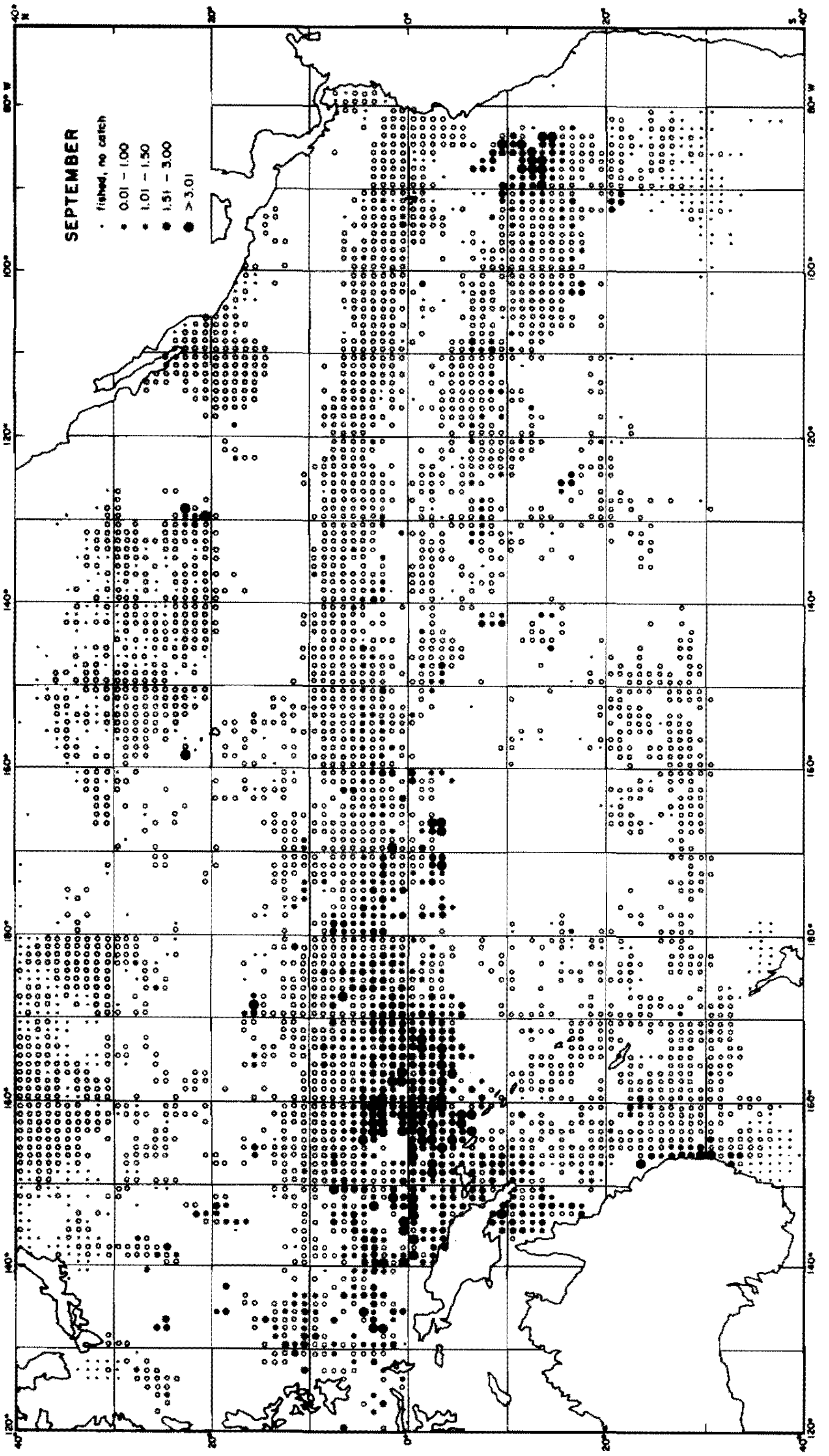

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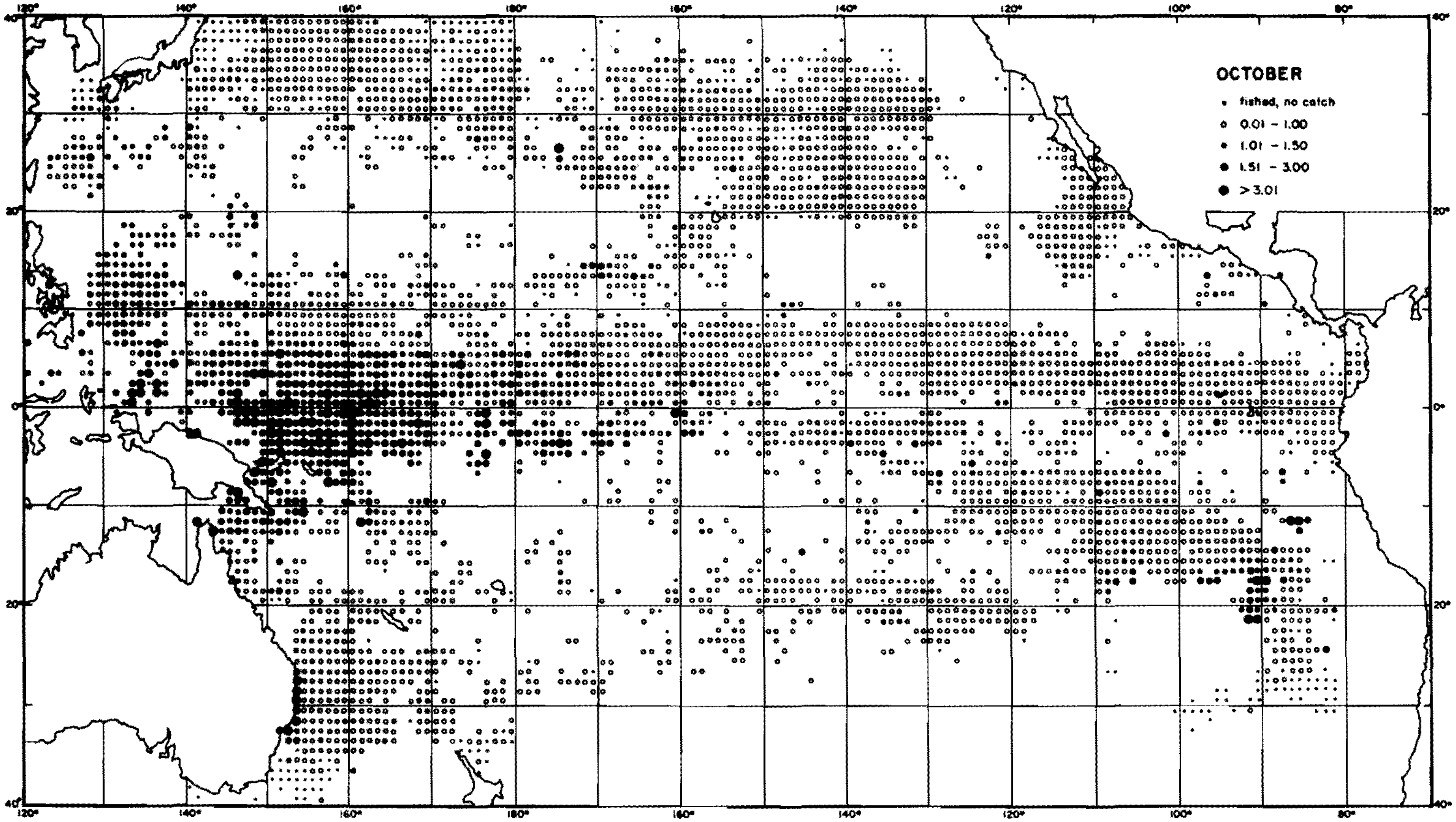

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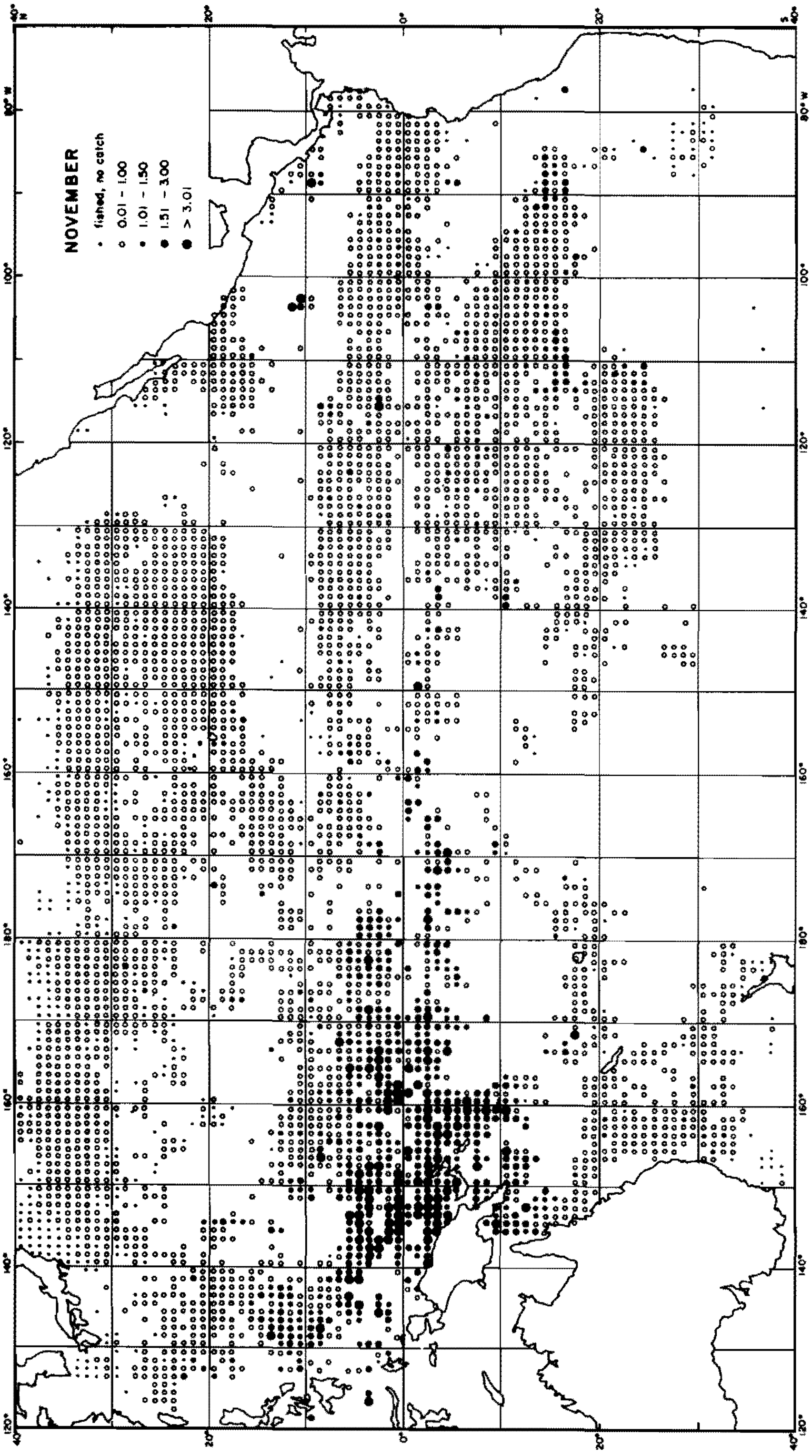

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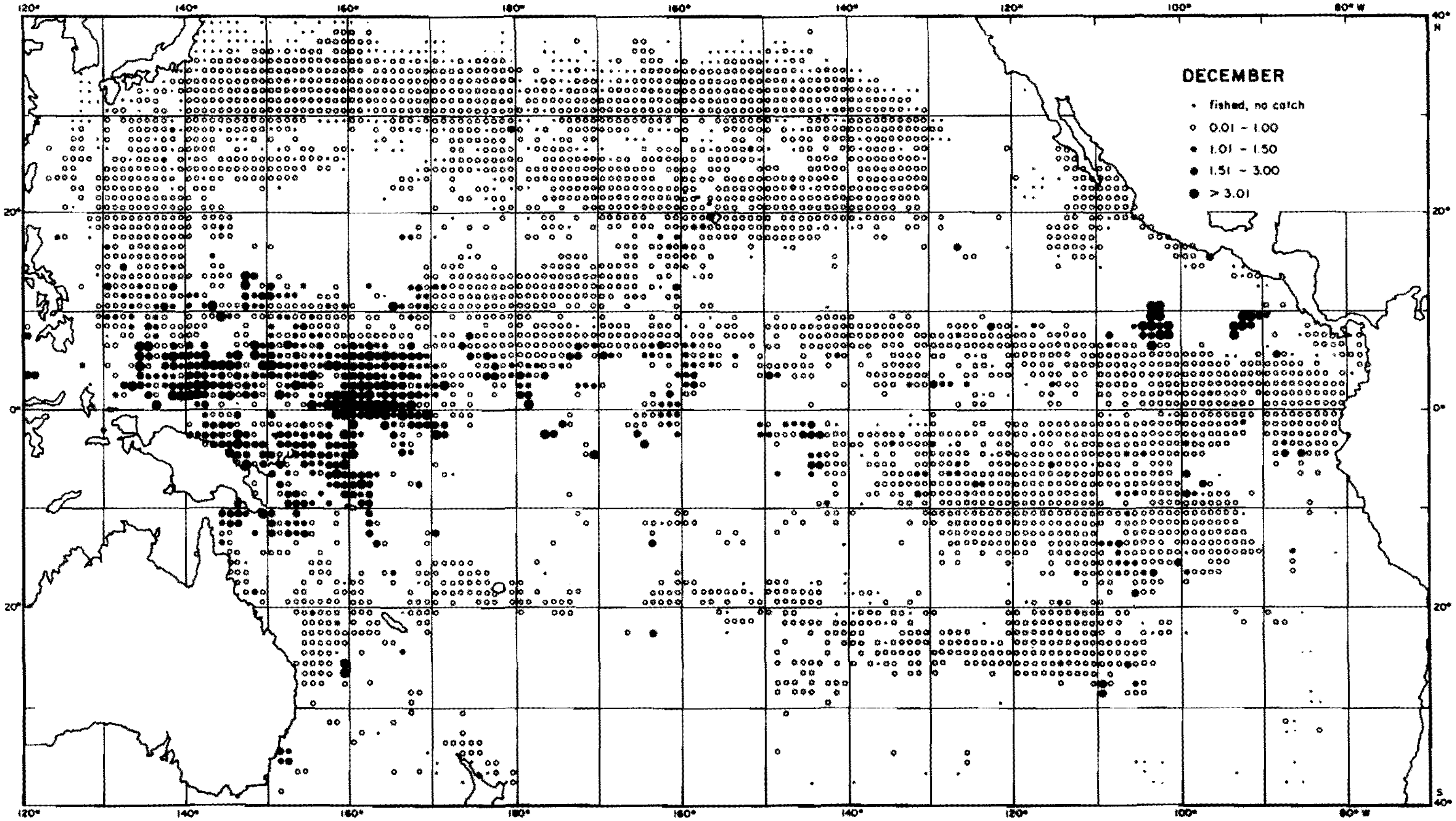

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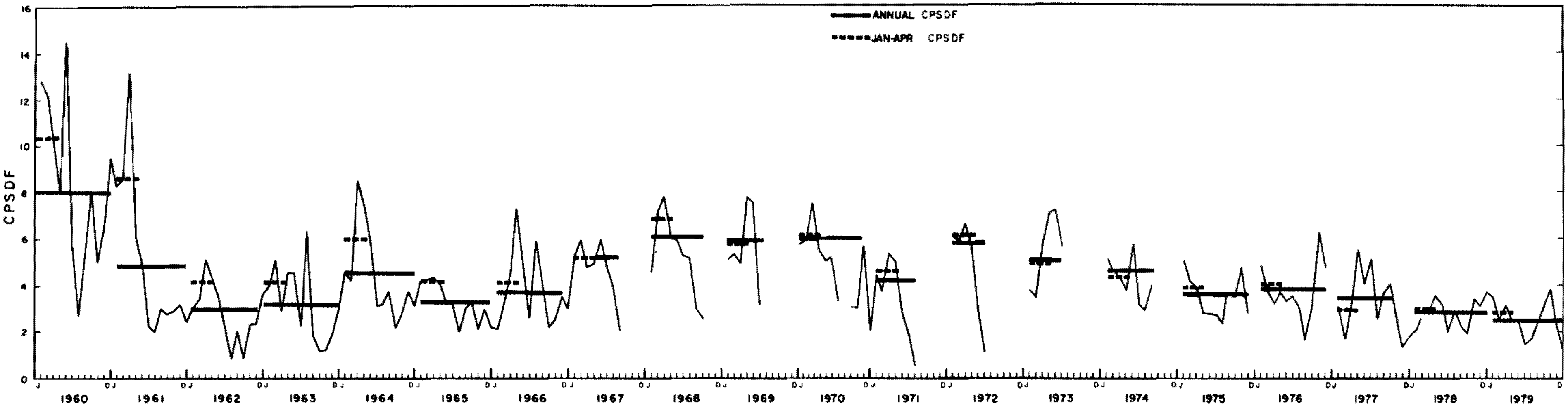
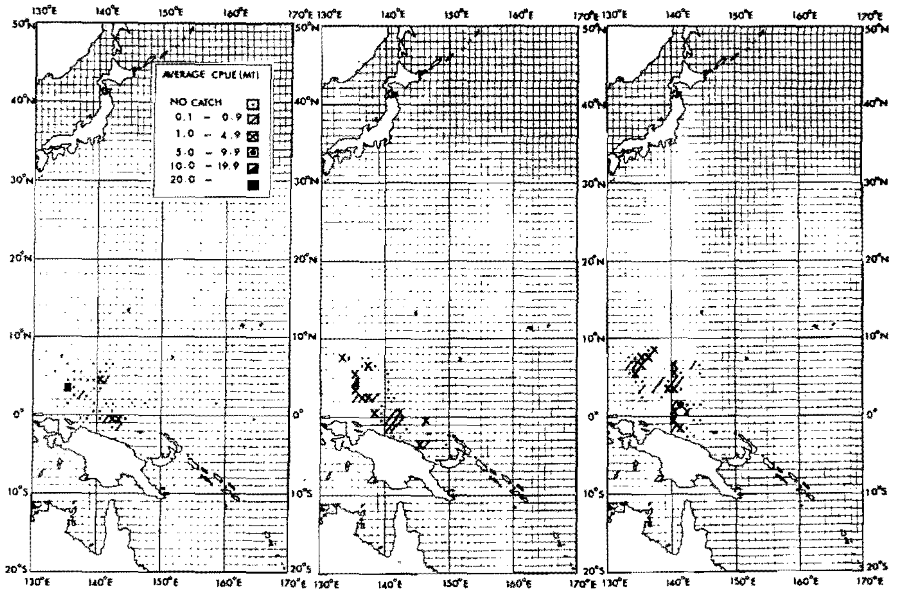


FIGURE 9. Catch per standard day's fishing in Class-3 purse-seine units in the CYRA (Figure 16) during 1960 through 1979 (from Anonymous, 1980a). Only the data from unregulated trips were used. The data for 1979 are preliminary.



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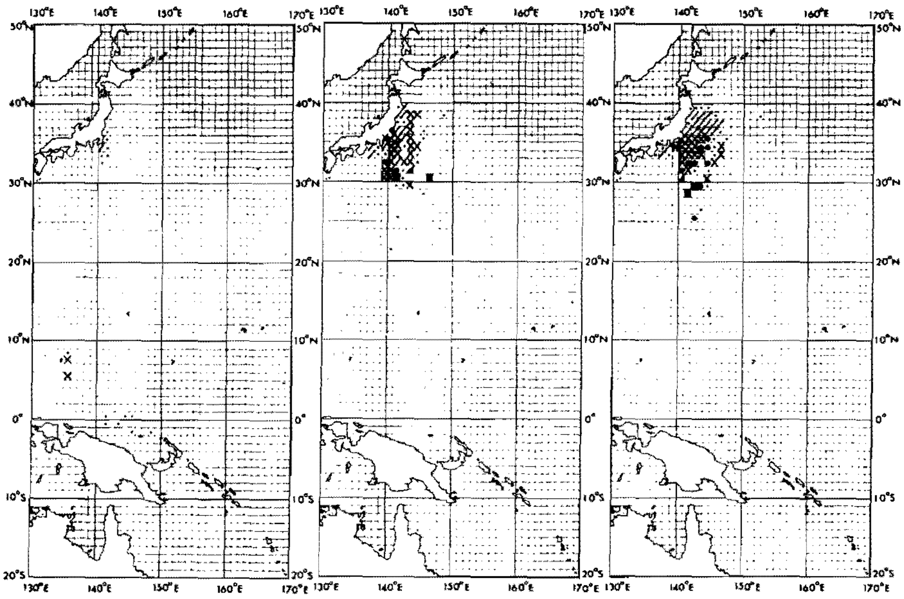

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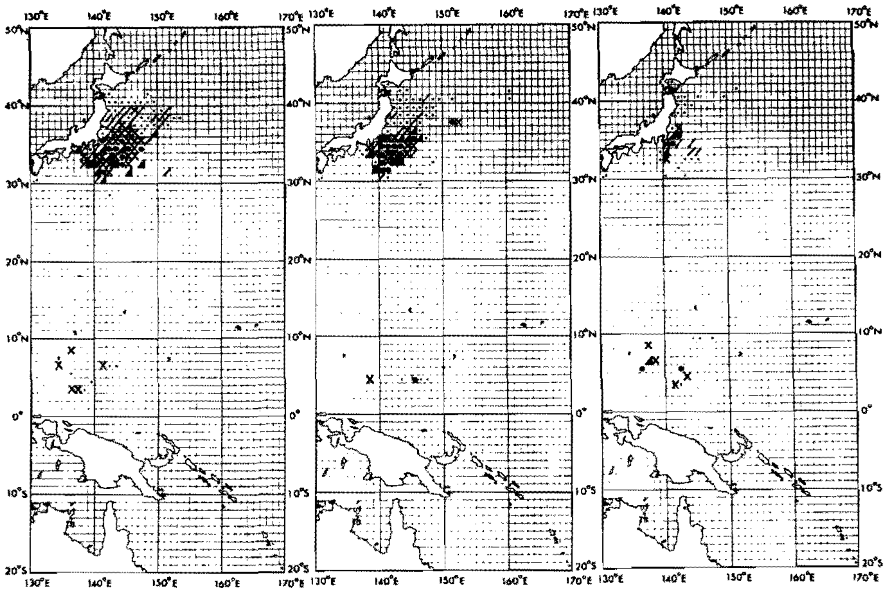
FIGURE 10. Monthly distributions of average CPUE (catch in tons/number of sets) of yellowfin exploited by Japanese purse seiners in the western Pacific during 1968-1974 combined in the tropical fishing grounds (south of 25°N) and 1971-1974 combined in the coastal fishing grounds (north of 25°N) (from Homna and Suzuki, 1978).



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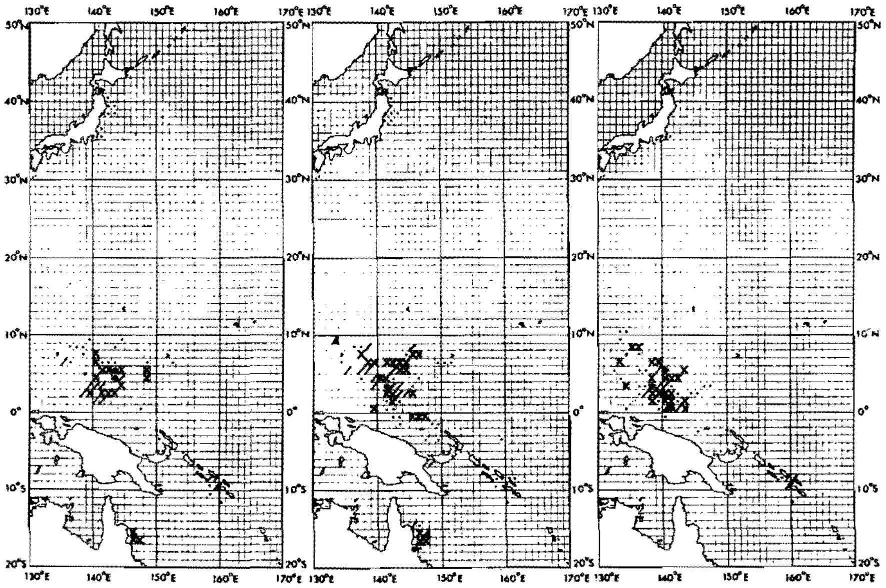

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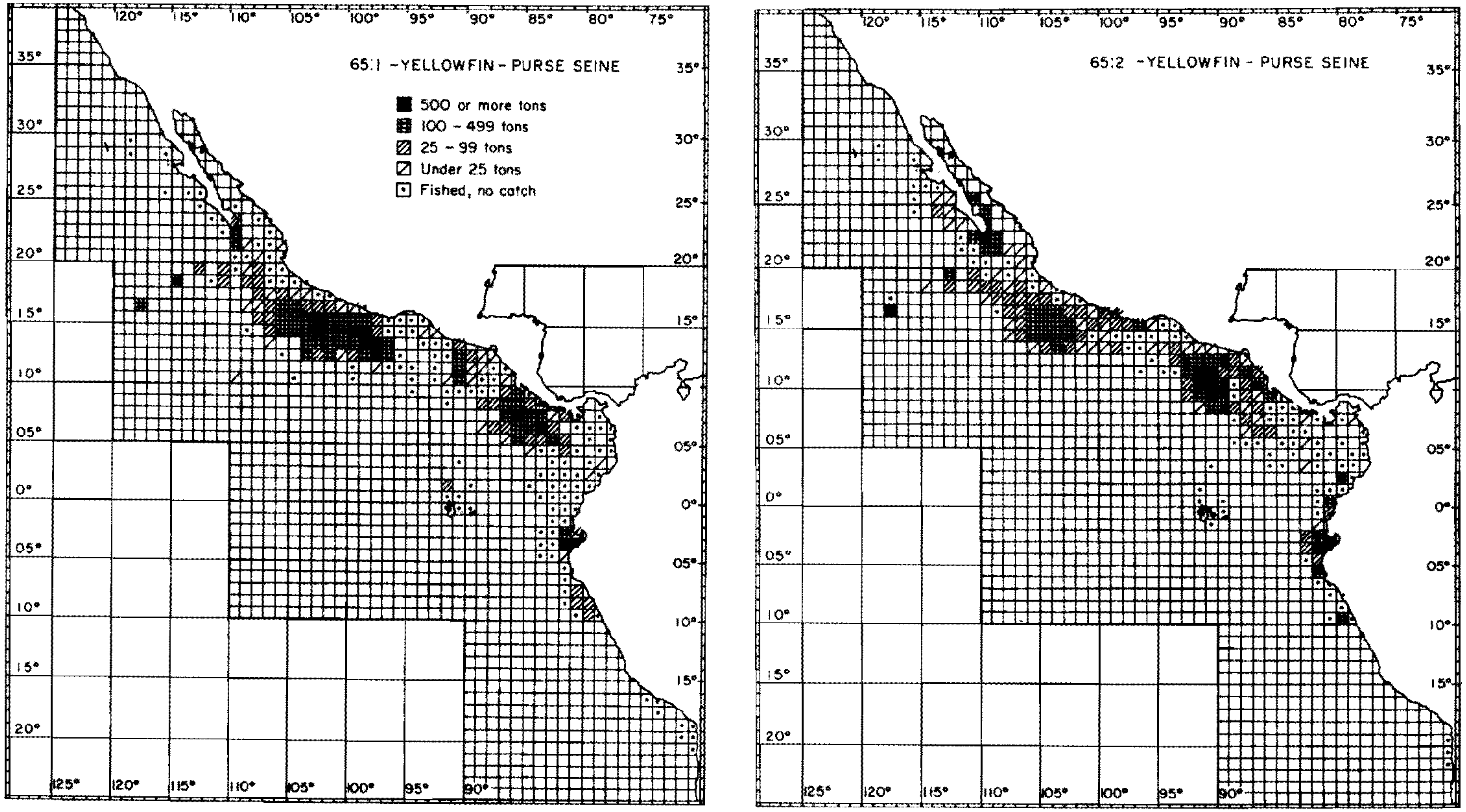
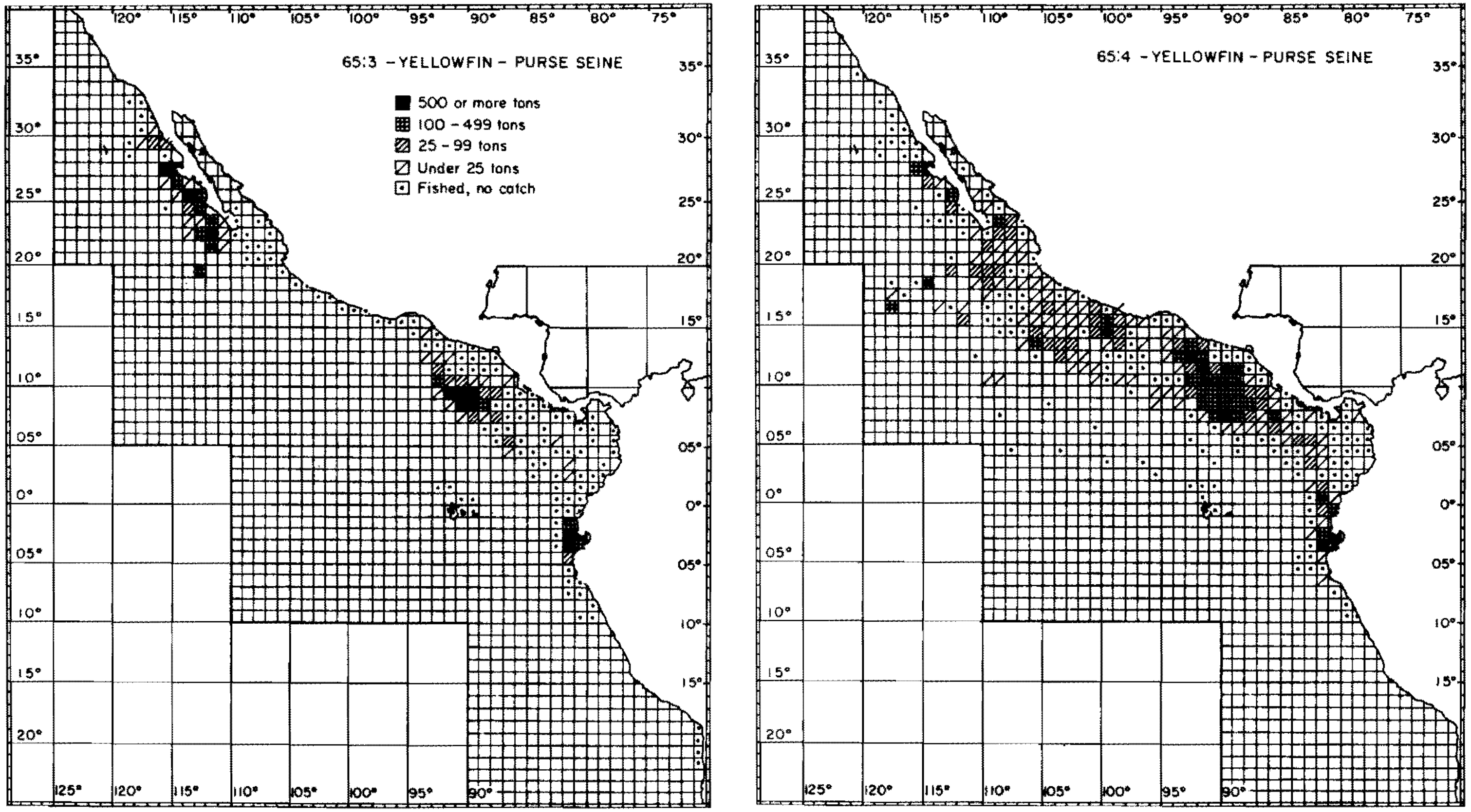


FIGURE 11. Quarterly distributions of yellowfin catch during unregulated trips by purse-seine vessels in the eastern Pacific for odd years from 1965 through 1973 (except the fourth quarter of 1967, when there was no logged catch) (from Suzuki et al., 1978).



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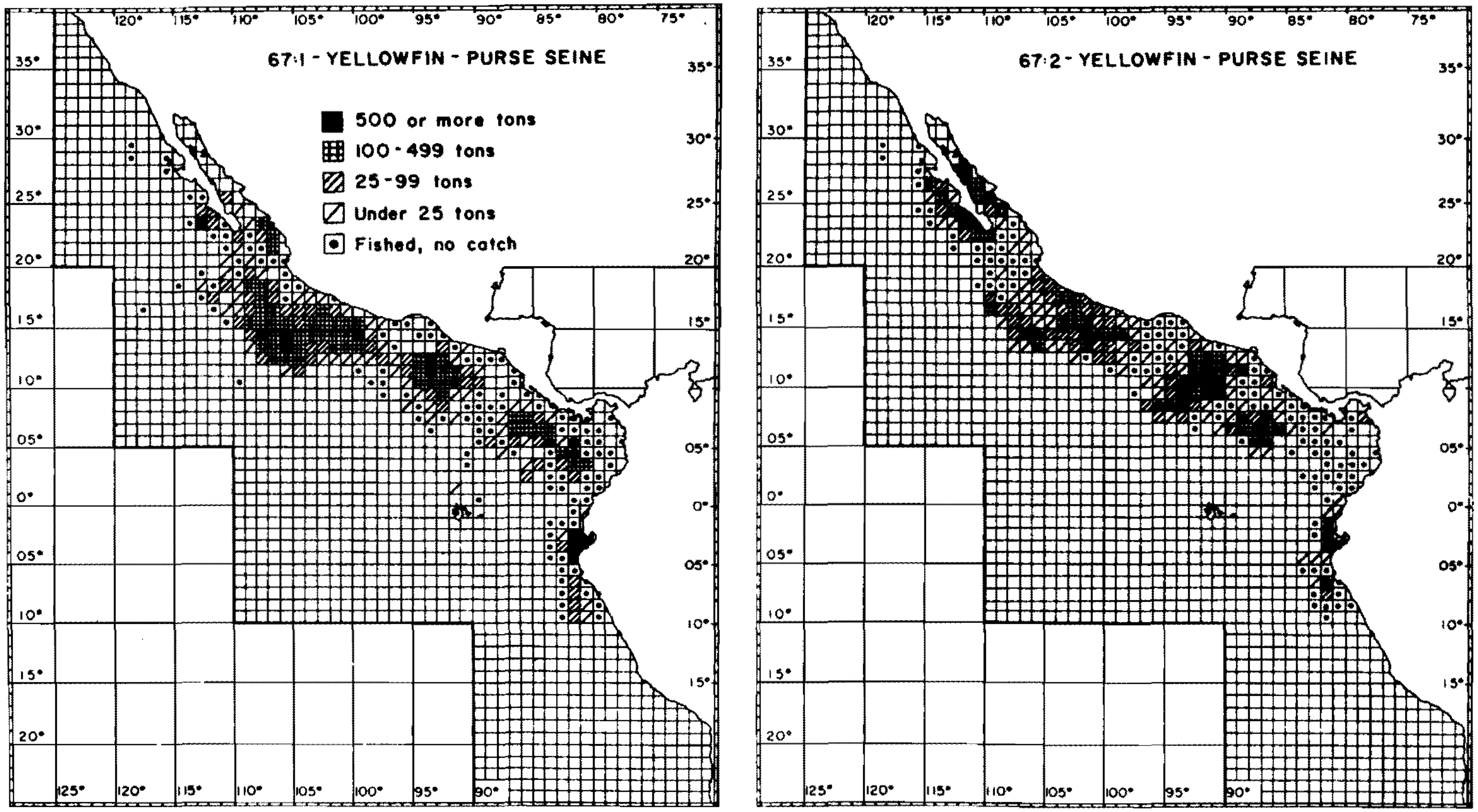

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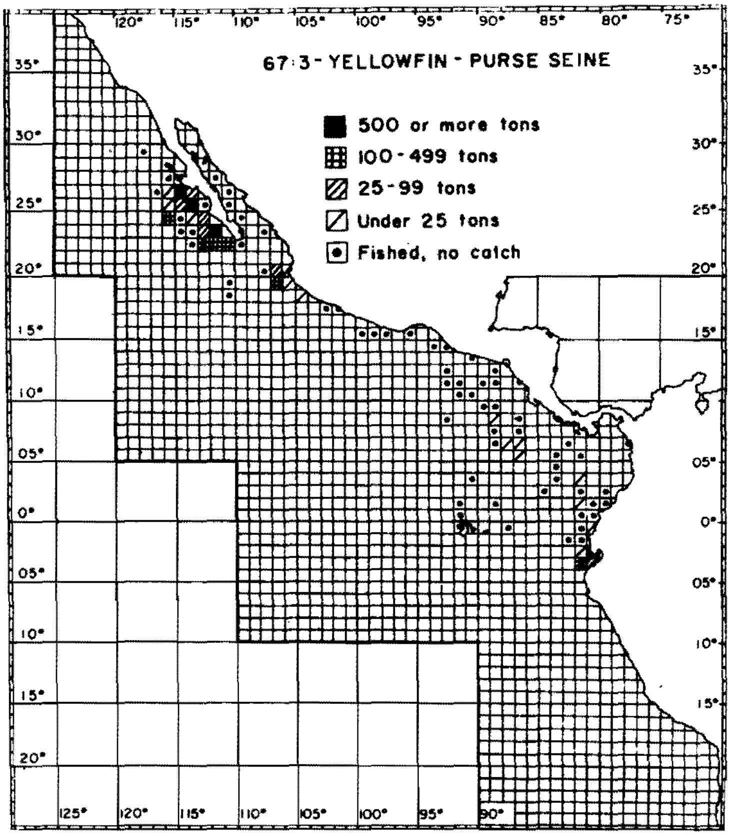

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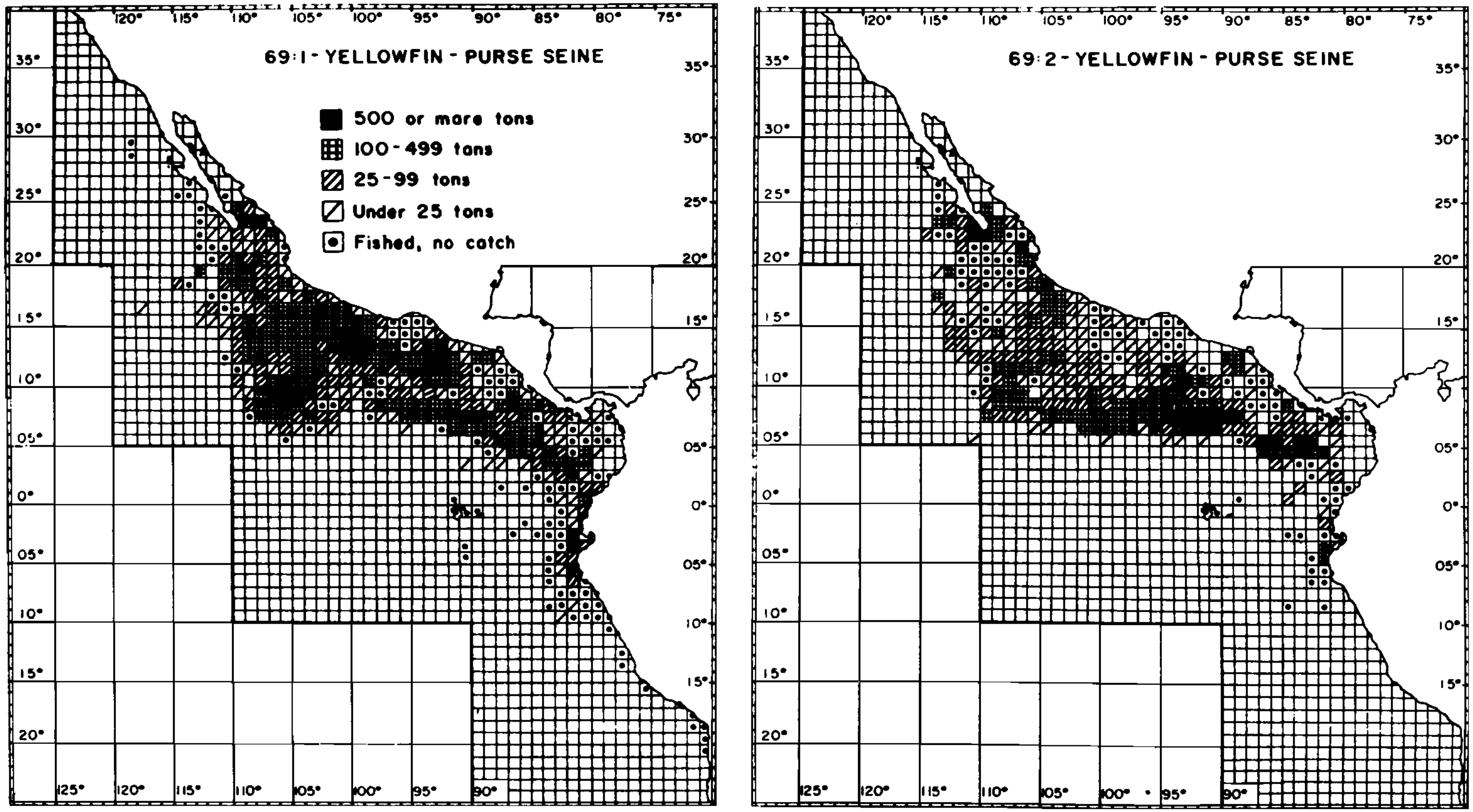

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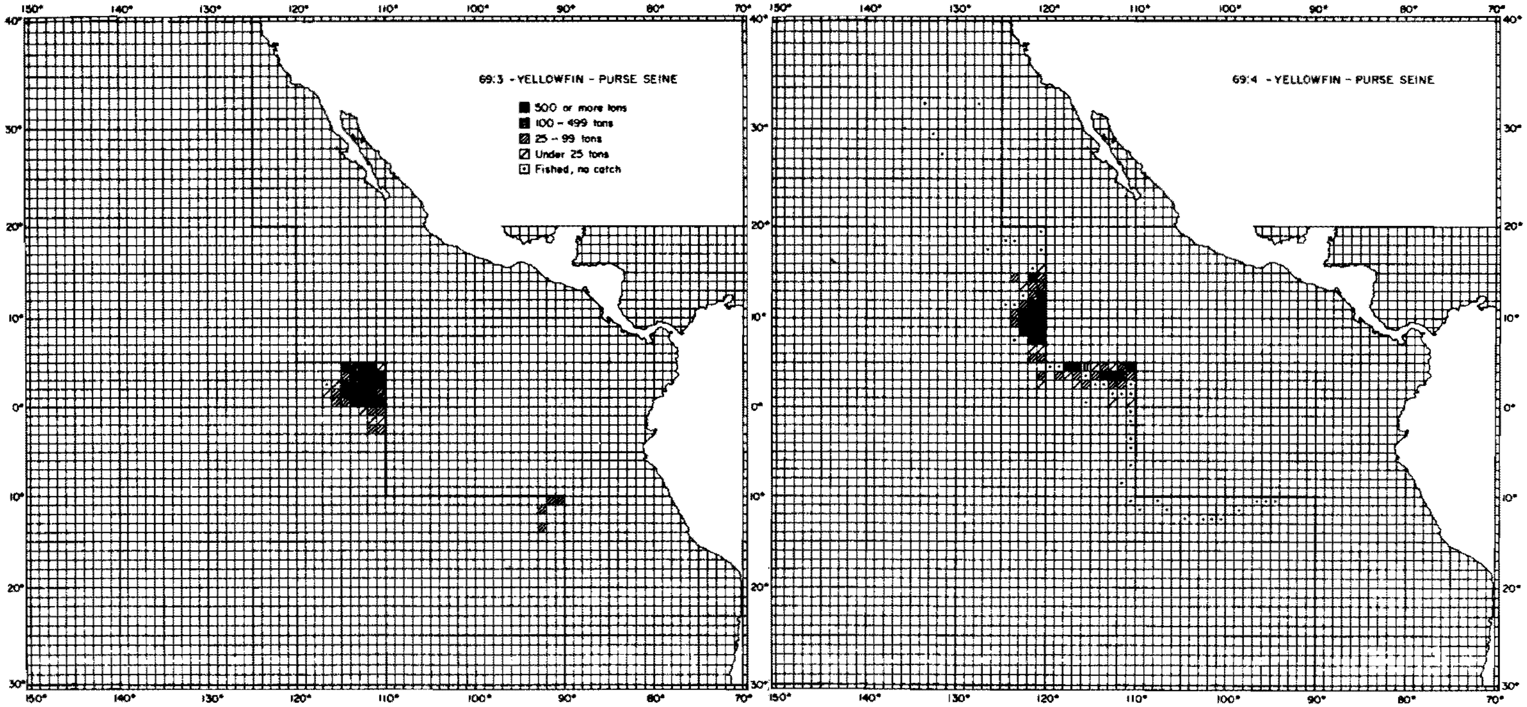

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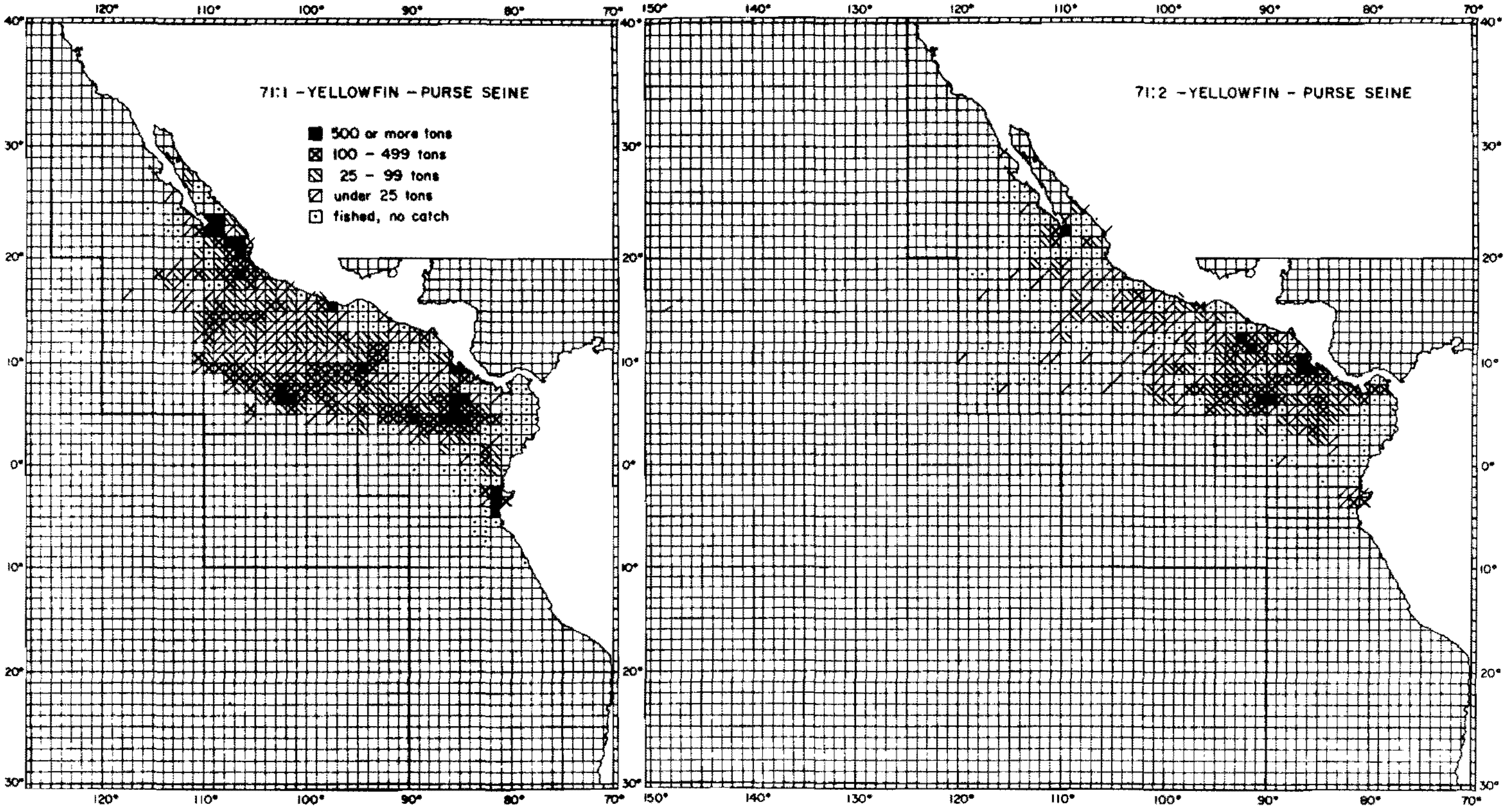

FIGURE 11. (continued)

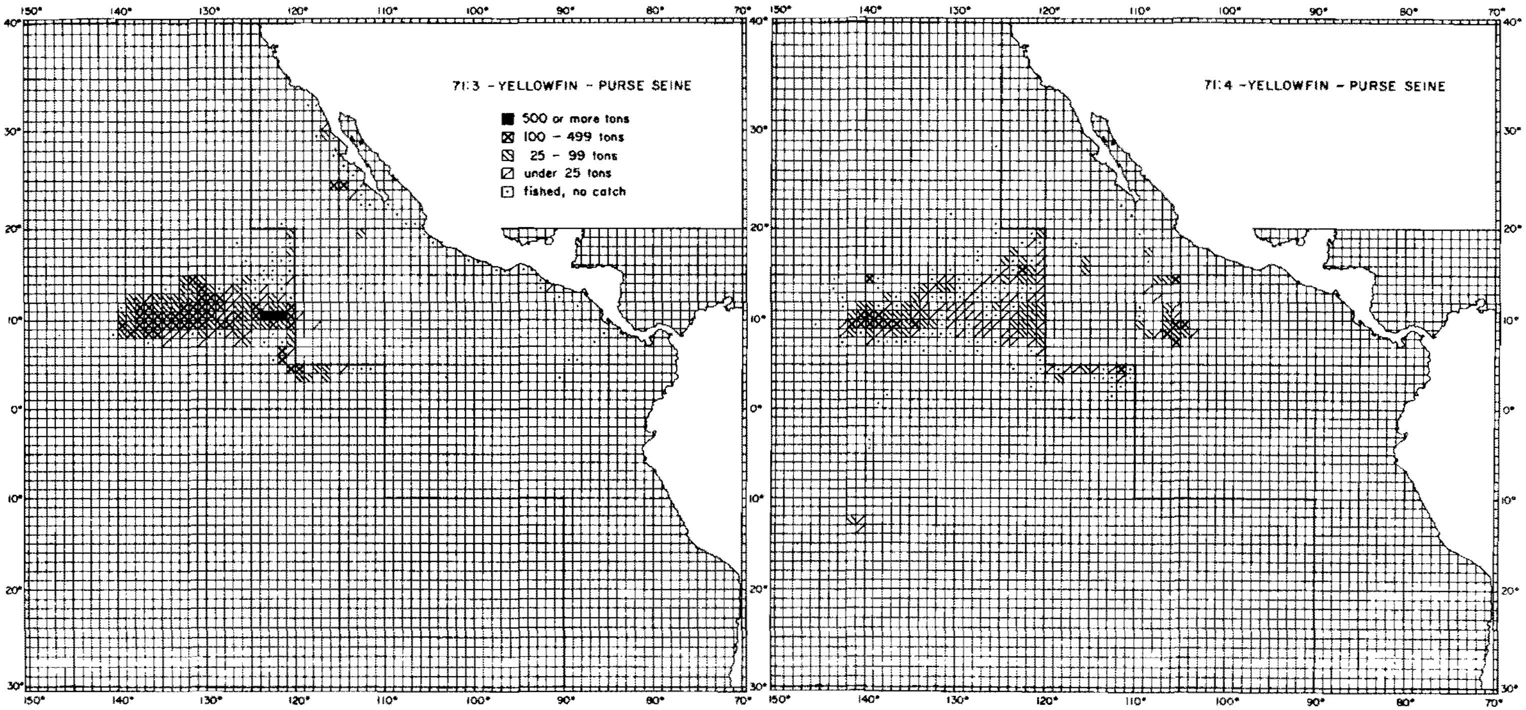

FIGURE 11. (continued)

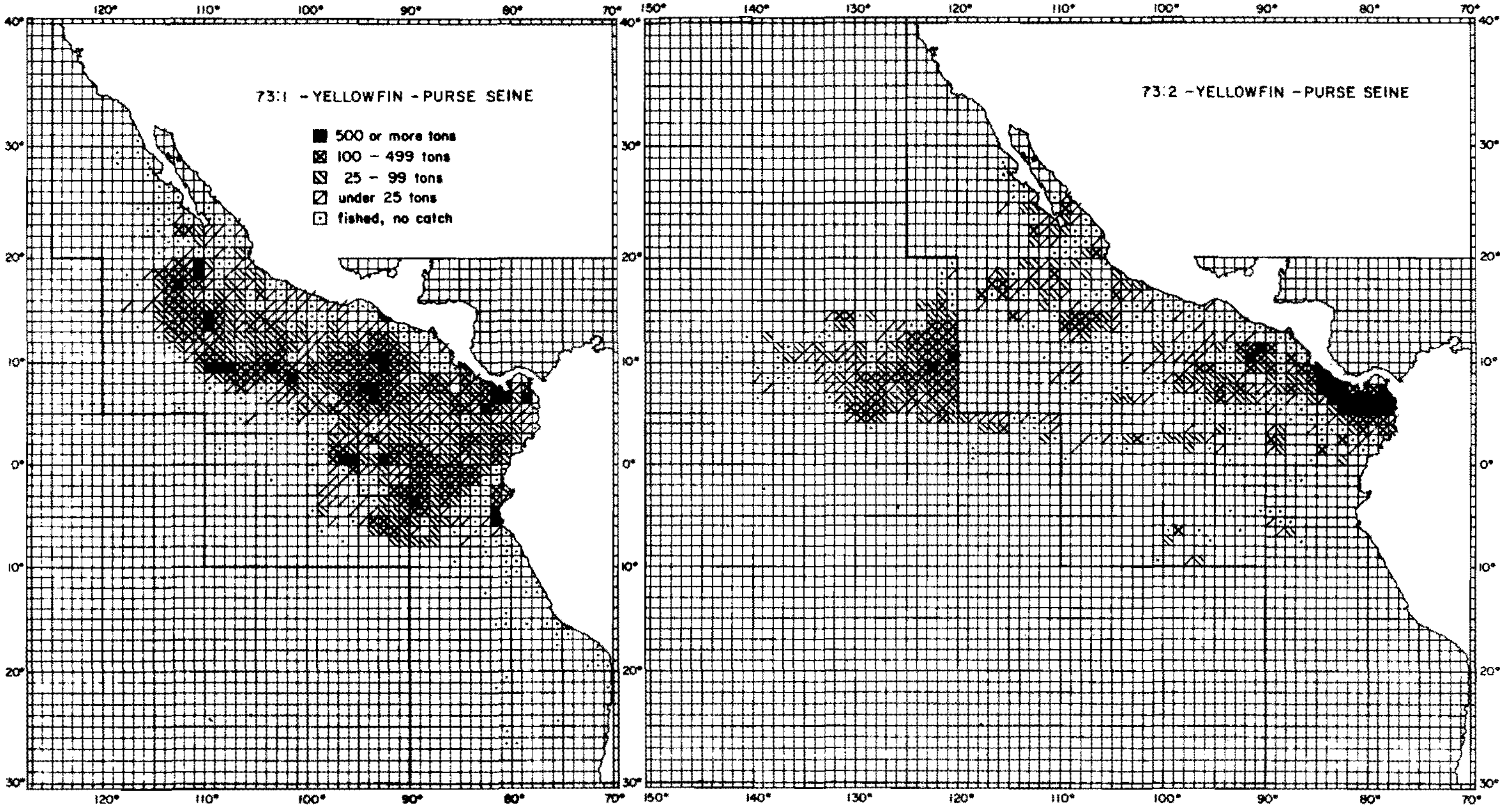

FIGURE 11. (continued)

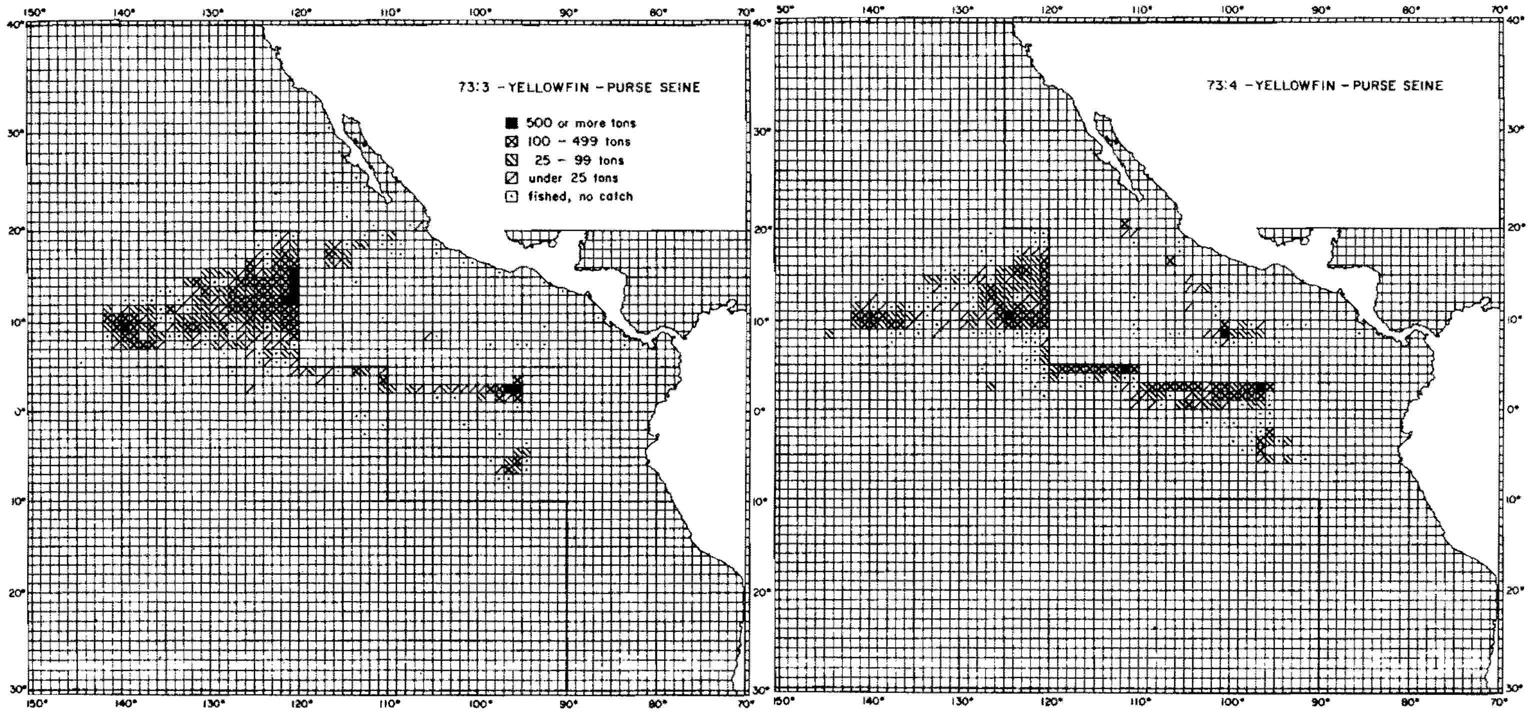

FIGURE 11. (continued)

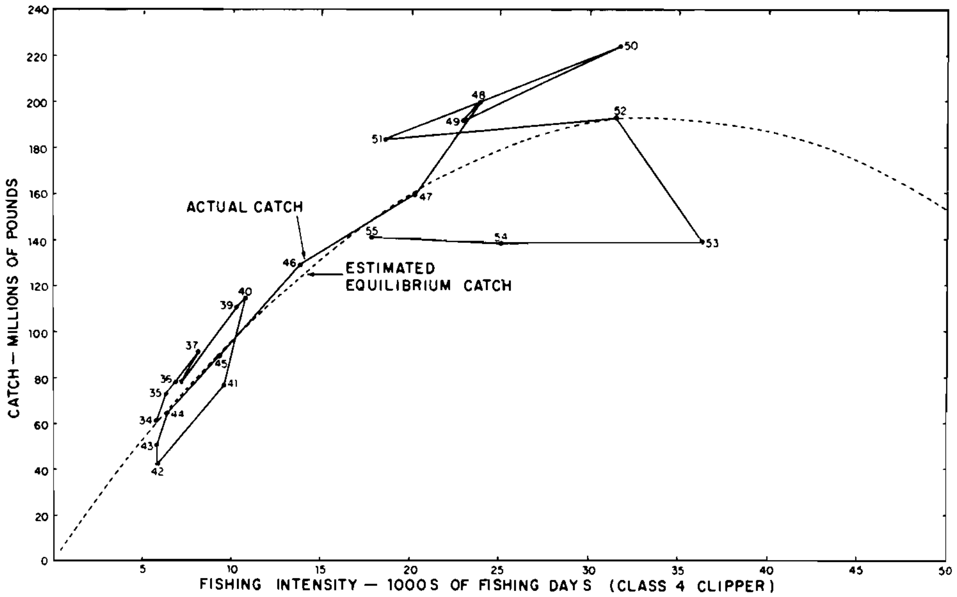

FIGURE 12. Equilibrium relationship between yellowfin catch and effort in the exploited portion of the eastern Pacific Ocean during the baitboat era (from Schaefer, 1957).

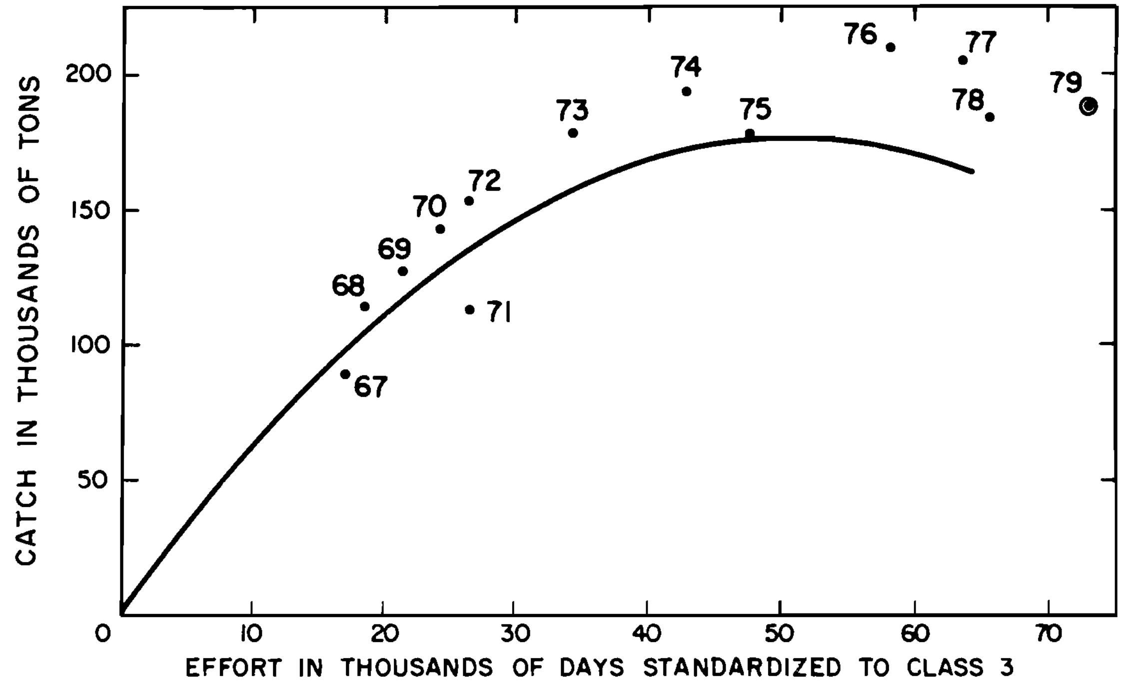

FIGURE 13. Equilibrium relationship between yellowfin catch and effort in the CYRA (Figure 16) during the purse-seine era (from Anonymous, 1980a).

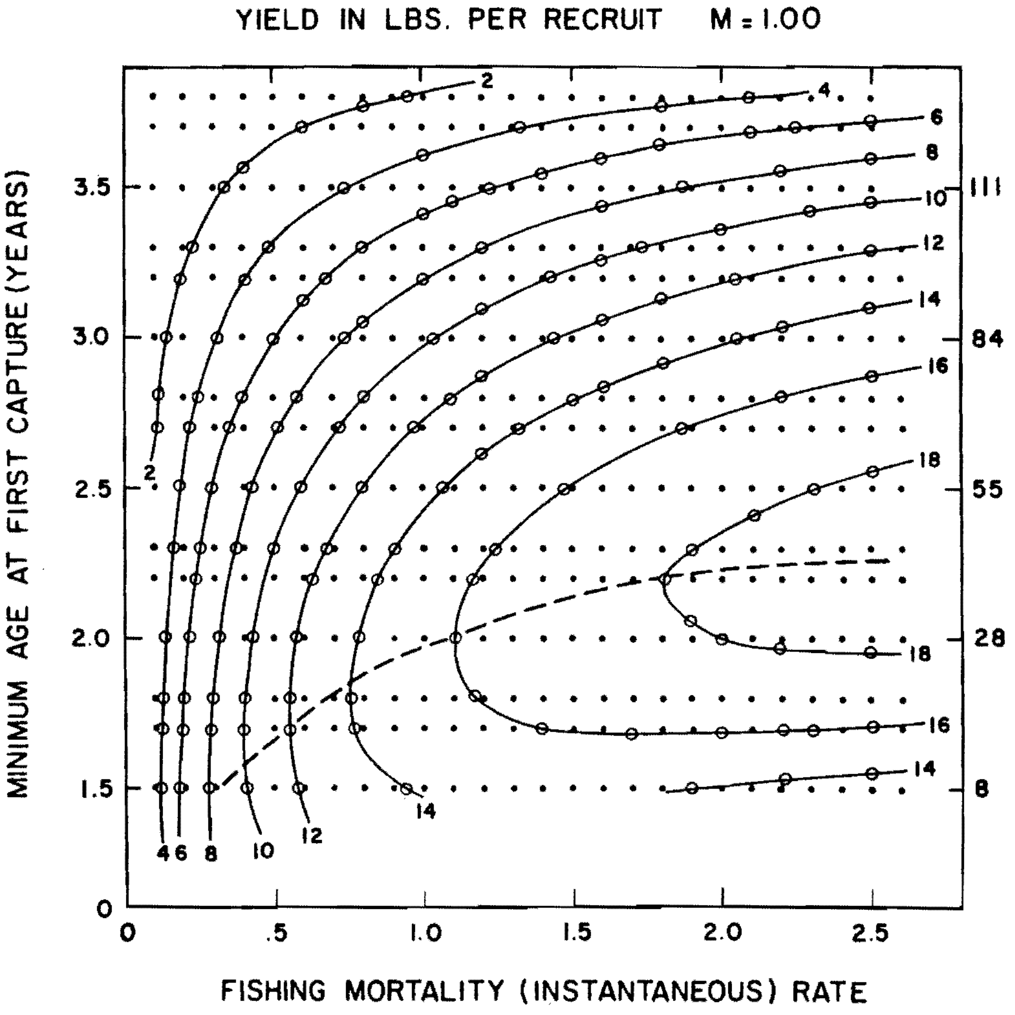

FIGURE 14. Yield per recruit, in pounds, for yellowfin in the eastern Pacific Ocean, assuming an annual instantaneous rate of natural mortality of 0.8 (from Hennemuth, 1961b).

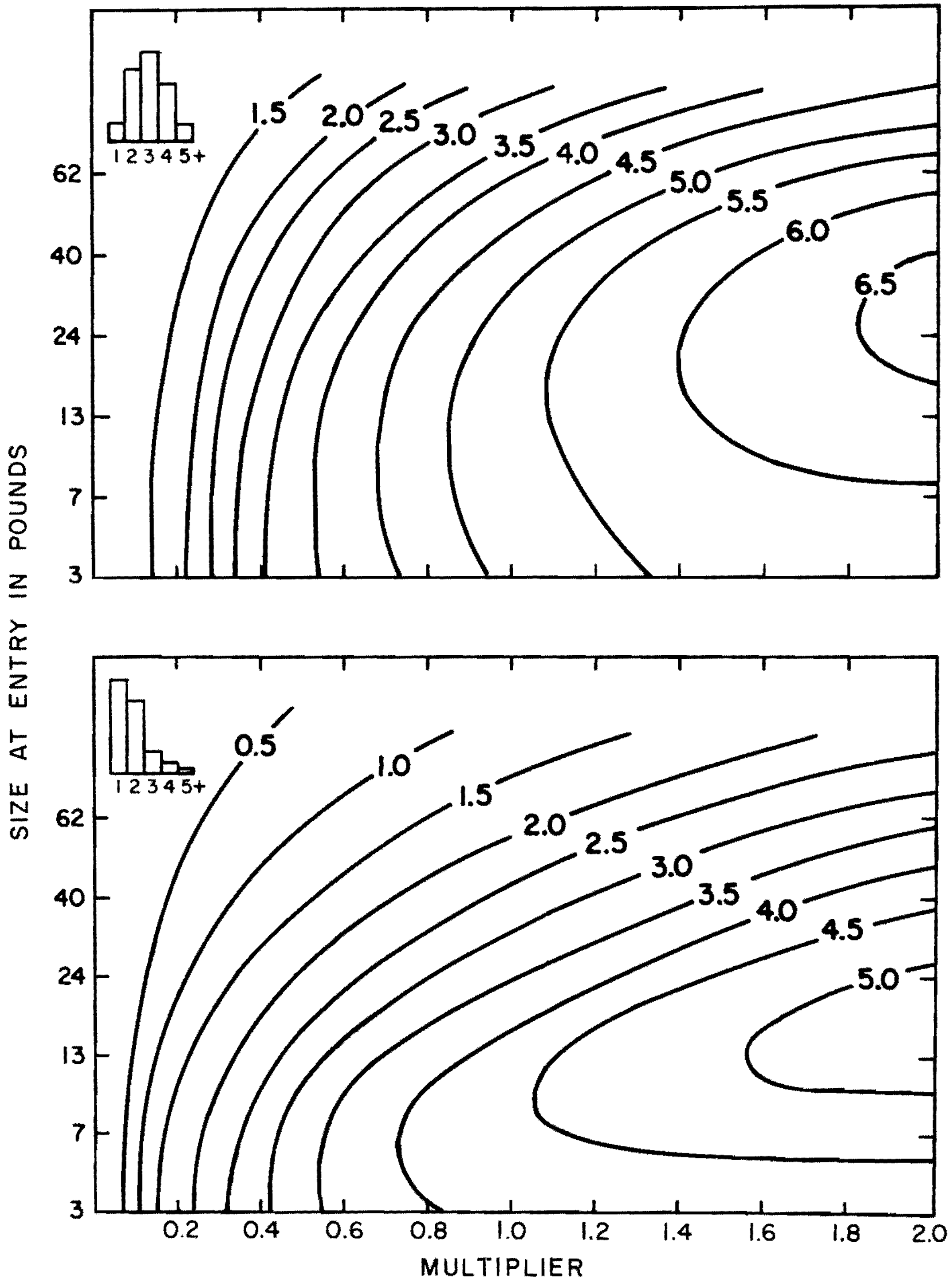

FIGURE 15. Yield per recruit, in pounds, for yellowfin in the eastern Pacific Ocean, assuming age-specific fishing mortality rates estimated from length-frequency data obtained during the 1968-1972 period (top panel) and during the 1973-1978 period (bottom panel) and an instantaneous rate of natural mortality of 0.8 (from Anonymous, 1980a).

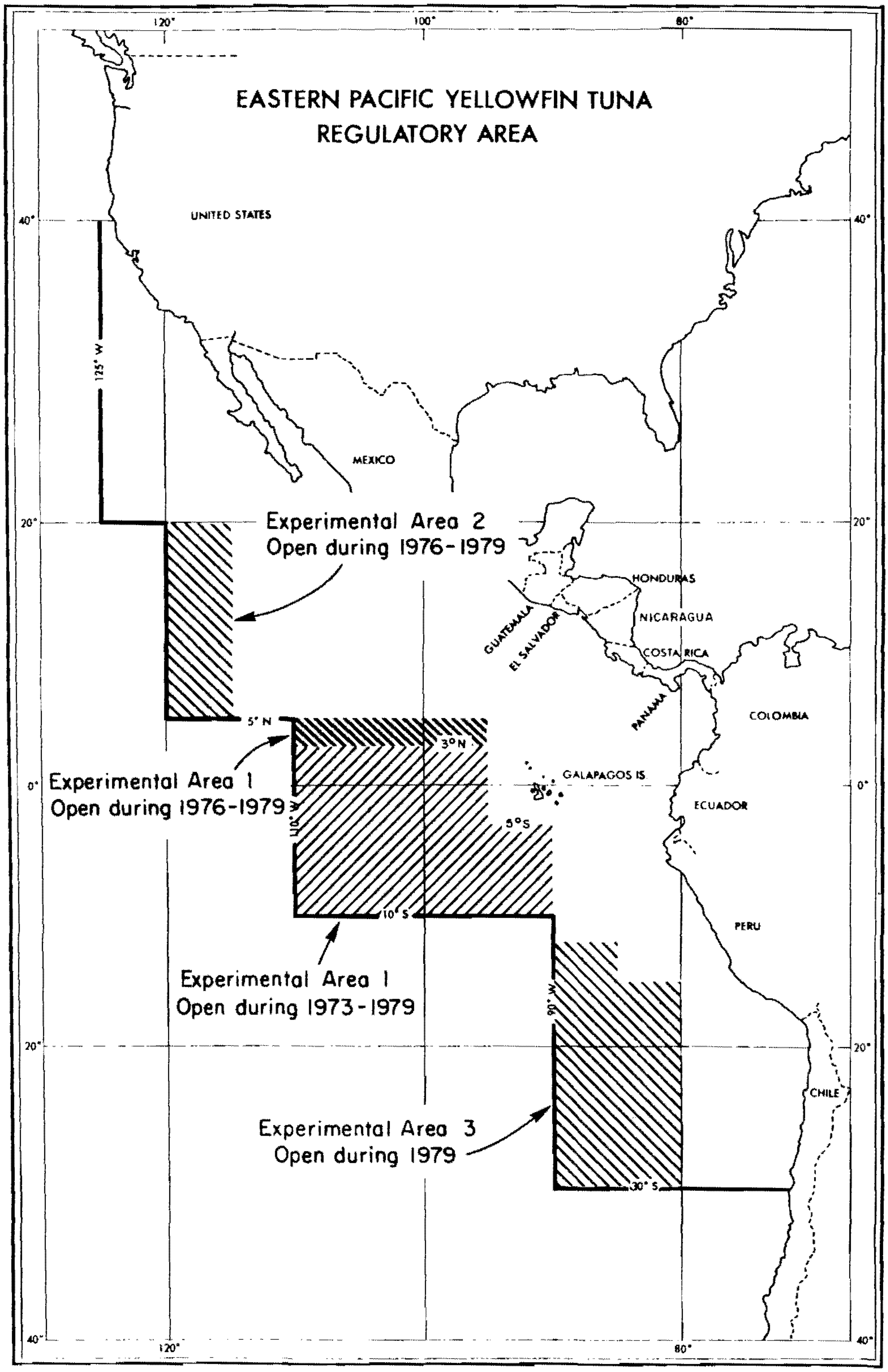

FIGURE 16. The Inter-American Tropical Tuna Commission's Yellowfin Regulatory Area (CYRA) and experimental areas (from Anonymous, 1980a).

TABLE 1. Spawning seasons of yellowfin in the Pacific Ocean.

General ocean region	Approximate months spawning occurs	Investigators
Western Pacific		
North of 10°N to southern coast of Japan and 120°-170°E	April-July	Kikawa, 1962; Matsumoto, 1966; Mori, 1970; Suzuki *et al.*, 1978
10°N-15°S and 120°E-180°	year-round; peak months July-Nov.	Wade, 1950a; Shimada, 1951; Kikawa, 1959
Northeast coast of Australia and 10°-30°S to 180°	Oct.-March; peak months Nov.-Feb.	Kikawa, 1959 and 1962; Legand, 1960; Suzuki *et al.*, 1978
Central Pacific		
Hawaiian Islands	May-Sept.; peak months June-Aug.	June, 1953; Matsumoto, 1966
10°N-10°S and 180°-120°W	year-round; peak months March-Sept.	Yuen and June, 1957; Matsumoto, 1966; Suzuki *et al.*, 1978
15°-25°S and 150°-130°W	Dec.-March	Kikawa, 1959
Eastern Pacific		
Revillagigedo Is., coast of Mexico, and Central America near shore	year-round; each area with different peak months	Orange, 1961; Klawe, 1963; Knudsen, 1977
0°-10°N and 130°-90°W	year-round; greatest activity during first half of year	Shingu *et al.*, 1974; Knudsen, 1977
0°-10°S and 130°-90°W	principally Jan.-June	Shingu *et al.*, 1974

TABLE 2. Major food components (compromising greater than 2 percent of the volume in each food study) of the diet of yellowfin in the central and eastern Pacific. The references are as follows: 1, Reintjes and King, 1953; 2, King and Ikehara, 1956; 3, Blunt, 1960; 4, Alverson, 1963; 5, Anonymous, 1979a.

	Central Pacific		Eastern Pacific		
			Coastal		Offshore
References	1	2	3	4	5
Food organism	Percentage of total volume				
Fish					
Gonostomatidae					
Vinciquerria lucetia					3
Exocoetidae	3			4	6
Carangidae					
Decapterus sp.	8				
Bramidae	3	11			
Gempylidae		6			
Scombridae		14			
Katsuwonus pelamis	5				
Auxis sp.			26	6	55
Euthynnus lineatus				3	
Nomeidae					18
Ostraciidae				5	
Tetradontidae				4	
Echeneidae			3	3	
Molidae		11			
Cephalopoda	28	35	13	8	6
Crustacea					
Portunidae			50	9	
Galatheidae				34	
Unidentified crab megalops	18				

TABLE 3. Estimates of parameters of the von Bertalanffy growth equation for yellowfin tuna in the Pacific Ocean (from Suzuki, 1971). The estimates of K and t_0 are in years.

Author	Fishing gear	Method	Years for sampling	Sample size	Range of body length (cm)	Fishing ground	Growth parameters		
							K	l_{oo}	t_0
Aikawa and Kato (1938)	-	reading of centra	-	6	-	-	-	-	-
Nose *et al.* (1957)	mainly longline	scale reading	1952-1953	300	100-140	Pacific (40°N-10°S)	-	-	-
Yabuta *et al.* (1960)	longline	"	1956-1959	1,000	70-140	Pacific (40°N-30°S, west of 180°)	0.33	190	0
Tan *et al.* (1965)	"	reading of centra	1962-1963	170	-	Pacific (0°-10°N, 155°-175°E)	-	-	-
Yang *et al.* (1969)	"	scale reading	1965	200	60-140	Pacific (3°-33°N, 113°-170°E)	0.36	195	0.27
Kimura (1932)	set net	weight frequency analysis	1924-1931	200	100-120	Suruga Bay (Pacific coast of Japan)	-	-	-
Moore (1951)	mainly longline	"	1948-1949	5,000	70-120	waters adjacent to Hawaii	0.44	192	0.22
Yabuta and Yukinawa (1957)	longline and pole-and-line	length frequency analysis	1953-1955	50,000	30-150	Pacific coast of Japan	0.55	168	0.35

TABLE 3. (continued)

Author	Fishing gear	Method	Years for sampling	Sample size	Range of body length (cm)	Fishing ground	Growth parameters		
							K	l_{oo}	t_0
Yabuta and Yukinawa (1959)	longline	length frequency analysis	1950–1957	110,000	80–150	Pacific (12^oN-5^oS, 130^oE-180^o)	0.66	150	0.40
Hennemuth (1961a)	mainly pole-and-line	"	1954–1956	–	70–140	western coast of North America (IATTC region)	0.60	169	0.83
Davidoff (1963)	pole-and-line and purse seine	"	1951–1956	–	80–140	"	0.60	167	0.83
Diaz (1963)	pole-and-line	increment technique (atelic)	1951–1956	–	80–140	western coast of America (entire IATTC region)	0.45	180	–
" "	"	increment technique (extended year class)	"	–	"	"	0.66	167	–
" "	"	increment technique (atelic)	"	–	"	western coast of North America (IATTC region)	0.36	214	–
" "	"	increment technique (extended year class)	"	–	"	"	0.70	166	–

TABLE 4. Age composition of yellowfin caught by Japanese longliners in the western and central equatorial Pacific, 1955-1964 (from Honma _et al._, 1971).

Year	Western equatorial Pacific						Central equatorial Pacific					
	Total	1	2	3	4	5 and older	Total	1	2	3	4	5 and older
1955	19,336	163	3,139	11,200	4,488	346	14,863	3	494	4,240	6,717	3,409
1956	23,718	164	8,183	11,855	3,416	100	18,355	10	195	3,420	10,058	4,672
1957	22,437	168	5,481	14,109	2,544	135	18,759	30	555	7,549	7,234	3,391
1958	22,753	154	5,668	14,218	2,634	79	14,596	58	1,015	5,175	5,435	2,913
1959	22,814	323	9,428	10,301	2,694	68	14,825	13	1,993	7,374	3,875	1,570
1960	27,987	36	11,472	14,480	1,920	79	15,694	3	1,317	8,827	4,413	1,134
1961	19,638	23	3,256	13,184	3,127	48	12,788	7	927	5,535	5,171	1,148
1962	17,382	192	6,376	7,641	3,071	102	9,348	1	841	4,248	3,606	652
1963	19,105	108	5,696	11,151	2,059	91	8,296	6	703	3,847	3,374	366
1964	19,154	50	5,202	11,574	2,234	94	6,982	4	564	3,859	2,171	384

TABLE 5. Estimates of the annual instantaneous natural mortality rates of yellowfin in the Pacific (after Hayashi and Homna, 1971).

Ocean region	Fishery	Investigator	Age range	Annual instantaneous natural mortality
Central and western equatorial Pacific	longline	Kamimura (1965) (as cited by Hayashi and Honma, 1971)	3 3 and older 4 and older	0.3-0.4 0.6 0.8
"	"	Ishii (1967a, 1967b, and 1969)	1 to 3 4 and older	0.34 0.91
"	"	Honma _et al._ (1971)	2 and 3 4 and older	0.3 or 0.9 1.2
Eastern Pacific	baitboat and purse seine	Hennemuth (1961b)	mainly 1 to 3	0.64-0.90 (0.77)
"		Schaefer (1967)	mainly 1 to 3	0.55-1.05

TABLE 6. Catches in the Pacific, in thousands of metric tons, of yellowfin by the major longline-fishing countries and by surface fisheries in the western and eastern Pacific.

Year	Longline catch				Surface catch					
					Western Pacific			Eastern Pacific		
	Japan	Rep.of China	Rep.of Korea	Total	Purse seine	Bait-boat	Total	CYRA	West of CYRA and east of 150°	Total
1950	3.7			3.7						
1951	15.7			15.7	0.9	3.6	4.5	-		
1952	11.7			11.7	2.3	2.6	4.9	-		
1953	17.2			17.2	1.2	5.2	6.4	-		
1954	23.2			23.2	3.9	4.3	8.2	-		
1955	22.5			22.5	2.6	3.9	6.5	-		
1956	22.3			22.3	0.7	4.3	5.0	-		
1957	50.4			50.4	1.1	1.7	2.8	-		
1958	56.4			56.4	3.0	2.9	5.9	66.8		66.8
1959	54.8			54.8	4.0	4.1	8.1	63.5		63.5
1960	66.1			66.1	1.4	1.8	3.2	109.8		109.8
1961	68.9			68.9	2.8	3.3	6.1	102.6		102.6
1962	61.1	2.9		64.0	6.9	4.2	11.1	74.0		74.0
1963	60.8	2.1		62.9	2.3	2.1	4.4	62.0		62.0
1964	59.6	2.9		62.5	3.6	4.9	8.5	88.6		88.6
1965	57.3	4.4	2.0	63.7	3.8	-	-	78.9		78.9
1966	69.0	6.4	3.0	78.4	5.8	-	-	80.6		80.6
1967	42.1	2.1	1.9	46.1	3.4	-	-	79.8		79.8
1968	50.2	5.1	5.3	60.6	6.9	-	-	100.9	1.1	102.0
1969	47.0	4.8	9.0	60.8	4.3	-	-	111.4	17.4	128.8
1970	48.3	4.0	10.0	62.3	5.8	-	-	128.0	27.8	155.8
1971	38.8	9.0	9.0	56.8	3.7	-	-	102.2	20.6	122.8
1972	47.7	9.7	-	-	4.6	-	-	136.1	40.6	176.7
1973	43.8	8.4	-	-	7.5	-	-	160.2	44.9	205.1
1974	43.4	4.6	-	-	12.2	-	-	172.9	37.3	210.2
1975	-	2.9	-	-	-	-	-	159.2	43.1	202.3
1976	-	3.4	-	-	-	-	-	190.4	46.0	236.4
1977	-	2.9	-	-	-	-	-	183.2	15.3	198.5
1978	-	4.1*	-	-	-	-	-	164.9	14.2	179.1
1979	-	-	-	-	-	-	-	175.9*	13.2*	189.1*

- Data not available

* Preliminary estimates (Yang, 1979; Orange, 1980)

TABLE 7. Summary of regulations for yellowfin in the eastern Pacific Ocean (after Bayliff, 1975). The CYRA catch (excluding experimental areas) includes longline-caught fish. One short ton is equivalent to 0.907185 metric ton.

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Quota (short tons x 1000)	79.3	84.5	93	120	120	140	120	130	175	175	175	175	175	175
Authorized increments to quota (short tons x 1000)	0	0	13	0	0	10+10	10+10	10+10+10	10+10	10+10	10+10	20+15	20+15	20+15
Safeguard proviso for closure due to low CPUE (short tons per day)	--	--	--	3	3	3	3	3	3	3	3	3	3	3
Allowance for incidentally-caught yellowfin during closed season (percent)[1]	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Special allocations, small vessels of each nation (short tons x 1000)	--	--	--	4	6	6	6	6	6	6	6[2]	6[3]	6[4]	6[5]
Special allocations, new vessels of each developing nation (short tons x 1000)	--	--	--	--	--	2	2	6	8	10	13	13	26.5	--
Special allocations, each member and cooperating nation with canneries and small catches (short tons x 1000)	--	--	--	--	1	1	1	1	1	1	1	1	1	1
Special allocation, U.S. vessels chartered for dolphin research (short tons x 1000)	--	--	--	--	--	--	--	--	--	--	--	1	1	1

TABLE 7. (continued)

		1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Closure date		9/15	6/24	6/18	4/16	3/23	4/09	3/05	3/08	3/18	3/13	3/27	7/07	5/06	7/21
Grace period (days)		0	0	0	0	10	30	30	30	30	30	30	30	30	30
Catch (short tons x 1000)	CYRA (excluding experimental areas)	91.2	90.0	114.4	126.9	142.6	113.9	152.5	167.6	187.4	174.3	182.1	171.4	167.9	187.9
	Experimental areas	--	--	--	--	--	--	--	10.2	3.9	2.1	28.6	31.5	14.8	6.2
	Total CYRA	91.2	90.0	114.4	126.9	142.6	113.9	152.5	177.8	191.3	176.4	210.7	202.9	182.7	194.1
	Outside CYRA	0.0	0.0	1.2	19.2	30.7	22.8	44.8	49.5	41.1	47.5	50.7	16.9	15.7	14.6

1. For 1966 and 1967 each vessel with permission to fish only for other species was allowed to land up to 15 percent by weight of yellowfin among its catch of all marketable species taken on any fishing voyage made after the closure of the fishery. For all succeeding years the percentage allowed was determined by each nation under which such vessels were registered under the provision that the aggregate of the incidental catch of yellowfin by the vessels of each nation could not exceed 15 percent of the combined total catch taken by these vessels during the period they were permitted to fish inside the CYRA.

2. For Panama this applied to vessels of up to 600 tons capacity.

3. For Costa Rica this applied to vessels of up to 1,100 tons capacity; for Nicaragua up to 4,000 tons of this applied to two vessels of up to 1,800 tons capacity; for Panama up to 3,000 tons of this applied to vessels of more than 400 tons capacity.

4. For Costa Rica this allocation was 7,500 tons, and applied to all of its vessels; for Nicaragua and Panama this allowance applied to all the vessels of each country.

5. For Nicaragua and Panama this applied to all the vessels of each country.

SYNOPSIS OF BIOLOGICAL DATA ON THE SOUTHERN BLUEFIN TUNA, *THUNNUS MACCOYII* (CASTELNAU, 1872)

Robert J. Olson

Inter-American Tropical Tuna Commission
La Jolla, California
1980

CONTENTS

1 IDENTITY

The scientific name for the southern bluefin tuna is Thunnus maccoyii.

2 DISTRIBUTION

2.1 Total area

Southern bluefin have a circumpolar (Ueyanagi, 1980) or near circumpolar distribution (Figure 1) in the Southern Ocean. Nakamura (1969) suggests that they may be distributed throughout the area between 30°-40°S latitude in that ocean, and are the dominant species of tuna south of 30°S latitude. In the south Pacific the northern boundary of its distribution is marked by the tropical convergence in the waters to the north of the North Island of New Zealand (Robins, 1963). A combination of the maximum distribution limits described by six investigators, augmented by Japanese catch statistics reports, is shown in Figure 1. The broken lines outline the 5-degree areas where vessel logbook records indicate that incidental, often lone, specimens were caught. A few specimens were recorded caught in 5-degree areas further north, up to the latitude of central Peru. These were not identified by scientists and, therefore, should not be considered scientific evidence of expansions of the distribution limits of southern bluefin. Several specimens have been collected in the waters off southern Chile (33°-41°S and 94°-115°W) during research operations (Shingu, 1967). Two large (1553- and 1640-mm) bluefin were caught by a purse seiner in the Gulf of Guayaquil, Ecuador (3°23'S-81°09'W) on June 14, 1969. Their identity as bluefin was confirmed by the striations on the livers, but it was not determined if they were northern or southern bluefin. The southern limit of the distribution of southern bluefin is usually considered to be to or somewhat beyond 50°S latitude (Shingu, 1967 and 1979; Hynd, 1969; Nakamura, 1969; Hisada et al., 1978), though Suda (1971: Figure 34) shows southern bluefin catches as far as 60°S latitude south of Australia. Hayashi et al. (1970) give the northern distribution limit in the western Atlantic Ocean as 30°S latitude in the waters west of 0° longitude. The southern limit was not defined. Research cruises have demonstrated the occurrence of southern bluefin north of 40°S latitude from off South Africa to Uruguay (Anonymous, 1966, 1968a, and 1969a; Kume and Hisada, 1969; Hayashi et al., 1970). Talbot and Penrith (1963) and de Jager (1963) describe its distribution along the southwest coast of Africa. (The information on bluefin presented by Talbot and Penrith (1963) and de Jager (1963) is attributed to Thunnus thynnus orientalis and T. thynnus thynnus. Gibbs and Collette (1967: 115) consider T. thynnus orientalis as used by Talbot and Penrith (1963) to be a synonym for southern bluefin, T. maccoyii.)

2.2 Differential distribution

The distributional range of southern bluefin changes appreciably with its development. The distributions of spawning adults, juveniles, and feeding adults within the major fishing grounds (Figure 1), and their respective fishing seasons, are listed in Table 1. The limits of the fishing areas given in Table 1 are wider than those shown in Figure 1 (fine lines), the former being a composite of more than one publication.

There is no information on the distribution of the spawn. The larvae of several species of tuna occur throughout the low latitude areas of the Indian Ocean, but the larvae of southern bluefin have been collected only in a limited area (Shingu, 1978). The areas where southern bluefin larvae have been collected are delineated in Figure 2. During the most recent larval surveys by the R/V Shoyo Maru, two larval nets were towed simultaneously, one at the surface and the other at a depth of 30 to 35 meters. During the 1978-79 cruise 1,211 southern bluefin larvae were collected, more than any of the six other species of larval tunas present. Most of the tuna larvae were collected at nighttime and at sub-surface levels (Anonymous, 1978d and 1979k).

2.3 Determinants of distribution changes

Certainly currents, temperature, and the presence of land are important ecological determinants of the distribution of southern bluefin. The longline fishery is concentrated in waters adjacent to the northern extremity (30°-40°S) of the West Wind Drift and within the West Wind Drift (south of 40°S) (Nakamura, 1969). Shingu (1967) states that the West Wind Drift and the northward branches of the West Wind Drift off the west coasts of continents and land masses (West Australian Current, Peru or Humboldt Current, and Benguela Current) seem to provide environmental conditions suitable to southern bluefin.

Adult southern bluefin have the distinction among the tunas of living in the most extreme continuously cold habitat. They rival the Atlantic northern bluefin, Thunnus thynnus thynnus, for inhabiting the most varied water temperatures of the tunas (Sharp and Dizon, 1978). Southern bluefin seek warmer water only during the spawning portion of its life history. Water temperatures in the spawning area at that time of the year (Figure 2 and Section 3.16) range from 25° to 30°C (Shingu, 1970 and 1978). Water temperatures and salinities in the areas where southern bluefin are commonly caught range from about 5° to 30°C and slightly below 34 o/oo to about 37 o/oo, respectively (Shingu, 1970 and 1978). The ranges of temperatures and salinities in major fishing areas are shown in Figure 3. Shingu (1978) presents graphs depicting detailed temperature isotherms and fishing positions in fishing areas 1, 2, 4, 5, and 7 (Figure 1). The preferred temperature of southern bluefin in the New South Wales, Australia, fishery is between 17° and 20°C (Williams, 1977). De Jager (1963) and de Jager et al. (1963) report that from winter of 1960 to autumn of 1961 the highest catches off South Africa were made in waters between 16° and 17°C. Thermal fronts, areas where large temperature changes occur, are known to attract southern bluefin (Williams, 1977; Pownall, 1979). McKenzie (1964) states, "In Australia, fish smaller than 60 pounds (27.2 kg) generally occur nearer the coast than larger sizes, and usually nearer convergences and current boundaries."

2.4 Hybridization

There are no records of hybrids involving southern bluefin.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

This is briefly discussed by Robins (1963).

3.12, 3.13, and 3.14 Maturity, mating, and fertilization

There is some disagreement concerning the age and size at which southern bluefin reach maturity. Robins (1963) states that maturity is attained during the fifth or sixth (mainly the sixth) year and between 110 and 128 cm. Shingu (1967), Nakamura (1969), Anonymous (1972b), and Hisada et al. (1978) give the age at maturity as 6 years. Shingu (1970), Anonymous (1979b), and Murphy and Sutherland (1980) state that southern bluefin mature at 7 years of age. Kikawa (1964a) found developing gonads in fish older than 7 years. Anonymous (1966b) and Hynd (1969) give the age of maturity as 8 years and 7 to 8 years, respectively. Hayashi et al. (1972) assume that none of the 5-year-olds, 20 percent of the 6-year-olds, 80 percent of the 7-year-olds, and all of the 8-year-olds have reached maturity. Kikawa (1964a) found fish greater than 140 cm to be maturing, and Hisada et al. (1978) and Shingu (1978) specify the size at maturity as 130 cm and 40 kg.

Mating in southern bluefin is presumably polygamous, and fertilization is external (Robins, 1963).

3.15 Gonads

Kikawa (1964a) estimated the total number of eggs in the ovaries of a southern bluefin specimen at 14 to 15 million. The ovary weights and fork length for that fish were 1700 g, 1689 g, and 158 cm, respectively.

Mimura (1962) found no apparent relationship between fish size and gonad weight for southern bluefin. However, this relationship has been graphed by Robins (1963) for fish from the waters north of New Zealand, by Kikawa (1964b) for fish from the Oki fishing area, and by Hayashi et al. (1970) for fish caught in the Tasmania, New Zealand, Oka, and Oki fishing grounds.

Shingu (1970: Figure 20) shows the distribution for gonad index frequencies of southern bluefin taken from May to March from the Oka and Oki fishing grounds and from the Tasmania and New Zealand areas.

3.16 Spawning

The spawning areas of southern bluefin and northern bluefin, in contrast to those of the other tunas, are narrow relative to their entire distributional range (Yabe et al., 1966). Only one spawning area (Figure 2), located in the east Indian Ocean south of the Sunda Islands (Java and adjacent islands) has been identified for southern bluefin (Mimura, 1962; Kikawa, 1964b; Ueyanagi, 1966a, 1967, 1969a, and 1969b; Shingu, 1967, 1970, and 1978; Kikawa et al., 1968; Hynd, 1969; Nakamura, 1969; Hayashi et al., 1970; Shingu and Hisada, 1971; Suda, 1971; Lucas, 1974; Murphy, 1977 and 1979; Hisada et al., 1978; Murphy and Sutherland, 1980. This area corresponds roughly to the original Japanese longline fishing grounds for the species, the Oka and Oki grounds. Nakamura (1969) describes a major spawning area (10°-20°S and 110°-125°E) and a minor spawning area (20°-30°S and 110°-125°E). Spawning fish inhabit the major spawning area, and to some extent the minor spawning area, from August to April. The minor spawning area, however, is occupied primarily by pre-spawners and spent fish.

Robins (1963) mentioned the existence of a spawning area off eastern Australia. Although the season during which spawning was supposed to take place in that area was unknown, he stated that "from recent data it may be inferred to be November-February." Hynd et al. (1966) analyzed the size composition of southern bluefin from the Australian fishery and concluded that there might be another spawning ground in the Tasman Sea. Hynd (1965 and 1969) discussed the possibility of the existence of a second and a third spawning group due to the fact that in each year class of juveniles found in coastal Australian waters, three groups can be distinguished on the basis of length. He reached no conclusions, but stated that if no juvenile populations were found in continental coastal waters near the area in question, it is unlikely there is a spawning group in the vicinity. Some Japanese fishermen believed that southern bluefin spawn in the seas adjacent to Tasmania and in the West Wind Drift area, due to the fact that mature fish seasonally occur in these areas (Nakamura, 1969). However, Shingu (1967) denied the possibility of spawning in the Pacific based on the size and age composition and gonad indices of the fish in the catch of that area, and Nakamura (1969) states that "It cannot be concluded, at present, whether they spawn in these areas." It appears that since the late 1960's investigators have discounted the possibility of the existence of spawning areas other than in the eastern Indian Ocean. Shingu and Hisada (1971) state, "In view of the series of survey ship and fishing boat data, there is almost no chance that this species spawns anywhere other than in the spawning grounds off the northwest coast of Australia."

The southern bluefin spawning season is usually described as beginning in September and ending in March, corresponding to the southern summer (Serventy, 1956; Mimura and Warashina, 1962; Robins, 1963; Kikawa, 1964b; Shingu, 1967; Kikawa et al., 1968; Hynd, 1969). Nakamura (1969) and Shingu (1970) report the spawning season to be from August to April, but Ueyanagi (1969a) and Murphy and Sutherland (1980) give a shorter spawning season, October to March. The peak of spawning is reported to be in November (Mimura and Warashina, 1962; Kikawa et al., 1968) or November-December (Shingu, 1967). Robins (1963) states that the peak of spawning differs by less than two months between the Oka fishing ground (November) and the Oki fishing ground (January).

3.17 Spawn

Kikawa (1964a) gives the mean diameters of 100 residual eggs remaining in the ovaries of two spent 140-cm southern bluefin as 0.895 mm and 0.785 mm.

3.2 Pre-adult phase

3.21 Embryonic phase

No information is available on this subject.

3.22 Larval phase

Larval southern bluefin have been described by Yabe et al. (1966), Ueyanagi (1969a), Matsumoto et al. (1972), and Richards and Potthoff (1973). The characters used to separate southern bluefin larvae from those of other Thunnus species are presented by Matsumoto et al. (1972). The identification is based mainly on the tiny black pigment cells, melanophores, present on the dorsal edge of the trunk. Southern bluefin larvae closely resemble northern bluefin larvae (Yabe et al., 1966). Matsumoto et al. (1972) and Richards and Potthoff (1973) express the need for further verification of larval southern bluefin identification, especially by methods utilizing osteological features.

Southern bluefin larvae are reported to be 3 mm long at hatching (Murphy, 1977), making them smaller then northern bluefin larvae (Ueyanagi, 1969a). Yabe et al. (1966: Appendix Table 2) present morphometric data for three southern bluefin larvae representing three stages of development, and they describe in detail the physical characteristics and pigmentation of each (see Shingu (1978) for an English translation).

The food of larval tunas is virtually unknown, but Ueyanagi (1966a) speculates that they feed on the larvae of fishes and squids.

The distribution of southern bluefin larvae is discussed in Section 2.2.

3.23 Adolescent phase

Since the juveniles live in the vicinity of coastal areas and in the surface layer, Ueyanagi (1966a) speculates that they consume mainly crustaceans, while the adults feed mainly on fishes and squids. However, Robins (1963) states that the diet of juvenile southern bluefin is, in order of importance, fishes, cephalopods, crustaceans, and salps.

3.3 Adult phase

3.31 Longevity

Southern bluefin are long-lived; a 3-year-old fish tagged off Albany, Australia, was recaptured off South Australia after 15 years and 4 months at liberty (Anonymous, 1979l). Murphy (1979) and Murphy and Sutherland (1980) state that they possibly attain an age of 20 years. However, the majority of the catch includes fish up to only 12 to 13 years of age (Section 4.12).

3.32 Hardiness

Southern bluefin kept out of water up to 1 minute during tagging operations appear to suffer no harm (Robins, 1963). They have also been reported to survive 80 hours in a live bait tank aboard a vessel after having been tagged and subjected to temperature changes from 15.5° to 21.1°C and then to 19.1°C (Robins, 1963).

3.33 Competitors

Robins (1963) lists albacore, Thunnus alalunga, yellowfin, T. albacares, bigeye, T. obesus, and skipjack, Katsuwonus pelamis, as competitors in feeding areas (away from continents, especially in the West Wind Drift), and mainly in transitional areas where the southern bluefin distribution overlaps with that of the above species. Anonymous (1972b) presents a list of the tuna and billfish species caught by longline in conjunction with southern bluefin (and catch statistics for each) in the fishing grounds off South Australia, New South Wales, South Africa, and in the Oki fishing ground. In the first two areas southern bluefin are caught with (and must be in competition with) albacore, bigeye, yellowfin, swordfish, Xiphias gladius, and striped marlin, Tetrapturus audax. In the third and fourth areas southern bluefin are caught with the above species plus blue marlin, Makaira nigricans, and black marlin, M. indica. De Jager (1963) lists 20 additional possible competitors of southern bluefin. Collette (1978) states that "the southern bluefin has a distributional pattern similar to those of Gasterochisma [the butterfly kingfish] and Allothunnus [the slender tuna] in the Southern Ocean," so there is a good chance that it competes with these for food.

3.34 Predators

Robins (1963) lists sharks, dolphins, and seals as predators of southern bluefin. No definite predators are known in the waters off South Africa, but Talbot and Penrith (1963) speculate that mako sharks, Isurus oxyrinchus, swordfish, and blue marlin are possible predators. De Jager (1963) states that blue sharks, presumably Prionace glauca, mako sharks, thresher sharks, Alopias sp., and brown sharks, Carcharhinus milberti(?), are considered to be predators of southern bluefin. Robins (1963) mentions rapid sounding as an escape mechanism.

3.35 Parasites, diseases, injuries, and abnormalities

Only two parasites are listed by Robins (1963): a trematode, Hirudinella sp., which inhabits the gut, and a copepod (Harpacticoida) found on the gills, the interior of the operculum, and in the caudal peduncle region. The intensity of infection of the trematode was described as light (Robins, 1963). Cressey and Cressey (1980) report the copepod Elytrophora brachyptera from the gill areas of two southern bluefin. Nematode parasites were found in the stomachs of 4 of 10 southern bluefin examined by Webb (1974) from the west coast of New Zealand. Abe and Hiragaki (1979) report an albinistic southern bluefin caught in the Tasman Sea which weighed 100 kg, without the caudal fin, viscera, and gills.

3.36 Physiology and biochemistry

The members of the bluefin group of the genus Thunnus, including northern bluefin, T. thynnus, albacore, T. alalunga, and southern bluefin, have been described as the most specialized and most modern of the tunas. They are the only members of the tribe Thunnini, composed of the genera Auxis, Euthynnus, Katsuwonus, and Thunnus, that have expanded their ranges out of tropical waters due to having lost the primitive central blood supply to the body tissues in favor of an increased lateral blood supply and heat exchanger system (Collette, 1978). This has enabled the members of the bluefin group to evolve a larger body mass (especially the northern bluefin), correspondingly larger thermal inertia, and body temperatures up to 21.5°C above ambient temperatures (Carey et al., 1971; Stevens and Neill, 1978). Countercurrent heat exchangers, retia mirabila ("wonderful nets"), provide a means by which the Thunnini are able to maintain body temperatures above the ambient temperature of the water. Konagaya et al. (1969) recorded body temperatures of southern bluefin up to 19.5°C above the temperature of the water in which they were caught. Metabolic heat produced primarily by aerobic means during swimming activity is shunted from the venous to the arterial sides of the circulatory system before it reaches the gills and is lost to the environment. Carey and Teal (1966), Carey et al. (1971), and Stevens and Neal (1978) describe in detail the morphology and workings of the central and lateral retial systems. In all the Thunnini except the bluefin group cutaneous arteries that supply the lateral retia originate from the dorsal aorta at the level of the sixth or seventh vertebrae and a well-developed dorsal aorta and postcardinal vein continue posteriorly to supply the central retia located in the haemal arch of the vertebrae. In the bluefin group the central retia are absent. The cutaneous arteries originate further anterior on the dorsal aorta to form large cutaneous retia, the major avenue of blood supply for the muscle. The dorsal aorta posterior to this becomes reduced in size and the postcardinal vein is absent (Collette, 1978; Stevens and Neill, 1978).

The species of the bluefin group are also unique among the Thunnini in possessing large complex visceral retia mirabila on the liver and gut. One to five vascular cones occur on the dorsal surface of each of the three lobes of the liver (Gibbs and Collette, 1967). Striations caused by blood vessels cover the ventral surface. These retia are also countercurrent heat exchangers that create high visceral temperatures, presumably to speed digestion and absorption (Carey et al., 1971; Collette, 1978; Stevens and Neill, 1978). Retia near the brain and eyes have been described by Linthicum and Carey (1972) for northern bluefin and albacore, among others (summarized by Stevens and Neill, 1978). Presumably southern bluefin possess similar adaptations.

Stevens and Neill (1978) and Sund et al. (1980) review the hypotheses proposed by several investigators to explain the adaptive significance of an elevated body temperature. Cole (1980), in this synopsis series, briefly discusses the principal arguments.

The question of whether tunas are able to thermoregulate is discussed by Stevens and Neill (1978) and Dizon and Brill (1979). According to the former, "the evidence suggests that large bluefin tuna, at least, practice substantial thermoregulation." Presumably southern bluefin do so also, though no direct evidence is available.

Sharp and Pirages (1978) presented evidence that the position of the red swimming muscles in conjunction with the relative development of the cutaneous and central vasculature is indicative of adaptations to habitat and preferred temperature in tunas. The red muscle is the principal site of aerobic metabolism and heat production. The lateral heat exchangers line the red muscle mass (Sharp and Dizon, 1978). The tropical species of the genus Thunnus, yellowfin, blackfin, T. atlanticus, and longtail, T. tonggol, have red muscle masses in contact with the lateral body surface and the vertebral centra. The red muscle in temperate species, the bluefin group, is completely internalized. The placement of the red muscle mass in southern bluefin is more medial and smaller than that of northern bluefin. Sharp and Pirages (1978) state that "internalization of red muscle in species preferring cooler water is most likely an adaptation which permits maintenance of a 'tropical' red muscle temperature".

Southern bluefin possess a well-developed gas bladder (Gibbs and Collette, 1967; Collette, 1978; Sharp and Dizon, 1978). In scombroid and xiphoid fishes the presence of a gas bladder appears to be associated with increase in body mass. Magnuson (1973) showed that most species with large mass have gas bladders and pectoral fins with high surface area, which act to increase bouyancy and reduce the minimum swimming speed required to maintain hydrostatic equilibrium. Thus, energy expenditure for swimming is reduced.

Sharp and Pirages (1978) analyzed the electrophoretic mobilities of several proteins in red, white, and heart muscle of scombrids. They found more biochemical similarity between *T. maccoyii* and *T. thynnus orientalis* (Pacific northern bluefin) than between *T. t. orientalis* and *T. t. thynnus* (Atlantic northern bluefin). This may indicate a need to further examine the taxonomy of these fishes.

Studies by Sprague (1967) and Fujino and Kang (1968a) have indicated the existence of polymorphisms in serum esterase and transferrin, respectively, of southern bluefin. Sprague's study indicated 5 phenotypes in 70 specimens from Australian waters, but no subpopulation study was made. Fujino and Kang tested 302 specimens from different locations around Australia and found only two phenotypes. No significant differences in gene frequencies were found between localities.

3.4 Nutrition and growth

3.41 and 3.42 Feeding and food

The diets of larval and juvenile southern bluefin are briefly discussed in Sections 3.22 and 3.23.

Adult tunas are generally considered to be opportunistic feeders, their stomach contents reflecting the forage species available in a particular area. Southern bluefin are no exception (Serventy, 1956); Robins (1963) stated: "In this species feeding appears to be random on pelagic small fish, squid, and crustaceans." The feeding ecology of southern bluefin has been examined for longline-caught fish off South Africa by Talbot and Penrith (1963). It appears that they feed primarily in the early morning and evening, and probably not at night. The occurrence of the fish, *Merluccius capensis*, and the shrimp, *Funchalia woodwardi*, in the stomachs of a large percentage of 263 specimens indicates that the fish were feeding in deep water.

Serventy (1956) lists 22 species and 1 family of fishes, 5 species of cephalopods, 4 species of crustaceans, 1 tunicate, 1 chaetognath, and 1 siphonophore found in the stomachs of southern bluefin caught off Australia. The principal forage species include:

larger fishes - jack mackerel (*Trachurus novaezelandiae*), mackerel (*Scomber australasicus*), pilchard (*Sardinops neopilchardus*);

smaller fishes - bellows fish (*Macroramphosus molleri*), bill fish (*Scombersox forsteri*), trevally (*Caranx georgianus*), mackerel fry (*Scomber australasicus*), and clupeoid fry;

cephalopods - *Nototodarus gouldi*;

crustaceans - euphausids and stomatopod larvae.

Cephalopods were always found associated with fish in the stomachs examined (Serventy, 1956). Talbot and Penrith (1963) analyzed quantitatively the food habits of South African-caught southern bluefin. They presented a table of the percent volume and percent frequency of occurrence of the food items found in the stomachs examined. The food groups of major importance were fish species and Funchalia woodwardi, comprising 64.3 percent and 29.8 percent of the food by volume, respectively. A large portion, 46.7 percent, of the specimens contained less than 10 cc of food, and 23.6 percent had empty stomachs. De Jager (1963) and De Jager et al. (1963) list the organisms eaten by 95 southern bluefin caught off South Africa. The most abundant items were pilchards, stockfish, and Funchalia woodwardi. Koga (1968) identified the organisms eaten by four southern bluefin caught in the Tasman Sea. They included fishes, crustaceans, cephalopods, and gastropods.

3.43 Growth rate

Southern bluefin grow more slowly than do yellowfin, bigeye, and northern bluefin, but more rapidly than albacore (Ueyanagi, 1966a). The age and growth data available for southern bluefin are summarized in Table 2. The table includes estimates of the parameters for the von Bertalanffy growth equation calculated by the investigators and lengths at age calculated by the compiler of this report using the respective growth parameters. The von Bertalanffy growth equation is as follows:

$$l_t = L_{oo} (1-e^{-K(t-t_o)})$$

where l_t is length in centimeters at age t, L_{oo} is the asymptotic length, and K is the annual growth rate constant. The growth of southern bluefin is also discussed by Serventy (1956), Hynd (1965), Ueyanagi (1966a), Hayashi et al. (1970), Suda (1971 and 1973b), and Anonymous (1975c). Serventy presents "a graph of growth rates showing the progression of means or modes, or both" of length-frequency data of fish taken off Australia during 1938-1942. Hynd (1965) used scales to estimate the ages of 50 southern bluefin. He could not construct an age-length relationship by tracing the progression of modes because the length distributions within the 2+ age group were often bimodal.

Lucas (1974) compared his results based on tag returns with Yukinawa's (1970) growth curve derived from scale readings, and found little difference in the results of the two methods for the 2- to 4-year-olds. However, tagged fish over 5 years of age seemed to have a slower growth rate than that indicated by scale readings. Yukinawa (1970) also showed that tagged fish generally grow more slowly than the rate indicated by a growth curve based on estimates from scales. This could be due to the investigators having made low age estimates for the older fish due to their having overlooked scale annuli. Hearn (1979) found evidence to support the hypothesis that tagging initially retards growth in southern bluefin. Murphy and Sutherland (1980) noted that participants in a recent tuna and billfish stock assessment workshop in Shimizu, Japan, called attention to the fact that the age structure of the population derived utilizing the von Bertalanffy growth parameters of Shingu (1970, data from Robins, 1963) was not compatible with the observed age structure of the tagged population. Murphy and Sutherland (1980) presented parameters estimated by a new procedure using tag return data (Table 2).

Yukinawa (1970) found similar growth rates among male and female southern bluefin.

From Serventy's (1956) graph of length-frequency distributions mentioned above, it appears that most growth takes place between October and May, the southern spring, summer, and fall seasons. Robins (1963), however, cited some unpublished tag return data which indicate that winter growth is similar to summer growth.

Further tagging experiments by Australian scientists are presently in progress in an effort to confirm previous estimates of growth rates of southern bluefin. Injections of oxy-tetracycline are being made at the time of tagging (Williams, 1980). Tetracycline is incorporated into the growing layer of sagittal otoliths (ear bones) of the fish. The tetracycline mark is used as a referrence point for relating growth increments to time at liberty after injection and tagging (Wild and Foreman, 1979).

3.44 Metabolism

There is no specific information available on this subject. However, metabolic rates of tunas are known to be higher than those of any other teleost group (Magnuson, 1978a). Stevens and Neill (1978) state that warmbodiedness has enabled tunas to achieve high, near mammalian rates of metabolism (Section 3.36).

3.5 Behavior

3.51 Migrations and local movements

The migration patterns of southern bluefin have been discussed by several investigators. The migration models that follow are, unless otherwise noted, based on information from the following sources: Robins (1963), Shingu (1967, 1970, and 1978), Kikawa et al. (1968), Hynd (1969), Nakamura (1969), Suda (1971), Hynd and Lucas (1974), Lucas (1974), Murphy (1977), Pownall (1977), and Murphy and Sutherland (1980).

The traditional model and an alternative model will be discussed. The traditional model, due to its rather complicated nature, will be detailed in seven stages. Figures 4 and 5 will serve as aids for following the migration patterns, but neither shows all the details given in the text.

I. Traditional model

A. The location of the spawning grounds of southern bluefin is given in Section 3.16. Some investigators assume that the young fish spend their first year of life on the spawning grounds.

B. The young fish then make their way southward in the neritic waters of the west coast of Australia. They first appear in the surface catch as 1- to 2-year-olds off western and southwestern Australia.

C. The age-2 and older juveniles then turn east and migrate in the surface layer along the south coast of Australia. Recent reports by Australian investigators indicate that they also disperse westward at this stage, and Suda (1971) reports that 3- and 4-year-olds perform east-west seasonal migrations along the south coast of Australia.

D. Several age groups of immature fish then make seasonal movements from the waters off southern Australia toward the east coast of Australia and around Tasmania and New Zealand. Fish of different age groups make this move at slightly different times, but generally during the latter half of the year. They enter the Tasman Sea via the southern coast of Tasmania in March to May, move northward in June to September, attaining their northerly limit (about 34°S latitude) in early spring (August), and then disperse southward in the late spring (October to December). The northern limit is associated with the 19°C isotherm (Robins, 1963). In general, northward movements occur in the colder months and southward movements in the warmer months. The fish may stay in these areas from 2 1/2 to 5 years. (According to Nakamura (1969), a fairly large number of juveniles of various age groups enter the West Wind Drift directly from the waters off southern Australia without having ever entered the Tasman Sea.)

E. Sometime between the ages of 4 1/2 and 6 years, especially during the southern summer (Shingu, 1970), the juveniles leave the continental shelf, move offshore into the West Wind Drift, and disperse in the Southern Ocean. They may remain offshore until sexually mature or make seasonal migrations to the Tasman Sea north of 40°S latitude and to the waters east of New Zealand in the southern winter.

F. It has been shown by the recoveries of fish tagged off Australia that southern bluefin in the West Wind Drift migrate both to the east and to the west. Several tag recoveries have been made south of the Cape of Good Hope, Africa, between 16°40' and 30°20' east longitude. Two tagged fish released off South Australia were recaptured at 45°00'S-2°30'E and 41°46'S-3°42'E 8 years and 2 months later and 7 years and 8 months later, respectively (Anonymous, 1974c, 1975d, 1976c, 1977d, and 1978c).

Many fish tagged off southern and southeastern Australia have been recovered east of New Zealand, especially off the North Island (Hynd, 1969; Anonymous, 1974c, 1975d, and 1977d).

G. It is believed that, upon reaching sexual maturity, southern bluefin make large-scale feeding and spawning migrations between the South Pacific and Indian Oceans via the Southern Ocean. Shingu (1967) presents evidence of fish making annual migrations during the southern summer from the West Wind Drift region of the Southern Ocean via the Oki fishing grounds to the spawning area of the Oka fishing grounds northwest of Australia. After spawning the adults return to the West Wind Drift and disperse once again. Some of these are known to immigrate to the Tasman Sea and waters east of New Zealand in the southern winter.

II. Alternative model

Murphy (1977) asserts that the migration patterns may not be as simple as those just described. He claims that there is evidence that not all young southern bluefin that appear off western Australia turn east and pass through the area of the Australian surface fishery. As evidence, he explains that Japanese longline catches of 61- to 80-cm fish (2 3/4- to 4-year-olds) in an area near South Africa are about as large as those in the Tasman Sea. Murphy proposes that on their way southward from the spawning grounds only the juveniles on the eastern edge of the population pass close to western Australia and turn east, following the route outlined in the traditional model. The others pass to the west of coastal western Australia, continue southward, and then turn east and west in the West Wind Drift without ever entering the Australian fishing grounds.

3.52 Schooling

The southern bluefin's principal habitat is described as the surface layer at immature stages and the subsurface or mid-water layer at the adult stage (Shingu, 1967; Hayashi and Kikawa, 1970). Robins (1963) reports schools of from 0.5 to 500 long tons (0.5 to 508 metric tons), and catches of up to 62 long tons (63 metric tons) from a single school. Hynd and Robins (1967) describe typical schooling behavior of southern bluefin in the Australian surface fishery. "Ripplers" are closely packed schools of fish swimming slowly just below the surface. Schools of southern bluefin apparently adopt their "rippling" behavior only when the water temperature is between 16.7° and 20°C and the fish are not feeding (Hynd and Robins, 1967; Williams, 1977; Pownall, 1979). Feeding schools are more dispersed and will not respond to chum. Schools in waters above about 21°C do not bite well (Williams, 1977).

No information is available on other species of fish and/or mammals that school with southern bluefin. They are not reported to associate with flotsam as are other tunas.

No detailed data are available on the bathymetric distribution of southern bluefin.

3.53 Responses to stimuli

Small schools that are not "rippling" disperse when subjected to a repeated sound of 48-kc frequency (Robins, 1963).

The principal bait species used in the Australian live-bait fishery include jack mackerels (*Trachurus novaezelandiae*), pilchards (*Sardinops neopilchardus*), and anchovies (*Engraulis australis*). Longline bait species known to give favorable results are 8- to 10-inch (20- to 25-cm) mullets (*Mugil georgii*, *Lisa argentea*, and *Aldrichetta forsteri*), jack mackerels, and scad (*Trachurus declivis*) (Robins, 1963).

4 POPULATION

4.1 Structure

4.11 Sex ratio

Robins (1963) reported the following sex ratios of southern bluefin caught by various gears in four major fishing areas: New Zealand, longline-caught fish, 1.22 males:1 female; southwestern Tasman Sea, longline-caught fish, 1.40 males:1 female; southwestern Tasman Sea, troll and livebait-caught fish, 1 male:1.22 females; Oka fishing ground, longline-caught fish, 1.2 males:1 female; Oki fishing ground, longline-caught fish, 1.38 males:1 female.

Nakamura (1969, after Suda, 1960) gave catch data by size and sex of southern bluefin caught in the area south of central Australia during an exploratory fishing operation. The sex ratios found are as follows:

Length (cm)	Males (number)	Females (number)	Sex ratio male:female
100	3	1	3.00:1
100-140	15	14	1.07:1
140-180	42	27	1.56:1

A sex ratio of 1.66 males:1 female for 226 southern bluefin caught by longline off South Africa was given by Talbot and Penrith (1963). De Jager (1963) and de Jager *et al.* (1963) report an almost identical sex ratio for an apparently different sample of 212 southern bluefin caught off South Africa.

4.12 Age composition

Age determinations of southern bluefin have not yet been made with certainty (Sund *et al.*, 1980). The average age composition of the catch by surface and subsurface gear of the 1958 to 1965 year classes is shown in Figure 6. The two fisheries utilize southern bluefin of different age groups, with some overlap. The surface fishery around

Australia exploits young fish (primarily 2- to 4-year olds), while the longline fishery utilizes primarily adult fish (Hynd et al., 1966; Anonymous, 1972b; Hayashi et al., 1972). The age distribution of the catch in the various areas of the fishery was briefly discussed in Section 3.51. More details are given in Table 1. The age and size composition of the catch differs markedly among fishing areas and seasons, but not within seasons. This is partly due to fluctuations in year-class strength (Shingu, 1967). The age composition of the longline catches during the 1965-66 to 1971-72 seasons in nine fishing areas and in all areas combined are shown in Figure 7. Warashina and Hisada (1974) point out that prior to the 1968-69 season, 7- and 8-year-old fish were dominant in the catch, but since then 5-year-old and younger fish have occupied a larger percentage of the catch. In the 1971-72 season the longline catch was composed of as many 4-year-olds as 7-year-olds (Warashina and Hisada, 1974).

The mean age and weight of the catch and the mean age at first capture in the Japanese longline fishery are shown in Table 3. The year-to-year fluctuations were caused partly by changes in the areas in which the majority of the effort was concentrated (Shingu and Hisada, 1971). A gradual downward trend can be seen in the mean age at first capture, though the values for the last three seasons have increased slightly. The graphical representation of Hisada et al. (1978: Figure 5) shows this trend clearly. According to Shingu and Hisada (1971) the gradual decrease in the mean age of the total longline catch may indicate "a serious decrease in older fish." It was expected that after the 1971-72 season the catch of older fish would continue to decline due to the voluntary closure of the Oka area to longline fishing (Section 6).

Although fish up to 18 to 20 years old are occasionally caught by the longline fishery (Section 3.31), there are few fish in the catch greater than 12 or 13 years of age.

The age composition of southern bluefin caught in the Atlantic Ocean is discussed by Hayashi et al. (1970).

4.13 Size composition

The length-frequency distributions of the southern bluefin catches for 1960 to 1977 by the Australian surface fishery and the Japanese longline fishery are shown in Figure 8. Both fisheries utilize fish of 70 to 130 cm, although most of the fish caught by the Australian fishery are less that 100 cm and most of those caught by the Japanese fishery are greater than 100 cm. A mode at around 150 cm is apparent in the longline catch for every year shown. In the 1970's the catch of fish less than 130 cm increased. Starting in 1974 the catch of small fish (45 to 65 cm) by the surface fishery increased substantially and the fishery off Western Australia began to take very small fish in the mid 1970's. According to Anonymous (1975c), the change in the size composition of the surface fishery catch was due to the introduction of purse seiners.

The size composition of the catches of southern bluefin by major fishing areas from 1957 to 1962 is shown in Figure 9. The smallest fish are caught by the surface fishery, especially off Albany, Western Australia. The catches by the South Australian and New South Wales fisheries ("Southern and Eastern coasts" in Figure 9) have nearly the same size range, but there is a higher frequency of smaller fish caught off South Australia. Individuals under 130 cm in length rarely appear in the catch from the Oka and Oki fishing grounds. However, the proportion of large individuals is greater in the Oka area (mode = 160 cm) than in the Oki area (mode = 150 cm) (Shingu, 1970 and 1978). Immature and adult southern bluefin are caught in about the same proportions between 30° and 40°S in the Tasman Sea and east of the North Island of New Zealand. The size range of the catch is about the same in the fishing areas south of 40°S in the West Wind Drift, but the proportion of individuals over 130 cm (adults) is larger in the West Wind Drift areas. Shingu (1978) presented length-frequency distributions for southern bluefin caught east and west of South Africa (south of Madagascar and southwest of Cape Town). In the former area, individuals under 130 cm constitute the majority, while those over 130 cm are more prevalent in the latter area. The length-frequency distribution from the area southwest of Cape Town is remarkably similar to that of the longline catch from Area 4 in Figure 1 (Shingu, 1978). Graphs of yearly and monthly changes in the length frequencies and weight frequencies of the catch in the major fishing grounds are shown by Mimura (1962), Hynd (1965), and Shingu (1965, 1967, 1970, and 1978).

In spite of the fact that several researchers have noted a declining age at first capture, Suda (1973a) states: "There appears [to be] only [a slight] decrease [in the] size of fish in the commercial catch from various sectors of the longline fishing grounds, probably due to the age-dependent-segregation, which brings [about the] occurrence of particular age groups in different parts of the fishing ground." His values of mean weight per fish in the longline catch are shown in Table 3 for the 1957-58 to 1971-72 seasons.

Murphy (1977) states that the largest southern bluefin ever observed was 188 cm long (about 277 lb or 126 kg). Goadby (1970) states they reach 500 lb (227 kg). The Japanese have authenticated southern bluefin over 2 m in length (Hearn, 1980). The IGFA all-tackle world record southern bluefin, caught at Hippolyte Rock, Tasmania, Australia, in May 1979, weighed 256 lb, 13 oz (116.5 kg) (Anonymous, 1980c).

Length-weight relationships calculated by several investigators are shown in Table 4. Warashina and Hisada (1970) reported that when southern bluefin reach about 130 cm in length the relationship between body length and weight changes, weight increasing faster that length (Shingu, 1978). They found distinct length-weight relationships for "fat" and "lean" fish. "Lean" fish appear in the catch during or just after the spawning season. Their lean condition is assumed to be due to the energy in the muscle fat reserves having been utilized in developing the gonads prior to spawning. Shingu (1978) presents a brief examination of length-weight relationships based on data from 1977.

4.2 Abundance and density

Catch per unit of fishing effort (CPUE) data can provide an index of abundance and/or density of a species of fish if its vulnerability to the fishing gear does not vary with time.

Density indices in terms of the Japanese longline catch per 100 hooks per day (henceforth referred to as catch per 100 hooks or hook rate) for the 1952-53 to 1975-76 seasons are presented in Figure 10. In all seven of the fishing grounds (Figure 1) included the density indices have shown a declining trend. The mean density of spawning adults has been decreasing since 1959. The density indices on the spawning grounds (Areas 1 and 2) during the 1968-69 season were 10 percent below the values in the early years of the fishery (Shingu and Hisada, 1971; Hayashi, 1974). Warashina and Hisada (1974) show that the hook rates continued to decline gradually through the 1972-73 season in all areas except Areas 3 and 9. The trend has continued; Shingu and Hisada (1979) note that the longline catch per 100 hooks in recent years is around 1/6 to 1/7 of that in the 1959-60 season. The decline is most apparent in areas where large fish are caught (Kikawa et al., 1968; Shingu and Hisada, 1971; Suda, 1973a and 1974; Warashina and Hisada, 1974). Shingu (1978) discusses in detail the historical changes in hook rates which took place in the fishing areas included in Figure 10.

In Figure 11 is shown the CPUE in terms of yield per boat-half-month in the Australian surface fishery for the 1963-64 to 1972-73 seasons. The abundance of juvenile southern bluefin caught in the South Australia and New South Wales fisheries does not show the same long-term declining trend mentioned above.

De Jager (1963) and de Jager et al. (1963) reported that southern bluefin are most abundant off South Africa during the winter and spring when no upwelling was evident.

4.3 Natality and recruitment

Investigators of the southern bluefin fishery have been concerned that the reduced abundance of spawners (Section 4.2) might result in decreased recruitment. However, a fairly stable CPUE for juveniles in the Australian surface fishery indicates that the recruitment has not been affected (Suda, 1971, 1973a, and 1974; Hynd and Lucas, 1974; Murphy, 1977; Hisada et al., 1978) (Figure 11).

Southern bluefin appear to be fully recruited to the surface fishery at 2.5 years of age and to the longline fishery at age 5 (Hayashi, 1974; Hynd and Lucas, 1974; Lucas, 1974; Anonymous, 1974d and 1975c). Murphy and Sutherland (1980) state that they appear to be fully recruited to the longline fishery only from age 7 onward.

Estimates of the mean recruitment to both fisheries are presented in Table 5. Yearly changes in the estimates of longline recruitment for the 1958-59 season to the 1970-1971 season are shown by Hayashi (1974: Table 4 and Figure 2). In the 1959-60 and 1960-61 seasons recruitment to the longline fishery was at its peak. It was followed by a decline to a low in the 1965-66 season. Hayashi (1974) attributes this partly to an increase in the catch of age-4 and younger fish in the surface fishery. In subsequent years recruitment showed moderate random fluctuations, but no downward trend (Hayashi, 1974; Lucas, 1974; Suda, 1974; Murphy, 1977; Hisada et al., 1978).

4.4 Mortality and morbidity

Hayashi et al. (1969) and Suda (1971), based on information on the life span of the southern bluefin and the life spans and annual instantaneous natural mortality coefficients (M) of other species of fish, assumed that M for southern bluefin is about 0.2. Hayashi et al. (1972) assumed that M is 0.2 for fish up to age 7, 0.6 for 8-year-olds, and 1.0 for fish 9 years old and above, based on their estimates of the annual instantaneous total mortality coefficients (Z).

Hayashi et al. (1972), using age composition and effort data, made a number of estimates for Z and for the annual instantaneous fishing mortality coefficient (F). They used age composition data to estimate an average value of Z of 1.53 for 8- to 10-year-old fish caught during the 1958-59 to 1968-69 seasons. Murphy and Sutherland (1979), using the semigraphical method of Gulland (1969) with tagging data, estimated Z for the 2- to 5-year-olds caught in the surface fishery and for the 7- to 14-year-olds utilized by the longline fishery to be 0.73 and 0.30, respectively. They later used newly calculated growth parameters (Table 2) to arrive at slightly lower estimates of Z, 0.71 and 0.25, respectively (Murphy and Sutherland, 1980). The estimate of Z for the 2- to 5-year-olds includes an unknown factor of emigration from the areas where the surface fishery operates to those where the longline fishery operates. It did not appear to them that Z had increased significantly during the 1960's.

Hayashi (1974) reviewed the work of Hayashi et al. (1972), and concluded that the estimates of F were too high, due to the fact that after 1968 the effort in the Oki fishing area had shifted from southern bluefin to bigeye and due to a decrease in the age at first capture of southern bluefin. His estimates of F range from 0.191 in the 1958-59 season to 1.514 in the 1969-70 season. His estimate of 1.23×10^{-8} for the coefficient of catchability (q) was only about half the estimate of 2.21×10^{-8} calculated by Hayashi et al. (1972). Hayashi (1974) explains that it is reasonable to assume that the F's in recent years had reached 1.5, but the recapture of tagged fish after up to 10 years at liberty indicate that the F's may be lower.

Lucas (1974), using a cohort analysis with tagging data, and employing M values of 0.15, 0.20, and 0.25, estimated F to be 0.114, 0.108, and 0.102, respectively, substantially lower that the estimates of Hayashi (1974). Murphy and Sutherland (1980) also employed a cohort analysis with tagging data. However, noting that the results of cohort analyses are quite sensitive to the growth curve used to allocate the catch to age classes, they utilized a new set of growth parameters (Table 2). They estimated F's for the 2- to 5-year-olds and 7- to 14-year-olds as 0.10, and 0.15, respectively, using an M value of 0.20.

Hynd (1965) and Murphy (1977) agree that tagging causes little or no mortality of southern bluefin.

4.5 Dynamics of the population

If mathematical models are to be applied to a fishery for population dynamics studies it is first necessary to determine the stock structure of the population in question. Some workers in the 1960's hypothesized the existence of two or three stocks of southern bluefin, based of the fact that catches of young fish are composed of more than one modal size group (Robins, 1963; Hynd, 1965 and 1969). However, morphometric studies carried out by Shingu and Warashina (1965) showed no morphological differences in 130- to 170-cm fish caught off northwestern, southern, and southeastern Australia and off New Zealand, and blood grouping studies have failed to show any differences in fish caught in different area-time strata (Hynd, 1969). Studies of serum esterase and transferrin of southern bluefin are described in Section 3.36. It is now generally accepted that the population of southern bluefin is composed of a single stock (Anonymous, 1969b; Shingu, 1970 and 1971; Lucas, 1974), and the studies described below are based on that assumption.

Only the yield-per-recruit model (Beverton and Holt, 1957; Ricker, 1975) has been applied to southern bluefin. The biomass of individuals of unexploited southern bluefin reaches a maximum of about 15.5 kg per recruit at 8 years of age (Hayashi and Kikawa, 1970; Hayashi et al., 1972) (Figure 12). The yield per recruit at various combinations of fishing mortality and age at first capture are shown in Figure 13. The yield per recruit reaches a maximum of about 15 kg for a fishery taking 7-year-old and older fish at a fishing mortality coefficient (F) over 2.0. The status of the longline fishery in the 1967-68 and 1969-70 seasons are indicated by dots on Figure 13. The ages at first capture and F for 1967-68 and 1969-70 were approximately 6.4 years and F = 2.4 and 6.0 years and F = 2.4, respectively. It is apparent that the model is sensitive to changes in age at first capture. The reduction in age at first capture from 6.4 to 6.0 years in 1969-70 and to a low of 5.5 years in 1971-72 (Table 3) may have also reduced the yield per recruit from just under 15 kg to just under 14 kg. The model shows that the yield does not change much with levels of F at 0.5 and above, providing the age at first capture stays fairly constant (Anonymous, 1972b), and according to Suda (1974) reducing the effort by as much as 5 x 10^7 hooks would probably not appreciably reduce the catch. Likewise, an increase in longline effort would not be expected to result in increased catches. This is also apparent from an empirical examination of the historical relationship between catch and effort in the longline fishery (Section 5.4). The yields per recruit at various levels of F for four fisheries are shown in Figure 14. The data indicate that increasing F by increasing the effort would not substantially increase the yield per recruit (Suda, 1974). It is also apparent from Figure 14 that exploitation of younger fish may reduce the yield per recruit. According to Suda (1974), the matter of concern is how to keep the amount of recruitment at or above its level at that time. The yield-per-recruit model was utilized by Murphy and Sutherland (1980) based on newly calculated growth parameters for the von Bertalanffy equation. Analysis of their results indicates that "yield per recruit maximizes at unattainably high rates of fishing mortality and an age of first capture that would eliminate the Australian fishery." At the level of F calculated by Murphy and Sutherland (1980) only a 13 percent gain in yield would result by eliminating the Australian surface fishery to increase the age of first capture to 4 years.

The relative stock fecundity is the fecundity of the stock in question relative to fecundity of that stock in its unexploited state. This is also shown in Figure 13. It is apparent that the relative stock fecundity is more sensitive to the age at first capture than to fishing effort at coefficients of fishing mortality greater than 1.0.

Hayashi _et al._ (1972) have examined the yields per recruit and relative stock fecundities which would result from various combinations of surface and longline fishing mortality (Figure 15). It is obvious that the yield per recruit and relative stock fecundity are greater with greater longline fishing effort and lesser surface fishing effort than the reverse. On the basis of this figure Anonymous (1972b) and Hayashi _et al._ (1972) recommended that the relative stock fecundity be maintained at at least 20 percent. In Section 4.3, however, it was shown that the recruitment has been fairly constant even though the relative stock fecundity has decreased to less than 10 percent during the 1969-70 season (Figure 13).

Lucas (1974) used the yield-per-recruit model to examine the interactions between the surface and longline fisheries. His results show theoretical changes in the relative yields of both fisheries at different levels of natural mortality and effective fishing mortality. Table 6, compiled by Anonymous (1974d) summarizes Lucas's results at an M of 0.2. The yields of both fisheries are sensitive to changes in fishing mortality, but not to changes in natural mortality (Anonymous, 1974d).

Murphy (1977) used new growth estimates based on tagging data in a yield-per-recruit model to see if the catching of 2-year-old fish is reducing the yield in the Australian surface fishery and Japanese longline fishery. He simulated the results with ages at first capture of 2 and 3 years, and showed that, at the most likely value of natural mortality (0.2), the yield-per-recruit is only 14 percent greater when fishing starts at age 3 than when it starts at age 2 (Table 7). Another analysis by Murphy (1977) indicated that increasing the age at entry to the surface fishery from 2 to 3 years would result in only a 5-percent increase in yield to that fishery alone.

No production model analysis has been attempted for southern bluefin, but Anonymous (1969b) and Suda (1973a and 1974) have estimated its maximum sustainable yield to be 35,000 to 40,000 metric tons.

4.6 The population in the community and the ecosystem

There is no specific information available on this subject.

5 EXPLOITATION

5.1 Fishing equipment

Accounts of the early development of the southern bluefin fishery are given by Shingu (1978) and Murphy (1979). The fishery began in Australia in 1938 off the coast of New South Wales, but trolling was the only fishing method used until 1951. Live-bait fishing was introduced in that year with the government charter of a U.S. tuna clipper, but the new method did not gain popularity until 1962. Japanese longline vessels began fishing operations for southern bluefin in 1952 in the Oka fishing ground followed by the North New Zealand area (Area 5 in Figure 1) in 1957 and the Oki fishing ground in 1958 (Shingu 1970 and 1978; Shingu and Hisada, 1971). Most of the longline effort has been by Japanese vessels, but vessels from the Republic of China and the Republic of Korea have also landed southern bluefin (Anonymous, 1972b and 1974d). A purse-seiner was used in the Australian fishery in 1966 (Anonymous, 1968b), though apparently for only one season. Purse seining was reintroduced in 1974, and from then until the end of the 1976-77 season the number of active purse seiners varied from one to four.

The following description of Australian vessels and gear is from Anonymous (1968b) and Pownall (1979) unless otherwise indicated. Trolling vessels make up only a small part of the Australian fleet, and they direct their effort primarily at species other than southern bluefin. They are diesel-powered boats ranging in length from approximately 20 to 50 feet (6 to 15 m) and utilize a crew of one to three. The gear consists of up to 10 lines, varying in length from about 2 to 25 fathoms (4 to 46 m). They are towed from outrigger booms and from the stern of the boat. Additional information on trolling is given by York (1979).

Baitboats are generally larger than trollers, though vessels as small as 24 feet (7 m) have been used for live-bait fishing. The minimum-sized vessels considered suitable for bait fishing are 40 feet (12 m) on the east coast of Australia and 50 feet (15 m) on the coast of South Australia, where the fish are generally found further offshore. The largest baitboats operating in Australia in 1968 were appoximately 100 feet (30 m) in length. Baitboats are diesel-powered, are equipped with modern electronic navigation and fish-locating aids, and utilize a crew of three to eight men. A small lampara net, in conjunction with a powerful lamp, is used to catch bait. According to Murphy (1979), "At least 20 species of fish are used for live bait, but the preferred species are yellowtail and pilchard." Bamboo poles up to 10 feet (3 m) in length are used in conjunction with a line that is a few feet shorter than the pole and a feathered jig or "squid." Live baitfish are placed on unfeathered hooks when the fish are not biting well on the squids (Murphy, 1979). Light aircraft are used extensively to locate schools of southern bluefin for the baitboats (Murphy, 1979).

The purse seiner used in the Australian fishery in 1966 was a 135-foot (41-m) diesel-powered boat with a capacity of 450 short tons (408 metric tons) of fish. It was equipped with a nylon net 525 fathoms (960 m) long and 40 fathoms (73 m) deep. No information is available on the purse-seine gear used in the 1970's. Murphy (1979) states that most of the catches by purse seiners during the 1977-78 season were made on schools held at the surface by baitboats.

Details of longline gear are available from Shapiro (1950), Shimada (1951b), Kanasashi (1960), Anonymous (1965a), Rothschild and Uchida (1968), Suzuki, Warashina, and Hisada (1977), and York (1979). According to Suda (1973b) and Murphy (1979), the Japanese fishery utilizes lines up to 100 km long bearing up to 2,000 hooks. Each line is made up of 300 to 400 "baskets" fastened end to end, each of which contains a main line of varying lengths and four or five branch lines and hooks. They are set and hauled once per day.

5.2 and 5.3 Fishing areas and fishing seasons

The seasons during which southern bluefin are caught are commonly given as a combination of two calendar years, such as 1971-72. They are considered to begin in April of one year and end in March of the next year.

The following, taken from an English translation of Shingu and Hisada (1971), is an account of the historical expansion of the longline fishery during its development: "Through 1965, Japan's longline boats fished mainly for adult fish in the spawning period

(August-April) in the offing northwest of Australia and for immature fish the season when they moved north (May-October) in the offing southeast of Australia. But, from 1966 on, the boats moved out into the area of the West Wind Drift in the Indian and Atlantic Oceans and caught feeding adults and immature fish throughout the year. The main fishing grounds in the 1968-69 fishing season were in the offing south of Africa, in the south-central Indian Ocean, in the vicinity of Tasmania and in the offing east of New Zealand. The size of the fishing grounds was nine times that of the 1957-58 fishing season" (Table 8).

The principal areas where the surface and longline fisheries catch southern bluefin are shown in Figure 1. The seasons and age groups associated with each area are listed in Table 1. Much of what is known on this subject is presented in Section 3.51 in the discussion of seasonal migration patterns. More details outlined by Shingu (1978) are presented here. The two principal areas for the surface fishery are along the coasts of South Australia and New South Wales, Australia. A small fishery for 2-year-olds occurs off Albany, Western Australia, in June and July, but was not discussed in detail by Shingu (1978). At the beginning of the southern winter the fishing is concentrated in the southern part of the New South Wales fishery. The fish begin to move northward during June and July. After September catches are made progressively southward, and in December the fish reach the waters off northeastern Tasmania. Peak catches in the New South Wales area are made during December, utilizing the southerly migrating individuals. Better catches are made during the trip south because the fish aggregate to form schools that can be caught by baitboats and purse seiners, whereas during the period of the northerly migrations individuals are scattered. The South Australia fishing season begins around January, following the close of the New South Wales season. Peak catches occur during February to April, and the season ends by May.

Shingu (1978) presented graphs depicting the distribution of hook rates of southern bluefin by the longline fishery during four seasons averaged over the years 1967 to 1972. Some areas produce catches all year and others most of the year. However, on examining Shingu's graphs a pattern of south-north and east-west expansions and contractions of fishing areas reflecting seasonal movements of southern bluefin is evident.

5.4 Fishing operations and results

5.41, 5.42, and 5.43 Effort and intensity, selectivity, and catches

Suda (1974) claims that southern bluefin is the most heavily exploited of the tunas. Catch statistics in numbers of fish and in metric tons are presented in Table 9 for the New South Wales and South Australia fisheries and in Table 10 for the Western

Australia fishery. (Additional data are given by Robins (1975).) The total Australian and Japanese longline catch statistics for 1949 to 1977 are presented in Table 11. The catch by other countries is small, insignificant, or significant but unknown. The following countries have reported catch or are assumed to have caught southern bluefin, according to Anonymous (1971-1979) and Klawe (1978): Argentina, Republic of China, Federal Republic of Germany, Indonesia, Republic of Korea, New Zealand, Poland, and South Africa. The Japanese and Australian catches are shown graphically in Figure 16. The Australian catch has shown a continual increasing trend, while that of Japan has declined since 1961. The Australian surface catch in number of fish has surpassed the Japanese longline catch since 1968, reaching a high of approximately 1,400,000 fish in 1977 (Figure 16). However, the longline fishery has always had a higher yield in weight.

The amount of effort in standard boat half months in the New South Wales and South Australia surface fisheries up to 1974 is included in Table 9. According to Anonymous (1974d), the total number of boats operating in the Australian surface fishery has fluctuated directly with the apparent abundance of the fish, but the number of standard boats has remained fairly constant on the average. Another measure of effort, the number of Japanese longline vessels operating in major fishing areas, is shown in Table 12.

Catches and effort by Japanese longline vessels in eight areas from 1957-58 to 1969-70 are shown in Figure 17. Shingu and Hisada (1971) called attention to the fact that the importance, in terms of catch and effort, of the Oka, Oki, and north New Zealand fishing grounds (Areas 1, 2, and 5), which were the first areas to be exploited by the longline fishery, has declined each year. However, the fishing grounds in the West Wind Drift (Areas 6, 7, 8, and 9), which have been developed more recently, have become increasingly important. In a more recent account, Shingu (1978) states that since 1969 longline effort has declined in areas where primarily large fish are caught (Areas 1, 2, and 8), whereas it has increased in areas where small fish and mixed large and small fish are caught (Areas 4, 5, 6, 7, and 9). Up to the 1967-68 season the catch in Areas 2 and 8 exceeded that in all other areas. However, since 1968 the catch in Areas 2 and 8 has decreased and that in Areas 7 and 9 has increased markedly (Shingu, 1978). This is also apparent in Figure 10.

The historical relationships between catch and effort for the surface and longline fisheries are shown in Figure 18. (There is some lack of agreement between Figures 17 and 18, perhaps due to the more recent figure (18) having been updated.) Japanese longline effort for southern bluefin increased slowly at first, while catch rose at a higher rate. By 1961 the catch reached its all-time peak of 1.2 million fish (over 74,000 metric tons) caught on only about 33 million hooks. After 1961 catch and effort fluctuated somewhat, resulting in an abrupt decline in catch to about 750,000 fish and a slight increase in effort to about 35 million hooks in 1964. (The catch by weight is given in Table 11.) After 1964, with the expansion of the fishing grounds (Shingu, 1978), longline effort rose rapidly to about 85 million hooks in 1968, with an increase in catch of only about 150,000 fish. The growth of the longline fishery slowed somewhat after 1969, at least partly due to the implementation of a regulatory program (Section 6) (Shingu and Hisada, 1979). Effort fluctuated between 88 and 110 million hooks between 1970 and 1977, but catch has continued to decline. Some longline effort has shifted in recent years to the Atlantic bigeye and northern bluefin fishing grounds (Anonymous, 1975c).

6 PROTECTION AND MANAGEMENT

In the late 1960's it was believed by many scientists that the level of fishing was reducing the spawning stock and level of recruitment of southern bluefin. Stock assessment studies were begun, stimulated by the poor catch of the autumn of 1968 (Anonymous, 1972b). The investigators believed that it was necessary to keep the longline fishing mortality coefficient and age at first capture along or above the contour corresponding to 20 percent relative stock fecundity (Figure 13), for reasons explained in Section 4.5 (Anonymous, 1972b; Hayashi et al., 1972). Three different management schemes were considered to bring the fishery from conditions corresponding to the 1967-68 point in Figure 13 to those which correspond to the 20 percent contour or above. One scheme was to reduce the fishing mortality coefficient (F) to 1.21, while keeping the age at first capture constant at about 6.4 (Figure 13, point A). This would have necessitated reducing the fishing effort by about one-half. This measure was preferred by Anonymous (1972b), but it would have caused hardship to the fishing industry. The second scheme entailed keeping F at the 1967-68 level, but raising the age at first capture to about 7 years (Figure 13, point B). This would have required closing all fishing areas in which immature fish are caught. This also would have caused hardship to the industry, though not as much as the first measure. Furthermore, large adults are not considered to be of good quality for raw consumption as "sashimi" by the Japanese. After spawning the fat reserves in the muscle are depleted (Warashina and Hisada, 1970), which lowers their market value (Anonymous, 1972b; Hayashi et al., 1972). The third scheme was a combination of the first two, that is, the fishing effort would be reduced somewhat while increasing the age at first capture. This would have required the closing of areas and seasons. Hayashi et al. (1972) considered this to have been the best proposal of the three.

The management proposal submitted by the Federation of Japan Tuna Fisherman's

Cooperative Associations and the Japan Tuna Fisheries Federation resembled the second measure mentioned above. The Federations chose to implement a voluntary regulatory program for the longline fishery involving the closure of certain areas during seasons when 5-year-olds and younger juveniles, as well as spawning adults, aggregate (Anonymous, 1972b). The areas and seasons of closure are shown in Figure 19. The program was put into effect on October 1, 1971. Scientists recommended, in addition to the regulatory program, that fishing be directed toward bigeye instead of southern bluefin in the Indian and Atlantic Oceans (Suda, 1973a).

Although the effect of the regulations is not yet apparent, it is likely that they have prevented the age at first capture from declining below the 1971-72 level of 5.54 (Hayashi, 1974; Warashina and Hisada, 1974; Hisada et al., 1978). The relative abundance of adults and the relative stock fecundity have continued to decline (Figure 20), and the yield-per-recruit has not increased (Anonymous, 1974d).

The Australian government has implemented some restrictions on the numbers of purse seiners and baitboats allowed to fish for southern bluefin. In 1976 it was decreed that the number of purse seiners to be licensed would be limited to four, the number that fished in the 1974-75 season (Anonymous, 1975e; Murphy, 1979). The areas affected are shown in Figure 21. The same restrictions were extended to baitboats in 1977 (Murphy, 1979), though no areas were mentioned. The Australian government has recently announced intentions to ban all longline fishing in a 48,000 square mile area off northern Queensland effective October 31, 1980 in an effort to preserve the sport fishery for black marlin (Anonymous, 1980g). Anonymous (1968b) reports that Australian state regulations control the netting of small fish species used for bait. Occasionally Australian canneries refuse to buy southern bluefin under 5 kg in weight (Murphy, 1979).

7 CULTURE

No information is available on this subject.

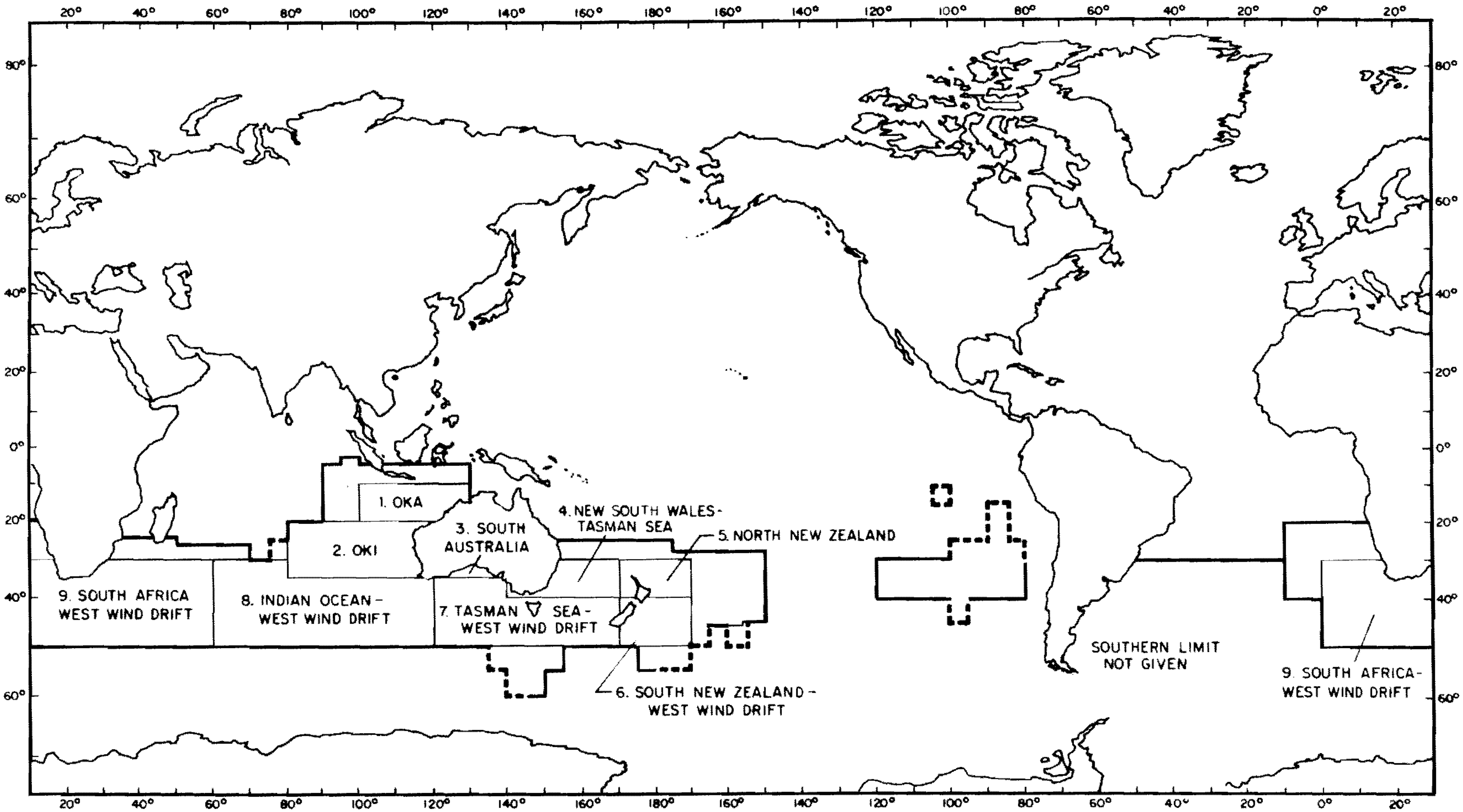

FIGURE 1. Combined distribution limits (bold lines) of southern bluefin (after Robins, 1963; Shingu, 1967; Hynd, 1969; Nakamura, 1969; Hayashi et al., 1970; Suda, 1971). The fine lines enclose the fishing areas defined by Shingu and Hisada (1971). The broken lines outline the area where there have been unconfirmed catch reports (Anonymous, 1974a, 1975a, 1976a, and 1977a).

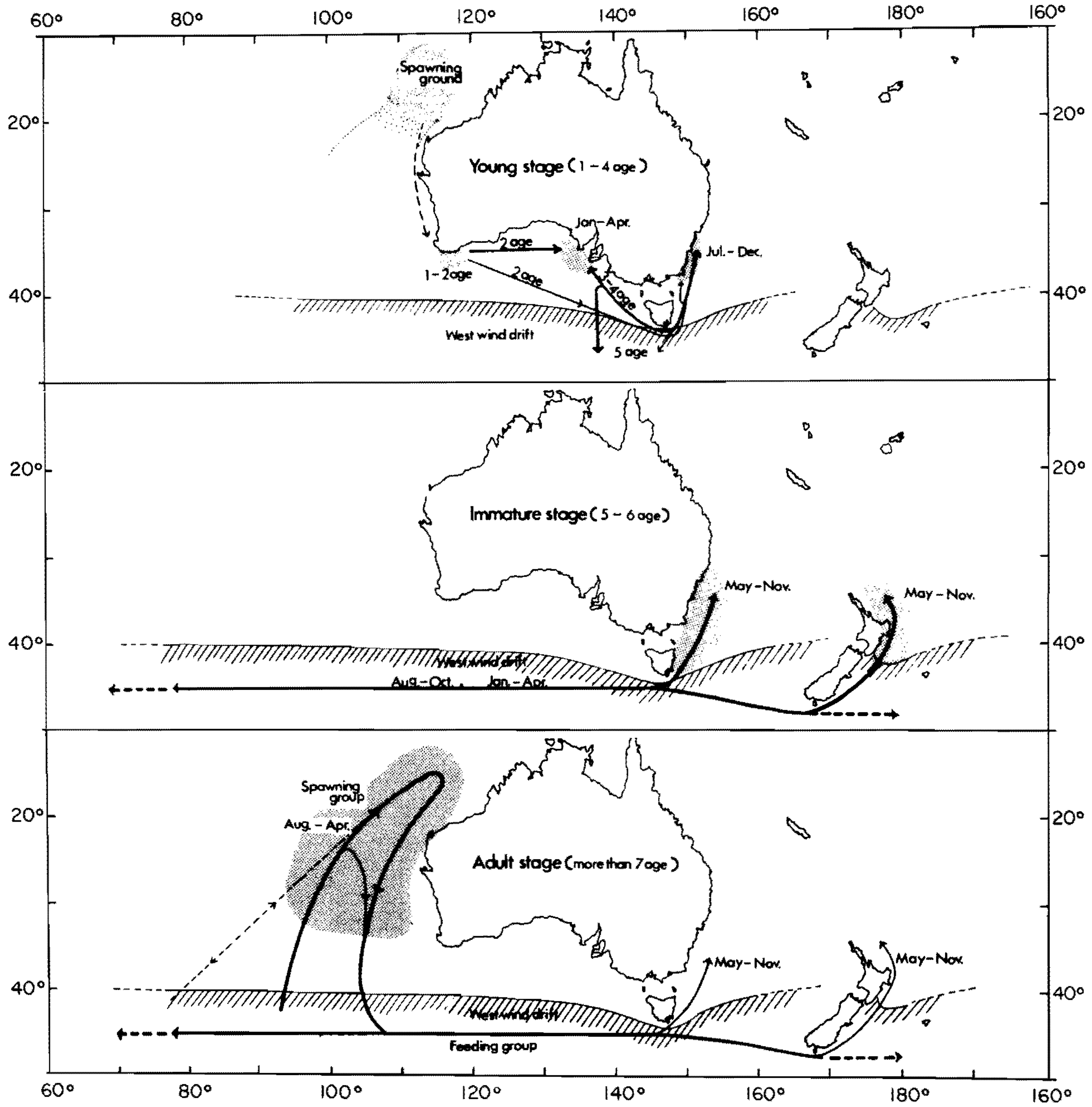

FIGURE 5. Migratory routes of southern bluefin in waters around Australia (from Shingu, 1970).

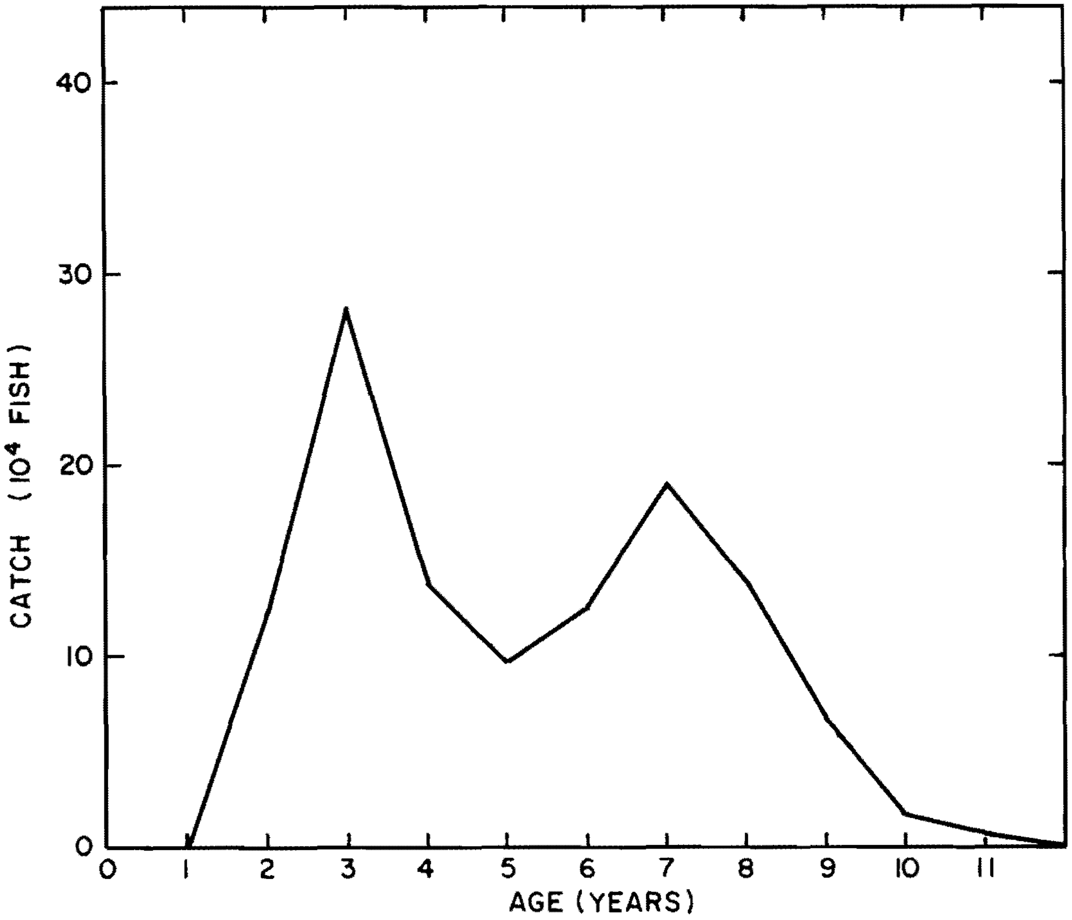

FIGURE 6. Average catch by age of the 1958 to 1965 year classes of southern bluefin caught by the surface and longline fisheries (after Shingu and Hisada, 1979).

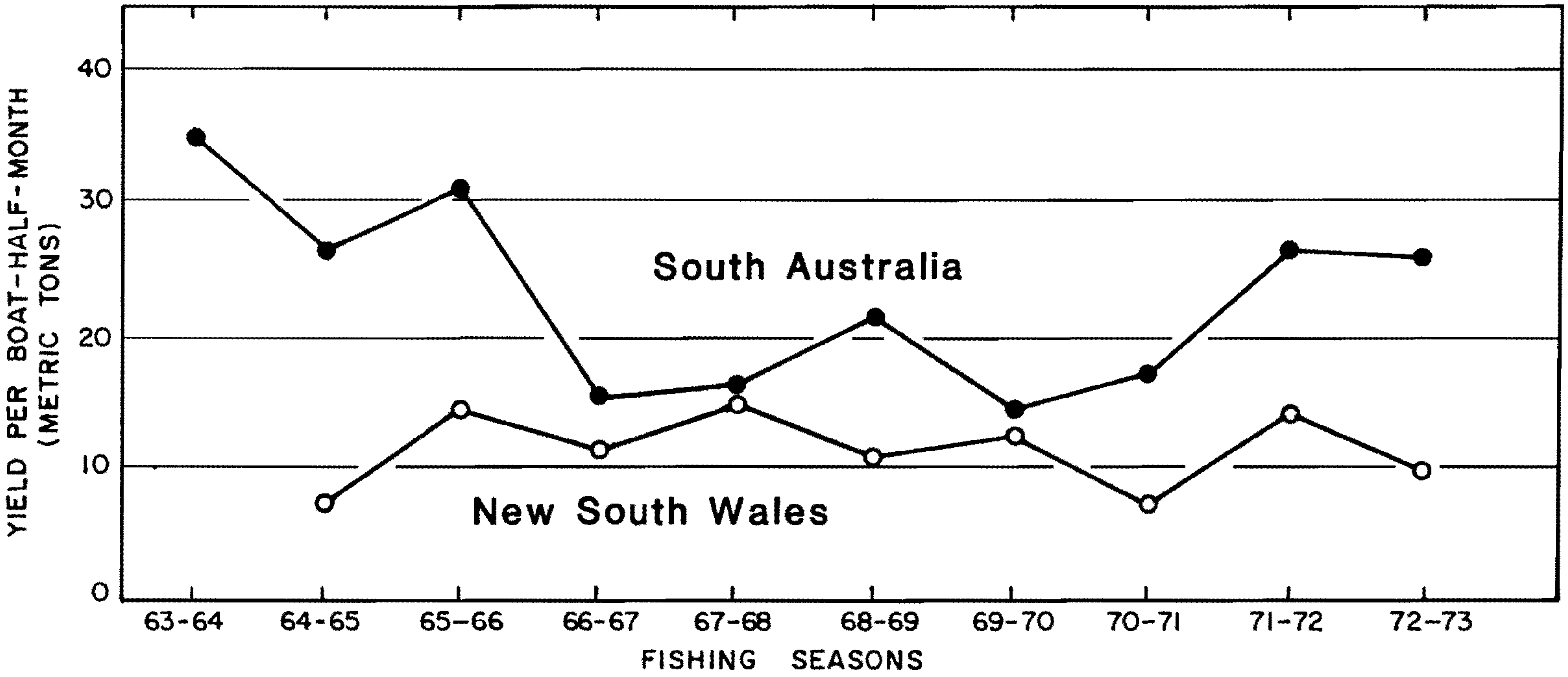

FIGURE 11. Yield per boat-half-month in the Australian surface fishery for southern bluefin (from Suda, 1974).

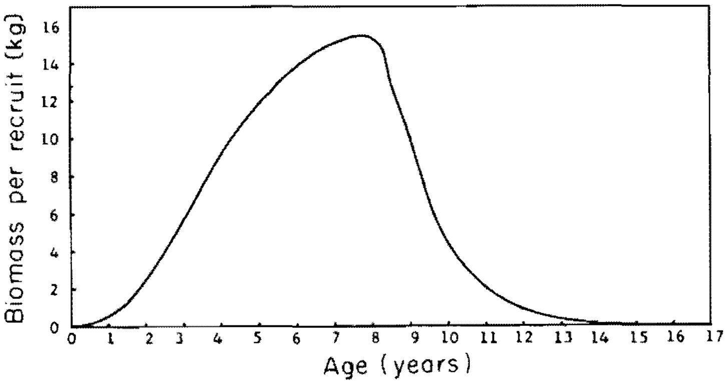

FIGURE 12. Age-dependent biomass per recruit of unexploited southern bluefin (from Hayashi *et al.*, 1972).

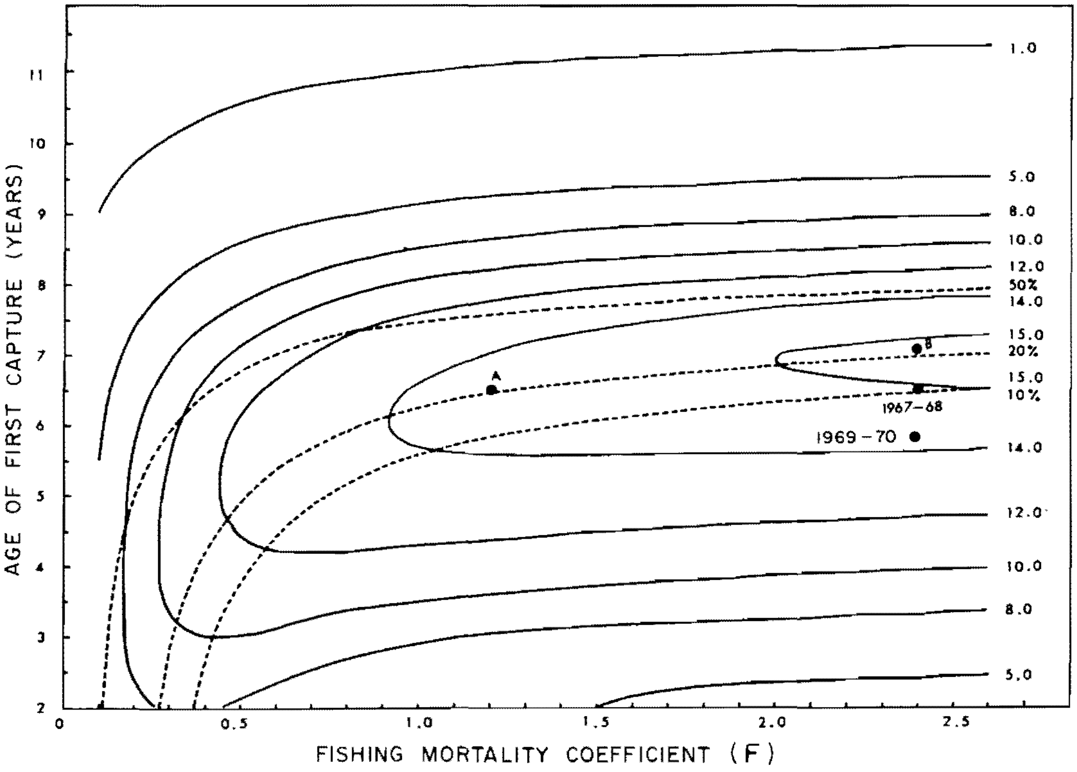

FIGURE 13. Yield per recruit in kilograms (solid curves) and relative stock fecundity in percent (broken curves) isopleths for southern bluefin (from Anonymous, 1972b, based on data of Hayashi *et al.*, 1972). The dots labeled A and B are explained in Section 6.

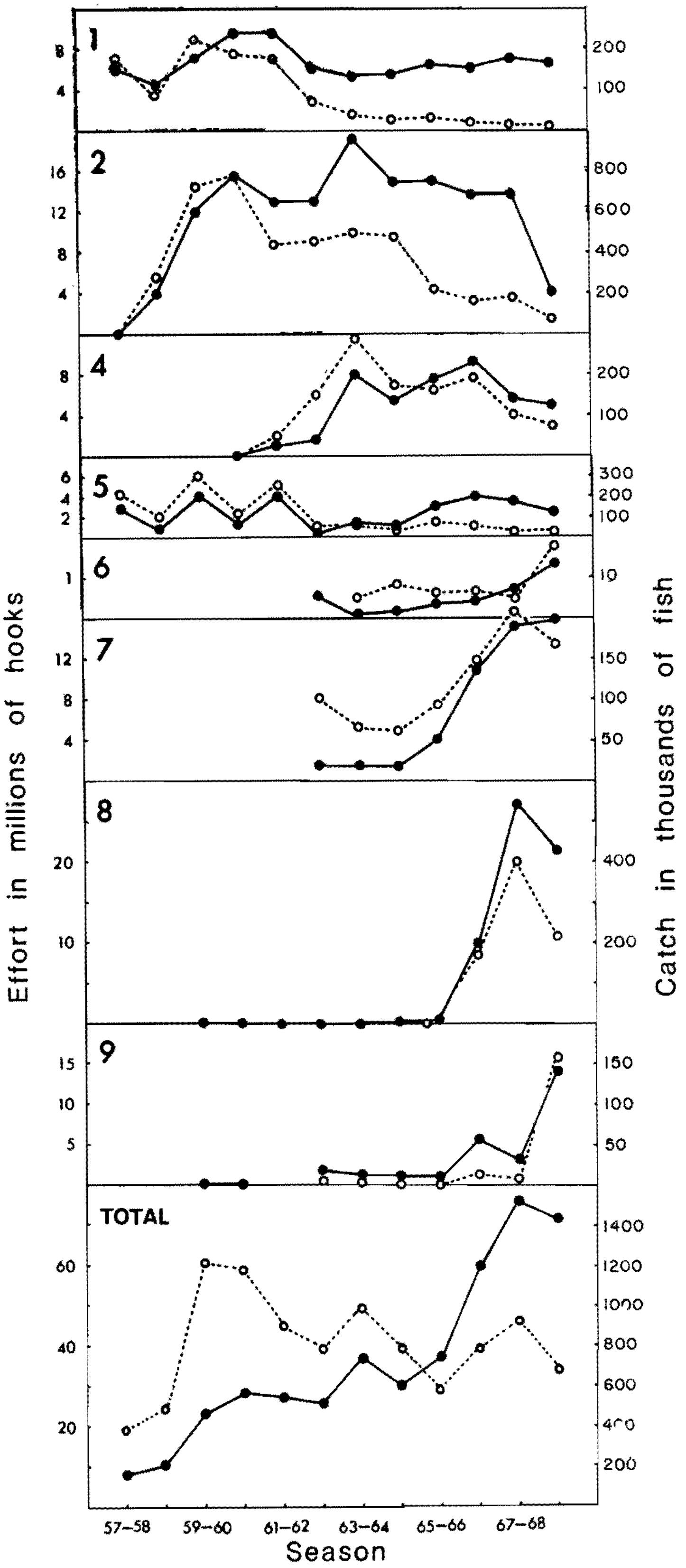

FIGURE 17. Catches in numbers of southern bluefin (open circles) and effort in numbers of hooks (dots) used by the Japanese longline fishery in eight fishing areas (shown in Figure 1) from 1957-58 to 1968-69 (from Shingu and Hisada, 1971).

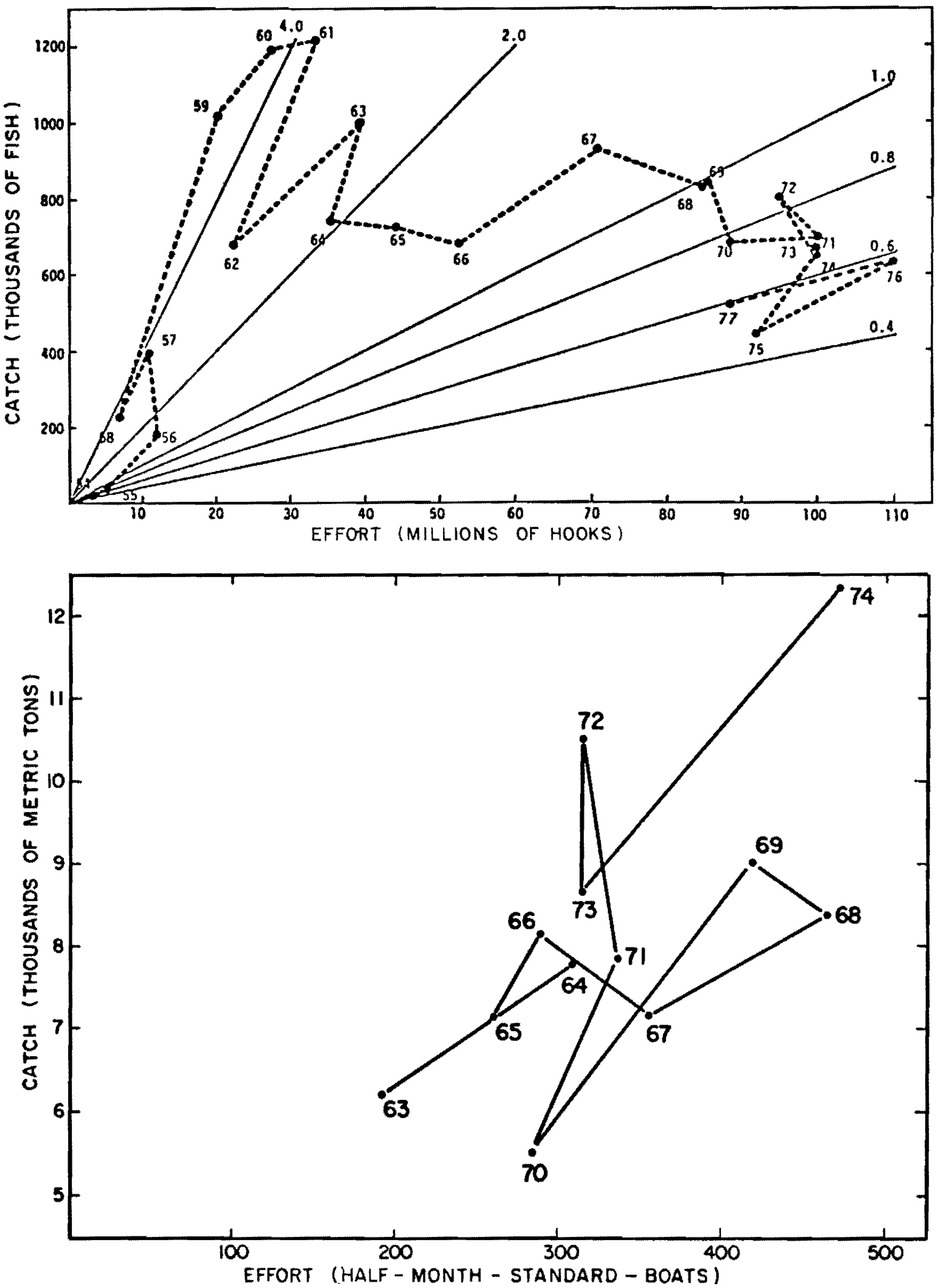

FIGURE 18. Relationships between catches of southern bluefin and effort by the Japanese longline fishery (upper panel) (from Shingu and Hisada, 1979) and by the surface fisheries in New South Wales and South Australia (lower panel) (from data in Table 9). The fine lines in the upper panel show hook rates.

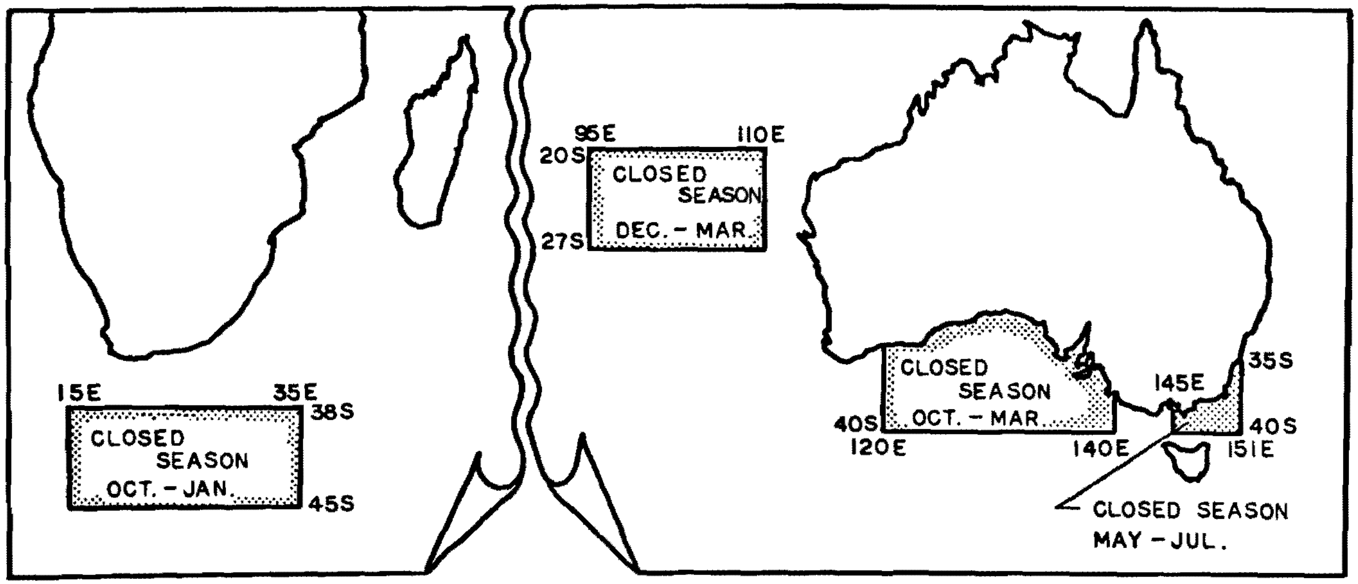

FIGURE 19. Areas and seasons involved in Japan's voluntary regulatory program for southern bluefin (from Suda, 1973a).

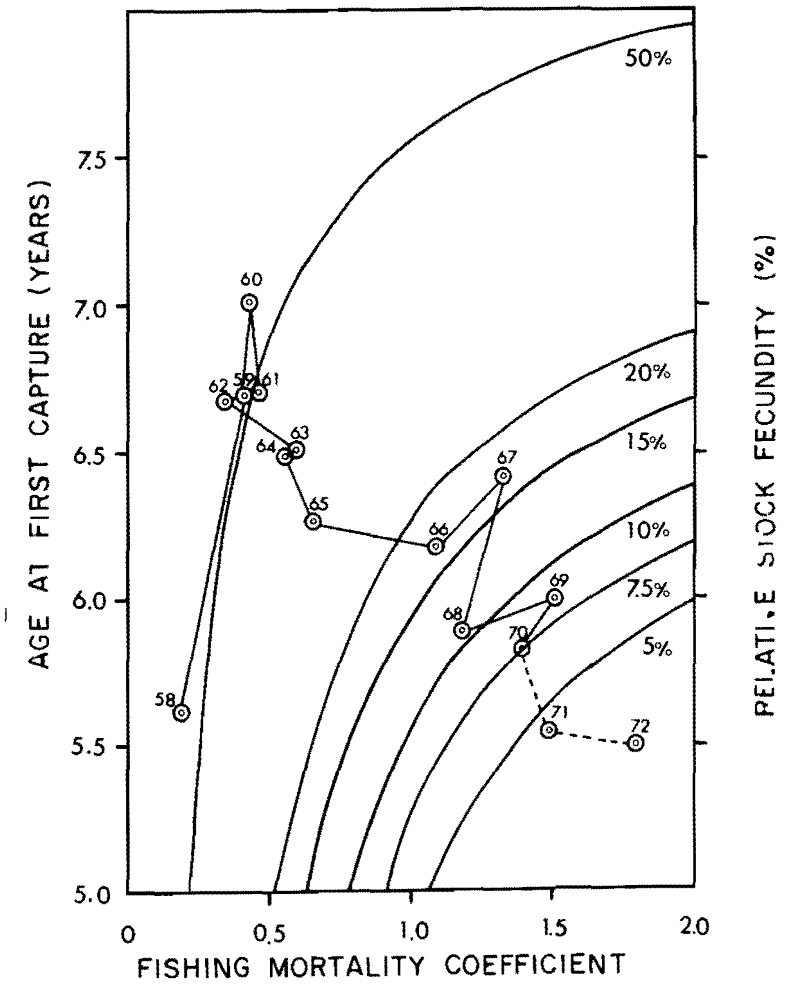

FIGURE 20. Relative stock fecundity, age at first capture, and fishing mortality coefficient of southern bluefin from 1958 to 1972 (from Hayashi, 1974). The estimates for 1971 and 1972 are provisional.

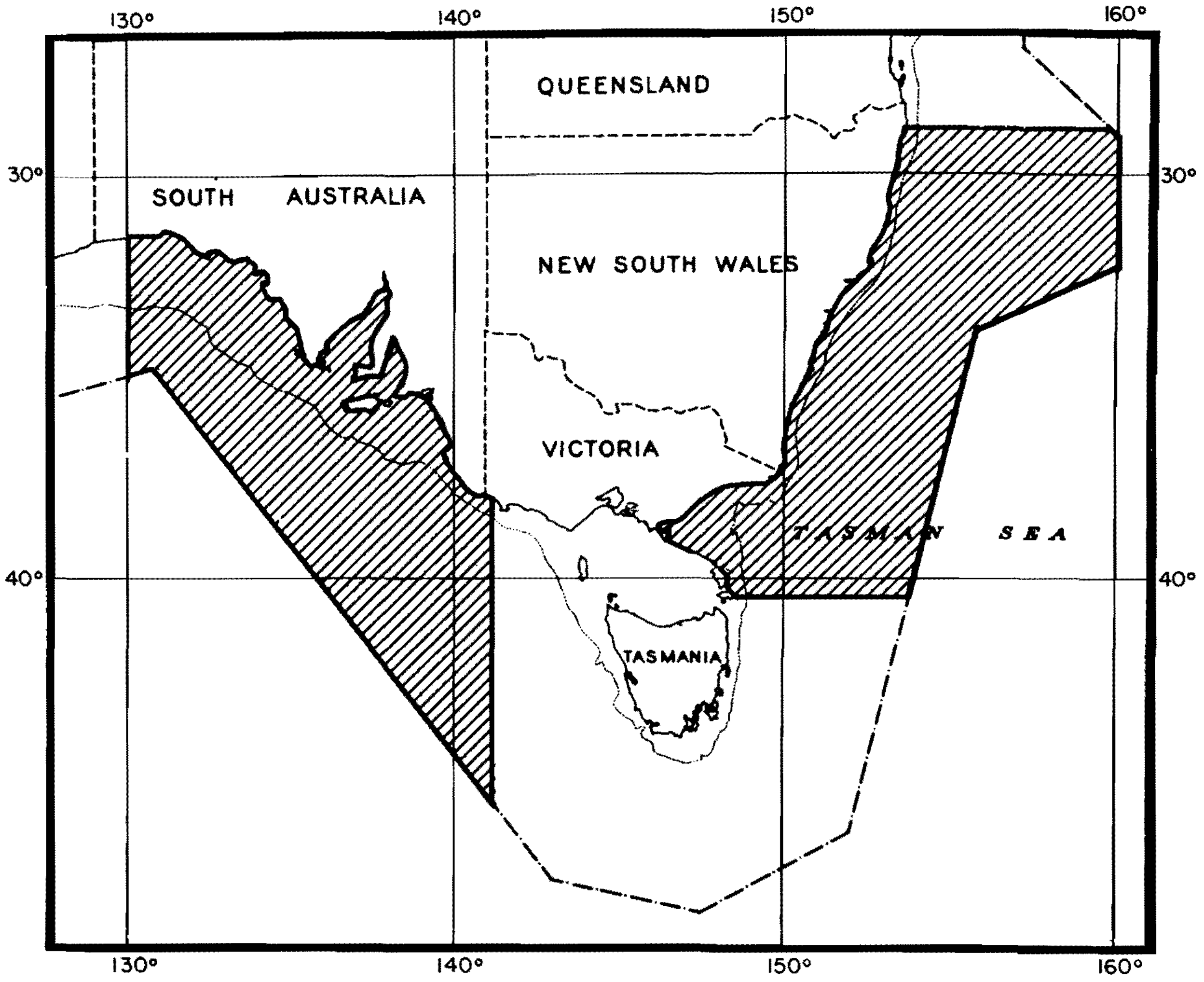

FIGURE 21. Areas along the coast of Australia in which purse-seine effort has been limited to four boats (from Anonymous, 1975e).

TABLE 1. Principal fishing seasons and age groups of southern bluefin caught in nine fishing areas (Figure 1) (after Shingu, 1970 and 1978; Shingu and Hisada, 1971; Suda, 1971; and Murphy, 1979). Shingu (1970) states that spawned-out adults immigrate into Areas 4, 5, and 6 in the southern winter. It is not known which age groups are involved.

Fishing areas	Locality	Age groups in catch	Principal months of fishing	Characteristics of catch
1. Oka fishing ground	5°-20°S 90°-130°E	6-13	Aug.-Mar.	spawning adults
2. Oki fishing ground	20°-35°S 80°-120°E	6-10	Aug.-Apr.	spawning adults
3. South Australia	north of 40°S 120°-140°E	2-5	Dec.-May	juveniles
4. New South Wales-Tasman Sea	25°-40°S 140°-170°E	2-7	Apr.-Dec.[1] Sep.-Jan.[2]	juveniles and adults
5. North New Zealand	25°-40°S 170°E-170°W	4-10	Apr.-Sep.	juveniles and adults
6. South New Zealand	40°-50°S 170°E-170°W	4-10	Mar.-Nov.	juveniles and adults
7. Tasman Sea-West Wind Drift	south of 40°S 120°-170°E	4-13	Apr.-May Nov.-Jan.	juveniles and feeding adults
8. Indian Ocean-West Wind Drift	south of 35°S 50°-120°E	4-13	all year	juveniles and feeding adults
9. South Africa	off Cape of Good Hope 0°-50°E	3-8	all year	juveniles and feeding adults

[1] Shingu and Hisada, 1971

[2] Murphy, 1979

TABLE 2. Parameters of the von Bertalanffy growth equation for southern bluefin estimated by various investigators and lengths at the first through tenth birthday anniversaries calculated from these.

Source	Method	von Bertalanffy growth parameters			Sample size	Age									
		L_{oo}	K	t_0		1	2	3	4	5	6	7	8	9	10
Shingu (1970) (data from Robins, 1963)	length frequencies	222.5	0.140	0.011	--	28.8	54.1	76.1	95.2	111.8	126.3	138.9	149.8	159.3	167.5
Shingu (1970)	tagging	187.4	0.149	0.021	--	25.4	47.9	67.2	83.8	98.2	110.6	121.2	130.3	138.2	145.0
Yukinawa (1970)	scales	219.7	0.135	0.040	1025	26.7	51.1	72.4	91.0	107.2	121.4	133.8	144.7	154.2	162.4
Hynd and Lucas (1974)	length frequencies	220.0	0.150	--	--	30.6	57.0	79.7	99.3	116.1	130.6	143.0	153.7	163.0	170.9
Lucas (1974)	tagging	171.5	0.187	0	<105	29.3	53.5	73.6	90.3	104.2	115.7	125.2	133.1	139.6	145.1
Murphy (1977)	tagging	180.8	0.146	-0.011	2578	24.8	46.0	64.3	80.2	93.8	105.7	115.9	124.7	132.3	138.9
Hearn (1979)	tagging	178.6	0.117	-0.010	629	29.2	53.4	73.7	90.7	104.9	116.8	126.8	135.2	142.3	148.1
Murphy and Sutherland (1980)	tagging	211.6	0.122	-0.410	844	33.4	53.9	72.0	88.0	102.2	114.8	125.9	135.8	144.5	152.2

TABLE 3. Mean age and weight of the catch (in kilograms) and mean age at first capture of southern bluefin in the Japanese longline fishery for the 1957-58 to 1976-77 seasons (after Shingu and Hisada, 1971; Hayashi *et al.*, 1972; Suda, 1973a and 1974; Hisada *et al.*, 1978). The values in parentheses are from Suda (1973a and 1974).

Season	Mean age of catch	Mean age at first capture	Mean weight of catch
1957-58	6.75	5.82	49.73
1958-59	7.20	6.63	55.06
1959-60	7.22	6.71	55.10
1960-61	7.60	7.02	59.82
1961-62	7.35	6.69	56.76
1962-63	7.31	6.67	56.37
1963-64	6.98	6.47	52.26
1964-65	7.02	6.49	52.71
1965-66	6.86	6.28	50.91
1966-67	6.80	6.17	50.19
1967-68	7.37	6.43	57.23
1968-69	7.10 (6.88)	6.07 (5.88)	51.44
1969-70	6.98	6.02	52.60
1970-71	6.99	6.22	52.90
1971-72	6.49	5.54	46.98
1972-73		5.70	
1973-74		5.60	
1974-75		5.90	
1975-76		6.20	
1976-77		5.80	

TABLE 4. Length-weight relationships of southern bluefin based on the equation $W = aL^b$, where W = weight in kilograms and L = length in centimeters.

Area	a	b	Source
Australia	3.13087×10^{-5}	2.9058	Robins, 1963
South Africa (males)	6.39400×10^{-5}	2.9200	de Jager, 1963
South Africa (females)	4.83100×10^{-5}	2.9800	de Jager, 1963
Southeastern Indian Ocean	1.01625×10^{-5}	3.1150	Shingu, 1970
Southwestern Pacific Ocean	0.94624×10^{-5}	3.1200	Shingu, 1970
"Fat" fish from Tasman Sea, West Wind Drift, and Indian Ocean southwest of Australia	0.05392×10^{-5}	3.7232	Warashina and Hisada, 1970
"Lean" fish from Oka and Oki fishing grounds	0.29420×10^{-5}	3.3438	Warashina and Hisada, 1970
Australia, longline catch	2.65000×10^{-5}	2.9400	Hynd and Lucas, 1974
West coast of New Zealand	110.70000×10^{-5}	2.1096	Webb, 1974

TABLE 5. Estimates of mean recruitment (in millions of fish) to the southern bluefin surface and longline fisheries averaged over various time periods.

Fishery	Calculated average recruits per year	Years	Basis of calculation	Source
surface	3.70	1972-1974	catch equation	Anonymous, 1974c
surface	4.09	1963-1968	yield (weight)	Hynd and Lucas, 1974
surface	3.30, M = 0.15 3.70, M = 0.20 4.10, M = 0.25	1962-1974	catch (numbers)	Lucas, 1974
surface	5.0-6.0	1955-1968 cohorts	cohort analysis	Murphy and Sutherland, 1980
longline	1.51	1958-1970	catch (numbers)	Hayashi, 1974
longline	1.78	1958-1970	yield (weight)	Hayashi, 1974
longline	1.91	1963-1968	catch (numbers)	Hynd and Lucas, 1974
longline	1.70	--	catch (numbers)	Lucas, 1974
longline	1.30	"recent years"	catch (numbers)	Anonymous, 1975c
longline	1.50	"recent years"	yield (weight)	Anonymous, 1975c
longline	1.20	1952-1961	cohort analysis	Anonymous, 1975c

TABLE 6. Southern bluefin equilibrium yield allocations (in thousands of metric tons) for several hypotheses about the relative magnitude of the Australian surface fishery and the Japanese longline fishery with M = 0.2 (from Anonymous, 1974b, after Lucas, 1974).

Longline fishing mortality coefficient	Surface fishing mortality coefficient	Surface[1] yield	Longline[2] yield	Total yield
0.50	0.00	0	65	65
	0.11	9	50	59
	0.25	18	35	53
0.11	0.00	0	58	58
	0.06	9	50	59
	0.13	18	42	60

1. Recent mean annual catch is 9,000 metric tons.
2. Recent mean annual catch is 50,000 metric tons.

TABLE 7. Yield per recruit of southern bluefin (in kilograms) for a constant M of 0.2 with ages at first capture of 2 and 3 years and various fishing mortality coefficients (from Murphy, 1977).

F	Age at first capture	
	2	3
0.01	1.2	1.2
0.05	4.5	4.5
0.10	6.4	6.7
0.20	7.2	8.1
0.30	6.9	8.2
0.40	6.3	8.0
0.50	5.8	7.6
0.60	5.3	7.3
0.70	4.9	7.0
0.80	4.6	6.8
0.90	4.4	6.6
1.00	4.1	6.4
2.00	3.0	5.4

TABLE 8. Total area (in number of 5-degree areas along the equator) of the Japanese longline fishing grounds for southern bluefin from 1957-58 to 1968-69 (from Shingu and Hisada, 1971).

Season	Area
1957-58	30.3
1958-59	47.3
1959-60	66.7
1960-61	62.6
1961-62	63.2
1962-63	73.7
1963-64	101.5
1964-65	109.6
1965-66	142.7
1966-67	213.8
1967-68	241.6
1968-69	283.2

TABLE 9. Annual catches of southern bluefin in the New South Wales (upper panel) and South Australia (lower panel) surface fisheries by boats with significant catches (in metric tons) (after Anonymous, 1975c, and Murphy, 1979).

Year	Number of standard boats (SB)	Number of half months standard boats fished	Weight of catch of these boats	Catch per SB per half month	Annual catch	Equivalent number of SB half months	Estimated number of fish caught	Number of fish per SB per half month
1962	19	73	1,216	16.7	1,383	83	108,000	1,300
1963	12	71	2,447	34.5	2,612	76	199,000	2,620
1964	26	149	1,737	11.6	2,275	195	277,000	1,420
1965	26	108	2,088	19.3	2,356	122	187,000	1,530
1966	21	103	1,979	19.2	2,144	112	168,000	1,500
1967	30	166	3,536	21.3	3,729	175	388,000	2,200
1968	41	289	4,541	15.7	5,438	346	676,000	1,950
1969	37	285	5,388	18.9	5,754	304	666,000	2,190
1970	29	207	3,041	14.7	3,614	246	472,000	1,920
1971	28	195	2,982	15.3	5,036	329	446,000	1,360
1972	32	177	3,455	19.5	6,138	314	376,000	1,200
1973	23	93	1,541	16.6	1,812	109	76,000	700
1974	30	175	3,036	17.3	5,339	308	336,000	1,090
1975					2,465		240,000	
1976					308		32,144	
1977					4,314		234,259	
1978					4,851			

TABLE 9. (continued)

Year	Number of standard boats (SB)	Number of half months standard boats fished	Weight of catch of these boats	Catch per SB per half month	Annual catch	Equivalent number of SB half months	Estimated number of fish caught	Number of fish per SB per half month
1963	21	122	3,301	27.1	3,591	133	233,000	1,750
1964	20	160	5,510	34.4	5,510	160	394,000	2,460
1965	23	152	4,703	31.0	4,770	154	290,000	1,880
1966	33	185	5,975	32.3	5,995	186	425,000	2,290
1967	28	190	3,386	17.8	3,428	192	244,000	1,270
1968	25	180	2,939	16.3	2,946	180	257,000	1,430
1969	21	133	3,221	24.2	3,257	134	500,000	3,730
1970	12	77	1,820	23.6	1,893	80	321,000	4,010
1971	26	141	2,793	19.8	2,819	142	327,000	2,300
1972	20	138	4,236	30.7	4,377	143	404,000	2,830
1973	32	221	6,540	29.6	6,839	231	501,000	2,170
1974	39	295	6,792	23.1	6,989	304	750,000	2,470
1975					4,842		599,000	
1976					6,938		865,500	
1977					8,649		1,159,691	
1978					4,934		742,394	

TABLE 10. Catches of southern bluefin from the Western Australia surface fishery (from Murphy, 1979).

Year	Catch	
	Metric tons	Numbers (in thousands)
1969	299	69
1970	708	189
1971	600	121
1972	758	129
1973	310	64
1974	321	65
1975	743	129
1976	289	56
1977	943	208
1978	1999	375*

* estimate

TABLE 11. Catches of southern bluefin by the Australian and Japanese fisheries in thousands of fish and in metric tons (from Murphy and Sutherland, 1980).

	Australia		Japan		Total	
Year	Number	Weight	Number	Weight	Number	Weight
1949	25	320			25	320
1950	10	122			10	122
1951	2	25			2	25
1952	18	227	7	556	25	783
1953	34	435	49	3,809	83	4,244
1954	48	605	27	2,183	75	2,788
1955	34	435	36	2,915	70	3,350
1956	66	841	186	14,948	252	15,789
1957	77	982	400	21,878	477	22,860
1958	159	2,024	225	12,417	384	14,441
1959	158	2,008	1,032	63,896	1,190	65,904
1960	242	3,072	1,188	75,672	1,430	78,744
1961	268	3,402	1,209	77,491	1,477	80,893
1962	404	5,136	675	40,852	1,079	45,988
1963	432	6,200	1,009	59,200	1,441	65,400
1964	671	7,782	744	42,718	1,415	50,500
1965	478	7,123	721	40,595	1,199	47,718
1966	593	8,137	683	39,607	1,276	47,744
1967	633	7,154	931	59,086	1,564	66,240
1968	934	8,381	828	49,482	1,762	57,863
1969	1,235	9,758	844	49,644	2,079	59,402
1970	987	6,212	699	40,622	1,686	46,834
1971	895	8,451	697	38,120	1,592	46,571
1972	914	11,268	806	39,604	1,720	50,872
1973	645	8,957	651	31,205	1,296	40,162
1974	1,117	13,206	672	33,924	1,789	47,130
1975	968	8,050	441	24,118	1,409	32,168
1976	954	7,535	634	33,714	1,588	41,249
1977	1,616	13,906	536	29,595	2,152	43,501

TABLE 12. Number of Japanese longline vessels that fished for southern bluefin from 1966 to 1970 in major fishing areas (from Hayashi et al., 1972). The yield per operation in the spawning area is included.

	Tasman and New Zealand area					Southern Indian and Atlantic Oceans				
	Number of boats					Number of boats				
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970
January			80	130	100				30	50
February	5	15	100	8	90					45
March			8	35	100					75
April			15	50						
May			9	60	100				20	55
June		80	10		80				5	30
July		4	12	65	65		1			50
August		14	250	30					60	30
September		11	14	20	40				30	10
October		10	13	10				4	35	
November		3	4	30	100			3	46	20
December			100	60	100				25	10

	Spawning ground									
	Number of boats					Yield per operation in metric tons				
	1966	1967	1968	1969	1970	1966	1967	1968	1969	1970
January		11	200	7	5		1.5	1.5	--	0.5
February		18	15	6			2.0	--	--	
March	35	22	20	20	10	3.0	2.0	1.5	--	0.8
April	--	18	10	5		2.0	1.3	--	--	
May		25	10	10	5		--	--	1.0	0.8
June			5		20			1.3		0.5
July			11	60	25			--	1.0	0.7
August		2	250	80	100		7.5	--	1.5	0.9
September		2	--	100	100		1.5	1.5	1.8	0.7
October	20		16	90		8.0		--	1.5	
November	100	250	--	60		2.5	3.5	1.7	1.5	
December	120			10		2.0			--	

SYNOPSIS OF BIOLOGICAL DATA ON THE BIGEYE TUNA, *THUNNUS OBESUS* (LOWE, 1839), IN THE PACIFIC OCEAN

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La Jolla, California
1980

CONTENTS

1 IDENTITY

The scientific name for the bigeye tuna is Thunnus obesus.

2 DISTRIBUTION

2.1 Total area

The bigeye inhabits the warm waters of the Indian, Pacific and Atlantic oceans. Bigeye is found across the entire east-west extent of the Pacific between northern Japan and the north island of New Zealand in the western Pacific, and from about 40°N to 30°S in the eastern Pacific (Figure 1). Bigeye has not been reported from the areas along the coast of Mexico and Central America between about 10°N and 20°N. Isolated specimens have been reported from as far north as 47°10'N on the coast of North America (Radovich, 1961; Meehan, 1965). Distribution is discussed in more detail in Sections 5.21 and 5.31.

2.2 Differential distribution

2.21 Spawn, larvae and juveniles

Nishikawa, Kikawa, Honma and Ueyanagi (1978) studied the distribution of larval tunas based on plankton net tows made during 1956-1975. Figure 2 is adapted from that paper. These collections indicate that bigeye larvae are more numerous in the western and eastern Pacific and relatively scarce in the central Pacific. In the western Pacific larvae are relatively abundant between 30°N and 20°S. In the eastern Pacific the area of relative abundance is between the equator and 20°N. Ueyanagi (1969b) stated that no tuna larvae, bigeye included, were found adjacent to Central America, which seems to be in conflict with the distribution shown in Figure 2. However, in Figure 2 the distribution is plotted by 5-degree areas of latitude and longitude, and the presence of larvae in a 5-degree area does not necessarily imply the larvae are present in all parts of the 5-degree area.

There is little information on the geographical distribution of juveniles, but it is assumed that their distribution is similar to that of the larvae.

2.22 Adults

The differential distribution of adult bigeye is discussed in Sections 2.1, 5.21 and 5.31.

2.3 Determinants of distributional changes

Water temperature, thermocline depth and season appear to be determinants of distributional change. Bigeye have been reported to occur in water as cold as 13° and as warm as 29°C (Alverson and Peterson, 1963). Suda, Kume and Shiohana (1969) indicated that the optimal temperature range for bigeye is 17° to 22°C, which coincides with the temperature range of the permanent thermocline. In the eastern Pacific, off Peru and Chile, there appears to be a seasonal migration of bigeye to the south during the southern summer (Sandoval T., 1971). In 1963 sea-surface temperatures 2° to 3°C higher than normal in the eastern Pacific along the equator coincided with an equatorward shift in the distribution of bigeye (Kume and Schaefer, 1966).

In tropical waters in the western and central Pacific major concentrations of bigeye occur not in the surface layer, but in or just below the permanent thermocline. There, concentrations of bigeye do not coincide with the occurrence of areas of high primary productivity which are found largely in the surface layer. In the eastern Pacific the thermocline rises toward the surface and bigeye, especially larger ones, are found nearer to the surface (Suda, Kume and Shiohana, 1969). Nakamura (1969) suggested that bigeye and other species of tunas stay with particular water masses or current systems during each phase of life. That is, they may be in one current system as immature fish and in another as spawners. For example there are two major longline fishing grounds for bigeye in the Pacific; the first is centered around 30°N and the other is in the equatorial area (see Section 5.2). The fish in the northern area are sexually inactive, young adults and spent spawners, while the bigeye in the equatorial area are spawners of various sizes.

2.4 Hybridization

No hybridization of bigeye with other species of tuna has been reported.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

The sexes of bigeye are separate and do not change. There are no external differences between male and female.

3.12 Maturity

Kume (1962) encountered running ripe female bigeye of 93, 110 and 134 cm and running ripe males of 110, 139 and 160 cm fork length in the Indian Ocean. Yasutake, Nishi and Mori (1973) encountered running ripe females of 119, 148 and 156 cm and running ripe males of 134-148 cm fork length in the central Pacific. Kume and Joseph (1966) reported running ripe females ranging from 115 to 167 cm in the eastern Pacific. Kikawa (1962) reported finding few sexually mature female bigeye less than 100 cm in length. Kume and Joseph (1966) estimated that bigeye in the eastern Pacifc are 100-130 cm in length at the end of their third year; thus bigeye likely first become mature during their third year of life.

3.13 Mating

Bigeye are palagic spawners and mating is presumably promiscuous.

3.14 Fertilization

Fertilization is external.

3.15 Gonads

The following description is adapted from Yuen (1955). The gonads are paired elongated organs lying along the dorsal wall of the body cavity. The ovaries are circular in cross section and are separated from each other except posteriorly where the oviducts join. In immature fish the ovaries are small and firm and about 1 cm in diameter. As the fish approach maturity the ovaries increase in both length and diameter. An ovary of a large ripe fish may be as much as 10 cm in diameter. A pair of ovaries may contain 1 billion undeveloped eggs.

The gonad index, widely used as an index of maturity, is the relation between the weight of the ovary and the weight or length of the fish. Kikawa (1962) defined gonad index as follows; $G.I. = W_o/L^3 \times 10^4$ where W_o is the weight of the ovaries in grams and L is the length of the fish in centimeters (L^3 being approximately proportional to the weight of the fish). He found that mature females had a wide range of gonad indices, but with a blunt mode between 3.5 and 5.5. Immature females had gonad indices below 4, with the mode centered between 0.6 and 1.5. He concluded that the best separation point between mature and immature gonads was 3.1. Yuen (1955) found evidence of at least two spawnings per female per year. He estimated that the number of eggs per spawning ranges from 2.9 million to 6.3 million. Larger fish tend to have more eggs per spawning, but there is wide variation for fish of the same size.

3.16 Spawning

Kikawa (1962) found that areas of high gonad index lie between 10°N and 10°S extending from 120°E to 110°W in the Pacific Ocean. Some spawning appears to take place all year, with the main spawning extending from April through September in the area between the equator and 12°N. In contrast, in the eastern Pacific he found the peak of the spawning to be January through

March in the area between the equator and 10°S. He concluded that the portion of mature fish increases from west to east in the tropical Pacific.

Kume and Joseph (1966) found two zones of mature fish in the eastern Pacific, one between the equator and 10°N extending eastward to 95°W and the other between about 5°S and 10°S extending east to about 110°W. In the area between the equator and 5°S the proportion of mature fish was considerably less than in the adjacent areas to the north and south. In the area between 10°N and 15°S from 120°W to 130°W mature bigeye were found to occur throughout the year, with the maximum sexual maturity in the first, second and third quarters. In the southern zone the maximum sexual maturity occurs during the first and second quarters.

Kume (1967) found that bigeye are sexually inactive when sea-surface temperatures drop below 23-24°C.

3.17 Spawn

Kume (1962) measured eggs from running ripe females and found that they range from 1.03 to 1.08 mm in diameter. The eggs contain an oil globule which ranges from 0.23 to 0.24 mm in diameter.

3.2 Pre-adult phase

3.21 Embryonic phase

Kume (1962) obtained running ripe male and female bigeye during a research cruise in the Indian Ocean and fertilized the eggs aboard ship. He recorded the following sequence of embryonic development. Thirty minutes after fertilization the blastodermal cap and pervitelline space had formed. First cleavage occurred 40 minutes after fertilization, and at intervals of 15 minutes the second, third, fourth and fifth cleavages occurred. The morula stage occurred 2 1/2 hours after fertilization. The embryonic shield formed 6 hours after fertilization, and the embryo was well differentiated. Fourteen hours after fertilization the optical vesicles were well defined, somites were visible and the embryo became less transparent. By 19 hours after fertilization the pupils of the eyes had developed and the tail had separated from the yolk sac. At that time the embryo was yellowish brown and moved inside the egg. Hatching began 21 hours after fertilization, and was completed in 30 minutes. One of the newly hatched larvae was 1.5 mm in total length.

3.22 Larval phase

Yasutake, Nishi and Mori (1973) described larval development from hatching to 86 hours after hatching. The newly hatched larvae were 2.5 mm in total length, but obtained lengths of 3.0 and 3.1 mm 24 and 48 hours after hatching, respectively. By 86 hours after hatching the early post-larval stage was attained. The development of the larvae is illustrated in Figure 3.

The geographical distribution of bigeye larvae is discussed in Section 2.21.

3.23 Adolescent phase

In this synopsis adolescent phase is taken to mean the stage of life between the juvenile stage (up to about 20 cm in total length) and the immature adult stage (up to about 55 cm in length). Adolescent bigeye do not differ significantly in appearance from mature adults except for their size. The pectoral fins, however, are proportionally longer in the adolescent phase than in the adult phase. During this phase bigeye enter the commercial catch for the first time. Fish as small as 32 cm are caught in the pole-and-line fishery off Japan (Honma, Warashina and Suzuki, 1973). Bigeye of 35-45 cm have been caught in the eastern Pacific purse-seine fishery. Adolescent bigeye are not caught by longline gear. This may indicate that, at this phase of life, bigeye do not range into the mixed layer; however, gear selectivity could be the reason for the lack of catch of adolescents by longlines.

3.3 Adult phase

3.31 Longevity

Kume and Joseph (1966) studied modal progressions of bigeye in the eastern Pacific longline catch. They devised an age-length curve which indicated that bigeye of 150 cm total length, which are common in the catch, are in their fourth year of life. There are, however, fish of at least 180 cm in the catch, so it appears that bigeye can exceed 5 years of age. Sakamoto (1967) estimated that in 1960 0.4% of the bigeye in the longline catch from the central Pacific were 9 years of age or older.

3.32 Hardiness

As stated in Section 2.3, adult bigeye can tolerate a temperature range of at least 13^{o} to 29^{o}C. Tagging experiments by the Inter-American Tropical Tuna Commission indicate that bigeye, like other tunas, are sensitive to the stress which occurs when they are confined in a purse seine.

3.33 Competitors

It is likely that bigeye compete for food with the other large tunas and billfishes that inhabit the same area. Juhl (1955) found no difference in food of yellowfin and bigeye caught by longline on a research cruise in the eastern Pacific. King and Ikehara (1956) examined the stomach contents of bigeye and yellowfin caught by longline in the central Pacific. Although they found some differences in the food items in the stomachs of the two species, they concluded that, when occupying the same general area, the two species have essentially the same feeding habits. Watanabe (1958) found some differences in the stomach contents of bigeye and yellowfin caught in the western Pacific. He concluded that the differences may have been due to the bigeye feeding at greater depth and more frequently at night than the yellowfin.

3.34 Predators

With the exception of man, large billfish and the toothed whales are probably the only creatures capable of preying on large bigeye. Small bigeye are preyed upon by dolphins, spearfish, swordfish, black marlin, sharks, larger tunas and man. It is probable that small bigeye are preyed upon by any animal which inhabits the same area and which is large enough and fast enough to catch them (Alverson and Peterson, 1963).

3.35 Parasites, diseases, injuries and abnormalities

Kishinouye (1923) lists two parasites found in bigeye caught off Japan; *Hexacotyle*, a trematode found among the gill-lamellae, and a species of Filariadae (a nematode) found in the red muscle. Silas (1967) and Silas and Unmercutty (1967) listed the following parasites of bigeye:

Trematodes; *Capsala nozawae*, *C. onchidiocotyle*, *Hexostoma acutum*.

Copepod; *Elytrophora brachyptera*.

Love and Moser (1977) compiled the following list of parasites of bigeye;

Tremotodes; *Hexostoma grossum*, *H. acutum*, *H. sibi*, *Neohexostoma robustum*, *Capsala gotoi*, *C. nozawae*, *Caballerocotyla biparasitica*, *C. klawei*, *C. verrucosa*, *C. pseudomagronum*, *Sibitrema poonui*, *Areotestis sibi*, *Cardicola ahi*, *Didymozoon longicolle*, *Dermatodidymocyst viviparoides*, *D. vivipara*, *Didymocystis bifurcata*, *D. nasalis*, *D. orbitalis*, *D. philobranchia*, *D. philobranchiarca*, *D. poonui*, *Didymocystoides bifasciatus*, *D. pectoralis*, *Univitellodidymocystis neothunni*, *Koellikeria pylorica*, *K. retrorbitalis*, *K. submaxillaris*, *Koellikerioiodes internogastricus*, *K. apicalis*, *K. externogastricus*, *K. intestinalis*, *Neonematobothrioides poonui*, *Opisthorchinematobothrium parathunni*, *Obitonematobothrium perioculare*.

Cestode; *Sphyriocephalus dollfusi*.

Copepods; *Brachiella thynni*, *Elytrophora brachyptera*, *E. indica*, *Gloiopotes buttoni*, *Caligus coryphaenae*, *C. productus*, *Pseudocycnus* appendiculatus.

Cressey and Cressey (1980) examined 40 bigeye and found the following parasitic copepods (all included in those listed above by Love and Moser (1977). The numbers in parentheses indicate the numbers of bigeye infested by each copepod.

Elytrophora brachyptera (20)
Caligus coryphaenae (18)
Brachiella thynni (10)
Elytrophora indica (9)
Pseudocycnus appendiculatus (3)

An abnormality or disease which occurs in bigeye as well as other tunas is "jelly-meat." This occurs in both the white and the red muscle. Arai and Matsumoto (1953) identified a sporozoan, Hexacapsula neothunni, from the jelly-meat portion of yellowfin tuna, but it is not known if this organism is the cause of the condition.

3.4 Nutrition and growth

3.41 Feeding

Bigeye feed at the surface and down to the bottom of the mixed layer, which may be 100-150 m deep (Suda, Kume and Shiohana, 1969). Bigeye feed both during the day and night. They are caught at the surface during the day by pole and line and by purse seine, and they are caught during both the day and the night by longline. Kume and Morita (1966) state that about 15% of the bigeye caught from the northwestern Pacific are taken by nighttime longlining.

3.42 Food

King and Ikehara (1956) examined the stomach contents of longline-caught bigeye from the central Pacific. They found that the food of bigeye, by volume, consisted of fish (62%), squid (33%), other molluscs (3%) and crustaceans (2%). Food items of major importance were pomfret (Collybus drachme), snake mackerel (Gempylus serpens) and squid of the families Ommastrephidae and Loliginidae. Alverson and Peterson (1963) list the following items in the diet of bigeye caught in the eastern Pacific by baitboats: fish 85% (by volume); crustaceans, 9%; squid, 5%; unidentified material, 1%. Four families of fish, Katsuwonidae (=Scombridae), Exocoetidae, Sciaenidae and Trichiuridae, were identified. Bathypelagic shrimp were the most numerous of the crustaceans, but isopods, portunid crabs and stomatopods were also found. Additional data on the food of bigeye are given by Watanabe (1958) and Blunt (1960).

3.43 Growth rate

As mentioned in Section 3.31, Kume and Joseph (1966) followed modal progressions of bigeye taken by longline in the eastern Pacific. Their data indicated that males and females grow at approximately the same rate up to 150 cm in length, but that males appear to grow faster at sizes greater than 150 cm. Therefore they did not use modes greater than 150 cm in their growth study. They estimated that, on the average, bigeye are 40 to 50 cm long at the end of their first year, 75 to 95 cm at the end of their second year and 100 to 130 cm at the end of their third year. They fitted the von Bertalanffy growth equation ($l_t = L_\infty(1-e^{-K(t-t_o)})$, where l_t is the length at age t, L_∞ is the asymptotic length, K is a constant and t_o is the apparent age at length zero, to the data. They derived the following values for the parameters in the equation: $L_\infty = 186.95$, $t_o = 2.11$, $K = 0.095$ (calculated on a quarter of a year basis).

The growth curve they derived is shown in Figure 4. Also shown are the growth curves derived by Shomura and Keala (1963) and by Yukinawa and Yabuta (1963). The curve of Shomura and Keala was calculated from length-frequency data from the Hawaiian longline fishery and that of Yukinawa and Yabuta was based on scale readings of fish taken from the entire Pacific Ocean. The parameters of the equation derived by Shomura and Keala are: $W_\infty = 518$, $K = 0.114$ and $t_o = 1.07$ for males, and $W_\infty = 364$, $K = 0.167$ and $t_o = 1.06$ for females. They used weight in pounds rather than length in centimeters and the parameters are calculated on a monthly basis. The parameters of the equation derived by Yukinawa and Yabuta, calculated on a 6-month basis are: $L_\infty = 215$, $K = 0.10412$ and $t_o = 0.0010995$.

3.44 Metabolism

The tunas, bigeye included, have the highest metabolic rate of any group of fish known. By means of vascular heat exchangers the tunas are able to maintain their body temperature at a higher level than that of the water they are swimming in. As muscle produces more power when warm, this allows the tunas to keep swimming constantly and attain extraordinary bursts of speed (Magnuson, 1978). Also the maintenance of body temperature at a higher level than that of the surrounding water would tend to facilitate the movement of tunas between the warmer water of the upper mixed layer and the colder water of the thermocline (Neill, Chang and Dizon, 1976). Carey, Teal, Kanwisher, Lawson and Beckett (1971) measured muscle temperature in 13 bigeye and found that, on the average, the muscle temperature was 7.9°C higher than the surface water temperature. In ability to regulate body temperature bigeye are intermediate between bluefin (greater thermoregulatory ability) and yellowfin (Graham, 1975).

3.5 Behavior

3.51 Migrations and local movements

Some data on tagged bigeye at liberty long periods of time are shown in Table 1.

Seasonal changes in the distribution of catches may be due to migrations of fish in or out of various areas. In recent years there has been a considerable catch of bigeye by purse seiners off the coast of Ecuador during November, December and January. The catches from this area during other months have been sporadic (Inter-American Tropical Tuna commission, unpublished data). Suda and Schaefer (1965a) noted the development of a concentration of bigeye in the fourth quarter and possibly first quarter of the year in the area to the north and east of the Galapagos Islands. The increasing catch of bigeye by baitboats in the area off the east coast of Japan during April, May and June and the decrease in catch thereafter may indicate a migration of bigeye into and away from these waters (Kume and Morita, 1967).

The catch of bigeye by nighttime longlines, which fish shallower than do daytime longlines, may indicate a migration toward the surface during darkness (Kume and Morita, 1966).

3.52 Schooling

Small bigeye school at the surface in the waters off the coast of Japan. Bigeye of all sizes school at the surface in the eastern Pacific Ocean, mainly between 10°N and 5°S from about 90°W to the coast of Central and South America. In the eastern Pacific bigeye occur mainly in two basic types of schools, those associated with a floating object of some sort such as a log, a piece of debris or a dead whale, and those that are not associated with a floating object or large animal (unassociated schools). Bigeye are less frequently found in schools associated with whales, whale sharks and, rarely, in schools associated with porpoise. In all of these types of schools bigeye are found alone (pure schools) or mixed with yellowfin, skipjack or both. In schools associated with floating objects several other species of fish may be present.

The size of bigeye schools, judged by the catch per successful set, varies greatly. In 1978 the catch per successful set ranged from less than 1 to 159 metric tons. During 1976-1978 the average catch per successful set was about 20 metric tons, but in about 50% of the sets the catch was between 1 and 10 metric tons (Inter-American Tropical Tuna Commission, unpublished data).

Apparently the larger bigeye that are caught by longlines in and below the mixed layer do not form dense schools.

3.53 Responses to stimuli

Bigeye respond to water temperatures, but fish of different sizes apparently have different temperature preferences. According to Suda, Kume and Shiohana (1969) large bigeye caught by longline prefer water temperatures in the range of 17° to 22°C. Hisada (1973) states that bigeye in the 80-120 cm range are dominant in the handline fishery of the Coral Sea at surface temperatures up to 26°C, but are replaced by yellowfin at higher temperatures. Kume (1967) stated that bigeye are sexually inactive when sea-surface temperatures drop below 23° to 24°C.

Bigeye apparently can tolerate dissolved oxygen concentrations down to 1.0 ml/l but avoid water with lower concentrations (Sund, Blackburn and Williams, 1980). Sharp (1978) estimated the minimum oxygen requirements for bigeye of different sizes as follows: 50 cm (fork length), 0.52 ml/l; 75 cm, 0.65 ml/l.

4 POPULATION

4.1 Structure

4.11 Sex ratio

Kume (1969a) found that for bigeye caught by longline in the Pacific north of 28°N between 140°E and 180° the sex ratio was almost equal for fish of all sizes, but in the area east of 180° males predominate among the fish smaller than 130 cm. In the equatorial Pacific, Kume (1969b) found a different situation. Males were more numerous than females over the entire size range of the longline catch, with the predominance of males becoming more pronounced with increasing size. Kume and Joseph (1966), working with data from the longline fishery east of 130°W, found that, over the range of lengths examined (about 82-184 cm), males were predominant in nearly all areas, and that the ratio of males to females increased with size up to the point at which males comprised 75% of the catch of fish over 170 cm.

4.12 Age composition

Sakamoto (1967) gives the following age composition for bigeye caught by the Japanese longline fishery in the equatorial Pacific Ocean in 1960:

Age	1	2	3	4	5	6	7	8	9 or greater
Percent	0.1	6.8	20.5	26.4	22.3	15.3	6.2	2.0	0.4

Kume (1967) estimated that during 1960-1962 the longline catch in the Pacific Ocean was made up mainly of fish of ages 2 through 7. Fish of ages 2 and 3 were distributed more or less evenly over the fishing area. The incidence of fish of ages 4, 5 and 6 increases progressively to the east, and age-7 fish are confined mostly to the area east of 140°W.

Kume and Morita (1967) found that the bigeye catch of the live-bait fishery off the east coast of Japan is composed of three size groups, which they believed correspond to fish of ages 1.5, 2 and 3.

According to the growth curve derived by Kume and Joseph (1966) (Section 3.43) the catch of the eastern Pacific surface fishery is largely composed of fish of ages 1 through 4 with those of ages 2 and 3 being the most important.

4.13 Size composition

The size composition of the bigeye catch varies somewhat among areas and types of gear; therefore, the size composition of some of the distinct fisheries will be discussed separately.

a) The pole and line fishery in the northwest Pacific (Kume and Morita, 1967)

There are three modal groups in the catch. The smallest group, composed of 50-55 cm fish, and the middle group, composed of 70-75 cm fish, are dominant in the catch. The largest modal group, composed of fish of about 100 cm, appears only sporadically.

b) The handline fishery in the Coral Sea (Hisada, 1973)

Most of the fish in the handline catch are between 80 and 100 cm, and there is a single mode. (The longline catch from the same area has two modal groups at about 100 and 130 cm.)

c) The longline fishery in the western, central and eastern Pacific (Kume and Joseph, 1966 and 1969; Kume, 1969b)

In the equatorial Pacific the size range of longline-caught bigeye is approximately 80 to 180 cm. Fish of less than 120 cm are distributed more or less evenly from west to east. The relative abundance of medium-sized fish (120-150 cm) and large fish (greater than 150 cm) increases from west to east.

The size composition in the eastern Pacific (east of 130°W) is illustrated in Figure 5, which shows the percentage length-frequency distributions for 1958-1966.

d) The eastern Pacific surface fishery (Anonymous, 1979a)

The annual length-frequency distributions of bigeye samples from purse-seine catches made in the eastern Pacific Ocean during 1975-1979 are shown in Figure 6. The size range is from less than 40 cm to about 170 cm, and in some years there appear to be four or five modal groups. In 1975 and 1976 most of the catch consisted of fish between 70 and 120 cm. In 1977, 1978 and 1979, however, the proportion of smaller fish in the catch was greater.

4.2 Abundance and density

4.21 and 4.23 Average abundance and average density

The term "abundance" is usually defined as the total number or weight of fish in a population, whereas "density" refers to the total number or weight of fish per unit area. It is difficult or impossible to obtain an accurate estimate of abundance or density in most commercial fisheries, including that for bigeye in the Pacific Ocean. However, catch per unit of effort, in many cases, can provide an index of relative apparent abundance. The index of apparent abundance or density in the longline fishery is hook rate (the number of fish caught per 100 or 1000 hooks fished). In the eastern Pacific average hook rate varied between 2.0 and 3.0 fish per 100 hooks during 1956-1963 and was 1.0 or less between 1965 and 1970 (Shingu, Tomlinson and Peterson, 1974). From 1949 through 1963 average quarterly hook rate generally was between 0.5 and 1.5 in the area between 4°N and 12°N and between 140°E and 160°E. During the same period further east between 180° and 160°W the average quarterly hook rate varied between 1.0 and 3.0 (Kume, 1969b).

4.22 and 4.24 Changes in abundance and changes in density

Kume and Joseph (1966) examined trends in hook rate in the eastern Pacific longline fishery for 1958-1963. They concluded that north of the equator there has been a downward trend in bigeye hook rate starting in 1961. South of the equator the downward trend started in 1960. They also examined changes in hook rate for fish of three size categories: small (less than 120 cm), medium (120 to 150 cm) and large (over 150 cm). North of the equator the quarterly hook rate for small fish remained fairly constant during 1961-1963, but the apparent abundance of medium and large fish showed a downward trend over the same period. South of the equator seasonal patterns in hook rate were apparent. The small fish showed a slight decrease in hook rate during the first and second quarters of the year and an increase during the third and fourth quarters. The medium group was usually more abundant in the first and fourth quarters of the year while the large fish showed the opposite trend. For the two larger size groups the data indicated a steady decline in apparent abundance from 1960 through 1963. The apparent abundance of the small size group remained stable over the same period.

Shingu, Tomlinson and Peterson (1974) examined trends in bigeye hook rate in the eastern Pacific Ocean for 1967-1970. They found the following seasonal pattern in fluctuation of hook rate; in the easternmost areas hook rates were higher during the last half of the year, while in the westernmost areas hook rates tended to be higher during the first half of the year. During 1967-1969 hook rate was fairly constant; however, in 1970 hook rate decreased slightly.

4.3 Natality and recruitment

According to Suda and Kume (1967), recruitment of bigeye to the Pacific longline fishery begins at age 2; less than 10% of the total recruitment is is complete at that age. By early age 3 recruitment is 29% complete and by early age 4 recruitment is 68% complete. By early age 5 recruitment is complete. In the eastern Pacific surface fishery fish as small as 40 cm are caught, and most of the fish in the catch are less than 120 cm (Figure 6). This would indicate that recruitment begins before age 1 and is complete by age 3 (see Section 3.43 for length-at-age data).

4.4 Mortality and morbidity

4.41 Mortality rates

Since the fecundity of bigeye is so great the survival rate of larval bigeye must be very low, but it may fluctuate greatly from time to time and place to place. The availability of the proper food organisms for the larvae when they first begin to feed may greatly influence larval survival.

Suda and Kume (1967), working with data from the Japanese longline fishery in the Pacific for 1957-1964, derived the following estimates of the total annual mortality coefficient (Z').

Years	Z'	Years	Z'
1957-58	0.627	1961-62	1.002
1958-59	0.709	1962-63	1.073
1959-60	0.726	1963-64	1.382
1960-61	0.622		

Their estimate of the annual natural mortality coefficient (M) is 0.361. This analysis was carried out using only data from fish older than age 5.

4.42 Factors causing or affecting mortality

The major factor affecting mortality of adult bigeye is probably the amount of fishing effort. Suda and Kume (1967) show that in the Japanese longline fishery the total mortality coefficient increases as the total number of hooks fished increases.

4.43 Factors affecting morbidity

The information which is available on this subject is summarized in Section 3.35.

4.44 Relation of morbidity to mortality rates

The effect of morbidity on the mortality rate of adult bigeye is probably small in comparison with the effect of fishing effort.

4.5 Dynamics of the population

It is not known whether the bigeye tuna of the Pacific constitute a single population or two or more subpopulations. There is some evidence of extensive migration, which indicates some homegeneity of the stock. In the north Pacific the concurrent appearance of dominant year classes throughout the area also indicates some homogeneity of population. However, there is a cline in size composition, the average size increasing from west to east, which indicates that intermingling of fish of different areas may be slow and incomplete (Kume, 1969a). The situation is similar in the equatorial and south Pacific. Increasing size of fish from west to east suggests a migration of older fish to the east. The simultaneous appearance of dominant year classes in the western equatorial Pacific and the southwestern Pacific indicates some internal association of the stock (Kume, 1969b).

Even though the stock structure of bigeye in the Pacific is largely unknown, it is possible to attempt to ascertain the effect that the fishery has had on the stock. Various investigators have attempted to do this, using data from the Japanese longline fishery in the eastern Pacific.

The longline fishery in the eastern Pacific (east of 130°W) started in the mid-1950's. Hook rate was stable through 1960, averaging 3.1 fish per 100 hooks fished. Hook rate declined in late 1961 and early 1962 to below 2.0 (Suda and Schaefer, 1965a). The decline in hook rate intensified in 1963, and a significant negative relationship between hook rate and number of hooks fished became apparent (Kume and Schaefer, 1966). Kume and Joseph (1966) looked at the hook rates of small, medium and large fish (Sections 4.22 and 4.24). During the early 1960's the hook rate of the small fish remained stable, while the hook rates of the medium and large fish declined. The small fish progressively became a larger proportion of the catch. The investigators concluded that the fishery has had a marked effect on the stock, but that it was not possible to ascertain whether the fishery had adversely affected the sustainable yield. In 1964 and 1965 hook rate continued to decline, but it rebounded slightly in 1966. The average weight of fish in the catch declined from 70 to 60 kg during 1958-1966. The hook rate for the small fish continued to remain stable, implying that recruitment had not been affected (Kume and Joseph, 1969). During 1967-1969 there was no large change in the hook rate.

The relationship between catch and fishing effort in the portion of the eastern Pacific (Areas 7-12 of Shingu, Tomlinson and Peterson, 1974) where most longline catches of bigeye occur is illustrated in Figure 7. In this figure catch, in thousands of fish, is plotted against millions of hooks fished during 1956-1970. In 1956-1963 the fishery was developing, and increases in effort resulted in increases in catch. Hook rate was generally between 2.0 and 3.0. In 1964 effort increased, but catch dropped. In 1969 there was a substantial increase in both effort and catch, but the hook rate was less than 1.0. It appears that catches such as those made in 1964 and 1969 are not sustainable. To obtain a better understanding of the effect of the fishery on the stock in the eastern Pacific it will be necessary to learn more about the relationship of the fish in the eastern Pacific to those further west.

4.6 The population in the community and the ecosystem

Bigeye tuna in the Pacific Ocean are part of the pelagic warm water community. Their feeding habits have been discussed in Sections 3.41 and 3.42, and their competitors and predators in Sections 3.33 and 3.34. The schooling association of bigeye with other species has been discussed in Section 3.52. The relationship of large bigeye to the permanent thermocline is discussed in Section 2.3. Bigeye have a tendency to gather around the boundary zone of current systems. In the transition zone between the Aleutian and North Pacific currents bigeye are found to be most abundant in the winter when the thermocline is at 100 m. Bigeye also accumulate seasonally in the subtropical convergence of the northern hemisphere (Kume, 1967).

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gear

The most important gear in the Pacific bigeye fishery is the longline. The "basket" is the basic unit of longline gear. It consists of a main line of approximately 300 m which is buoyed to the surface by a float line at each end. Branch lines, each with one baited hook, are suspended from the mainline. Usually there are five branch lines to each basket. The float lines vary in length from about 16.5 to 20.0 m and branch lines are 30 m. The baskets are fastened end to end, so that each setting of the longline extends over many miles. In 1956-1962 the average daily longline set per vessel was 400 baskets with 1960 hooks. The usual bait is frozen saury (Cololabis saira), but mackerel (Scomber japonicus), jack mackerel (Trachurus japonicus) and squid are also used (Suda and Schaefer, 1965a; Shingu, Tomlinson and Peterson, 1974).

About 15% of the bigeye catch from the Pacific Ocean north of 20°N is made by nighttime longline. This gear differs somewhat from the daytime longline described above. It fishes six hooks per basket instead of five, and it has an additional floatline in the middle of each basket. The float lines are 12 m long. the shorter floatlines, with the extra one in the middle, causes the nighttime longline to fish shallower than the daytime longline. The nighttime longline is baited with squid, and swordfish is the principal catch (Kume and Morita, 1966).

In the 1970's the "deep" longline became commonly used by the small and medium-sized Japanese longline vessels fishing in the central and western Pacific. This gear has 10 to 15 branch lines per basket, but is otherwise basically the same as the regular longline gear. The theoretical maximum hook depth for the deep longline is 300 m, as opposed to 170 m for the regular longline (Suzuki, Warshina and Kishida, 1977).

Bigeye are caught by pole and line, using live bait, in the northwestern Pacific during the spring and summer. The vessels engaged in this fishery also catch skipjack and albacore. In this method of fishing schools of tuna are attracted to the fishing vessel by throwing live bait, usually small clupeoids, into the water. Once the tuna are alongside they are caught by poles and lines baited with feathered lures or live bait.

In the eastern Pacific bigeye are caught by purse seiners that are fishing primarily for yellowfin and skipjack. A typical purse seine is about 1100-1400 m long and 110-150 m deep. The seine is set around a school of fish and the bottom is pursed (closed) by drawing in a steel cable which runs through rings suspended from the bottom of the net. When the bottom is closed the webbing is pulled aboard until the catch is confined in a space small enough that the fish can be brailed aboard the vessel.

5.12 Boats

Longline vessels are typically 50-400 in gross tonnage, the larger ones operating in more distant water (Suda and Schaefer, 1965a). Most are constructed of steel; crew's quarters and engine are in the stern and the longline is hauled amidships. The Japan-based baitboats that catch bigeye range in size from about 50 to 250 gross metric tons. The purse seiners fishing in the eastern Pacific range in size from about 100 to 2000 metric tons in fish-carrying capacity. The newer vessels are of steel construction, and most of these are between 500 and 1100 metric tons carrying capacity.

5.2 Fishing areas

5.21 General geographic distribution

The average distribution of the Japanese longline fishery for bigeye in the Pacific Ocean is illustrated in Figure 8. The fishery extends almost entirely across the Pacific in an east-west direction. It extends from Japan to New Zealand in the western Pacific and from about 5°N to 25°S in the eastern Pacific. In the north Pacific the fishery extends in a band from Japan to about 130°W. In the west the band extends approximately from 22°N to 38°N. In the eastern end the band is narrowed, extending from about 23°N to 35°N. Hook rates are higher east of about 180° (Kume, 1969a).

In the equatorial Pacific the area of highest hook rate extends as a band along 5°N, and in the eastern Pacific there is a second band of high hook rate from 3°S to 10°S, with a tongue extending southeastward to about 25°S. As in the north Pacific, hook rate tends to increase from west to east (Kume, 1969b).

The northwestern Pacific surface fishery, at its greatest extent, extends approximately from 138°E to 160°E and from 27°N to 38°N (Kume and Morita, 1967).

The geographical distribution of the bigeye catch in the eastern Pacific by purse seiners is illustrated in Figure 9. In this figure the catch for 1978 is shown by 1-degree areas of latitude and longitude. There was a small catch off the coast of Baja California, but most of the catch was made between 5°N and 5°S. The area of highest catch was from 2°S and 5°S adjacent to the coasts of Ecuador and Peru.

5.22 Geographic ranges

This is given in Sections 2.1 and 5.21.

5.23 Depth ranges

The live-bait fishery off Japan and the eastern Pacific purse-seine fishery are conducted at the surface. Conventional five-hook-to-a-basket longline gear fishes at depths of between 80 and 150 m with hooks 1 and 5 being the shallowest and hook 3 being the deepest (Suda and Schaefer, 1965a). The deep longline fishes at a maximum of 300 m (Suzuki, Warshina and Kishida, 1977). The nighttime longline probably fishes at two thirds to one half of the depth of the regular daytime longline. In the western Pacific experimental fishing with a vertical longline took bigeye at depths of 340-380 m (Hanamoto, 1976). The depth range at which bigeye are caught by longline apparently varies with latitude in the Pacific. Hanamoto (1974) listed the following variation in depths of capture at different latitudes between 90°W and 130°W:

Latitude	Depth
9°N-3°N	90-140 m
3°N-3°S	50-150 m
3°S-9°S	110-160 m
9°S-13°S	120-160 m

5.24 Conditions of the grounds

The fishery for bigeye in the Pacific is generally conducted in deep water, and the gear does not come in contact with the bottom. Most of the fishing is carried out in tropical or subtropical waters, and fishing operations are sometimes interrupted by tropical storms. In the eastern Pacific purse-seine fishery, where the fish are located visually, squalls which limit visibility can curtail fishing or cause vessels to leave an area in which they would otherwise remain.

5.3 Fishing seasons

5.31 General pattern of seasons

The longline fishery is carried out all year long, but there are seasonal differences in apparent abundance. In the north Pacific the hook rate in the winter is approximately twice that of the summer. This may be due to the formation of a seasonal thermocline in the summer which could raise the swimming level of bigeye above the effective longline depth (Kume, 1969a). In the tropical Pacific seasonal changes in apparent abundance are not as pronounced as in the north Pacific. There are some seasonal changes, however, particularly in the eastern Pacific. The quarterly distributions of bigeye hook rate averaged for 1967-1970 are shown in Figure 10. The major seasonal differences occur in the area between 15°S and 30°S from 80°W to 90°W. In this area hook rate is considerably higher in the third and fourth quarters than in the first and second quarters.

The surface fisheries for bigeye are more seasonal than the longline fishery. In the live-bait fishery off Japan most of the catch is taken during April through July (Kume and Morita, 1967). Most of the catch of bigeye in the handline fishery in the Coral Sea is made in October through December (Hisada, 1973). The quarterly distributions of the catches of bigeye in the eastern Pacific purse-seine fishery, averaged over 1976-1978, are illustrated in Figure 11. Catches are greater in the first and fourth quarters than in the second and third quarters.

5.32 Dates of beginning, peak and end of season

The longline fishery for bigeye takes place all year so there is no beginning or end of the season. The purse-seine catches in the eastern Pacific are greater during the first and fourth quarters of the year (Section 5.31).

5.33 Variation in date and duration of season

There does not appear to be much year-to-year variation in the dates or duration of the seasons (Section 5.31).

5.4 Fishing operations and results

5.41 Effort and intensity

In the longline fishery the number of hook-days (generally referred to as hooks) fished is the measure of fishing effort. Shown below is the annual number of hooks fished, in thousands, and the number of bigeye caught, also in thousands, by the Japanese longline fishery in the entire Pacific Ocean for 1962-1977 (Anonymous, 1979j).

Year	No. of hooks (thousands)	No. of bigeye (thousands)	Year	No. of hooks (thousands)	No. of bigeye (thousands)
1962	290,051	1,927	1970	282,531	1,317
1963	337,113	2,534	1971	273,371	1,272
1964	283,140	1,782	1972	279,156	1,657
1965	288,771	1,401	1973	286,918	1,622
1966	301,617	1,537	1974	293,824	1,497
1967	305,999	1,543	1975	263,874	1,576
1968	286,853	1,329	1976	331,645	1,892
1969	306,024	1,812	1977	328,470	2,308

Longline vessels of the Republic of Korea and of the Republic of China (Taiwan) also operate in the Pacific, but the effort and catch data for these are not included in the above table. Longline gear catches other species of tunas and billfishes, the species composition of the catch varying with area and season. Some of the above effort is directed primarily at species other than bigeye.

The annual number of hooks fished and catch of bigeye in the eastern Pacific Ocean (east of 130°W) by Japanese longline vessels during 1962-1977 are shown below (Anonymous, 1979j). These data have the same shortcomings as do the data for the entire Pacific.

Year	No. of hooks (thousands)	No. of bigeye (thousands)	Year	No. of hooks (thousands)	No. of bigeye (thousands)
1962	26,519	484	1970	52,132	316
1963	50,573	710	1971	40,138	272
1964	62,005	577	1972	52,839	368
1965	43,538	259	1973	76,916	630
1966	47,404	397	1974	54,522	375
1967	42,335	324	1975	60,801	559
1968	50,436	330	1976	73,913	564
1969	66,859	620	1977	95,766	909

The purse-seine fishery in the eastern Pacific is directed primarily at yellowfin and skipjack, but the catch of bigeye has been increasing in recent years. The unit of effort in the eastern Pacific purse-seine fishery is the standard day's fishing. Estimates of the amount of fishing effort are obtained from catch data and logbook records. At present there are no estimates of the amount of purse-seine effort directed at bigeye because the purse seiners usually do not search for bigeye, the catches of bigeye being made incidentally to those of yellowfin and skipjack.

The situation is somewhat the same with the live-bait fishery off Japan, where the fishing effort is directed primarily at skipjack and albacore.

5.42 Selectivity

Longline gear is selective to the larger sizes of bigeye, the live-bait fishery is selective to small bigeye and the purse-seine fishery takes both large and small bigeye. In the eastern Pacific the size range of bigeye caught by the surface fishery and by longline is nearly the same, but the proportion of fish above 100 cm is higher in the longline catch (Barrett and Kume, 1965). This is discussed in more detail in Section 4.13.

5.43 Catches

Estimates of bigeye catch, in numbers of fish, by the Japanese longline fishery in the entire Pacific and in the eastern Pacific are in Section 5.41.

The Food and Agriculture Organization of the United Nations compiles records of total catch of all important species of fish and other aquatic animals. These records are never complete, but they are probably the best presently available (Klawe, 1978). the estimated bigeye catches, in metric tons, for the entire Pacific Ocean for 1970-1978 are as follows (Anonymous, 1971-1979).

Year	Catch	Year	Catch
1970	76,000	1974	89,388
1971	67,800	1975	102,417
1972	88,900	1976	126,550
1973	89,300	1977	143,987

The Inter-American Tropical Tuna Commission (IATTC) maintains records of catches made by the surface fishery in the eastern Pacific Ocean. These records are reasonably complete, but there are some shortcomings in regard to bigeye. The fishermen are paid the same price for bigeye and yellowfin and, until recently, most of the small amount of bigeye that was landed was not separated from yellowfin. This situation has improved in recent years. At some ports bigeye and yellowfin are separated, and at ports where the two species are usually not separated employees of the IATTC try to estimate the amounts of each species in the catch.

The estimated catches of bigeye, in metric tons, by the eastern Pacific surface fleet from the eastern Pacific Ocean east of 150°W are as follows (Anonymous, 1980a).

Year	Catch	Year	Catch
1961	213	1970	1,333
1962	327	1971	2,567
1963	75	1972	2,238
1964	68	1973	1,979
1965	118	1974	889
1966	263	1975	3,905
1967	1,471	1976	10,557
1968	2,525	1977	7,617
1969	575	1978	11,373
		1979	8,159

The reason for the increase in catch in recent years is not clear. It may be partially due to improved reporting, as discussed above. Another factor may be the catch quotas on yellowfin which were first imposed in 1966. Vessels on trips for which there is a restriction on the amount of yellowfin that can be caught may direct some of their fishing effort directly at bigeye.

6 PROTECTION AND MANAGEMENT

There is no legislatively imposed limitation on the catch of bigeye in the Pacific Ocean nor are there size limits or closed areas or seasons. The Japanese government does, however, control the number of Japanese flag vessels of each type which can engage in the tuna fishery. This may reduce the catch of bigeye somewhat. Also the recent imposition of 200-mile limits by most nations bordering the Pacific Ocean may serve to limit the catch of bigeye but this is, as yet, uncertain.

7 CULTURE

No attempts have been made to raise bigeye in captivity.

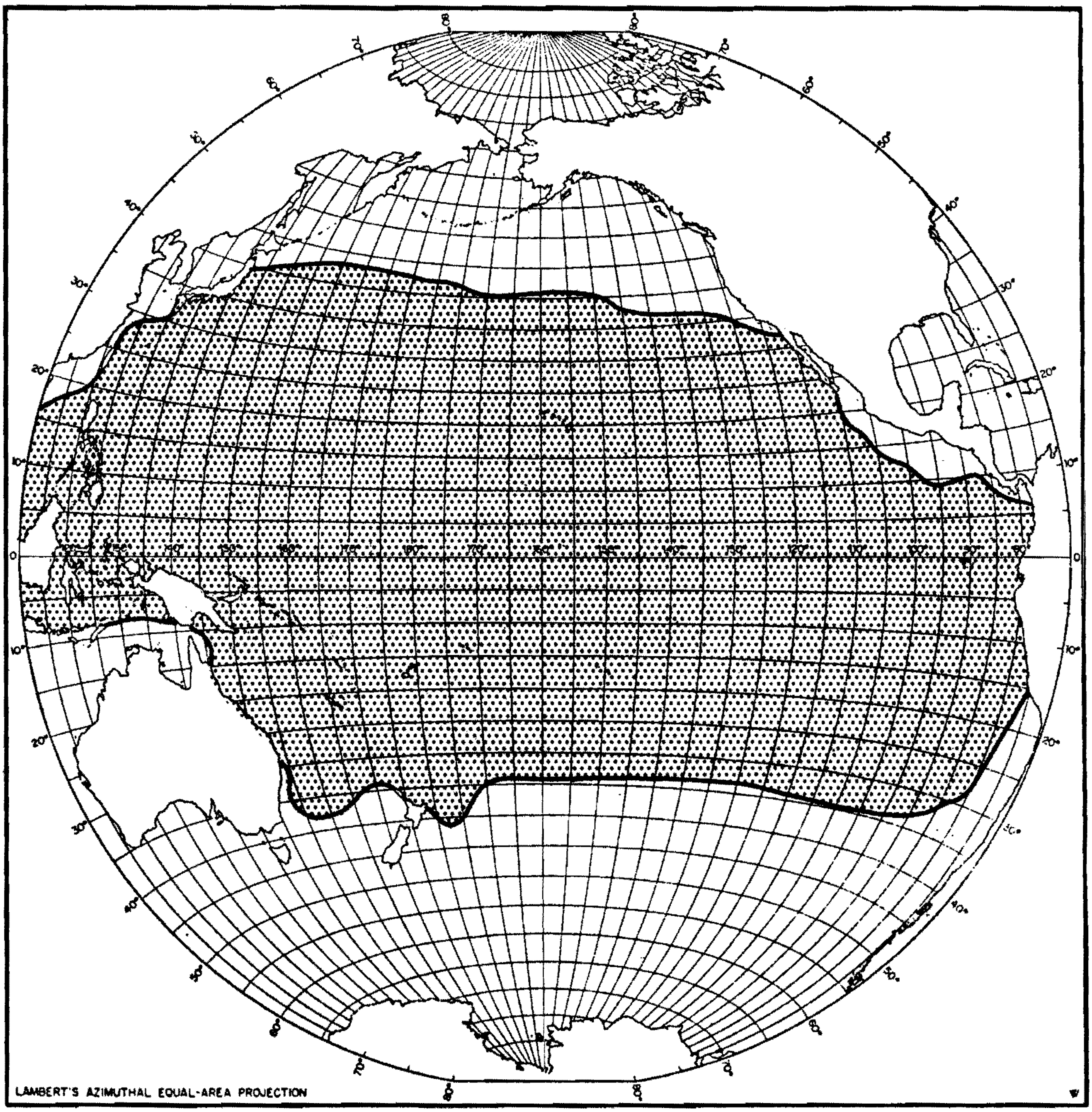


FIGURE 1. Distribution of bigeye in the Pacific Ocean.

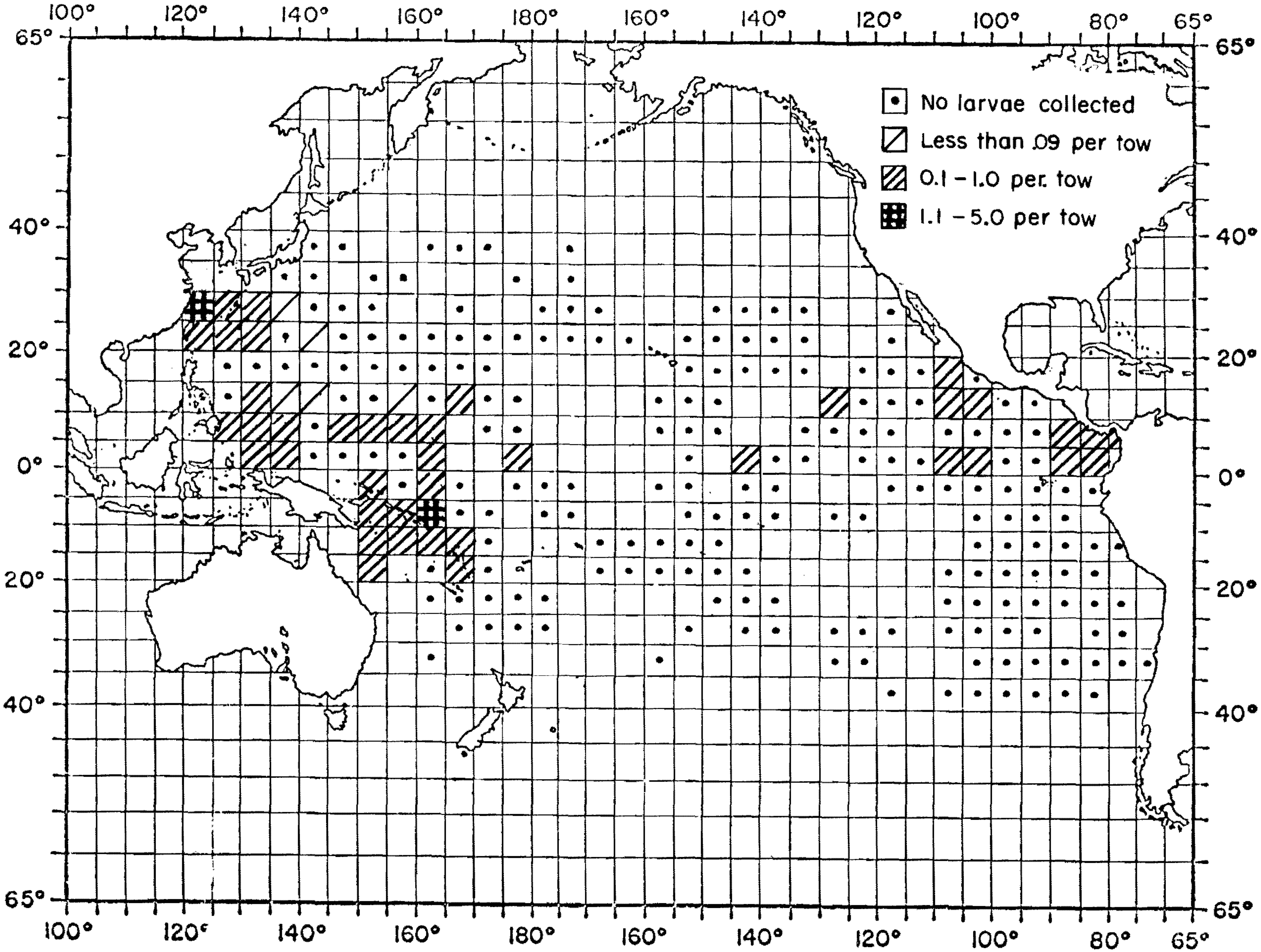


FIGURE 2. Distribution of bigeye larvae in the Pacific Ocean (from Nishikawa et al., 1978).

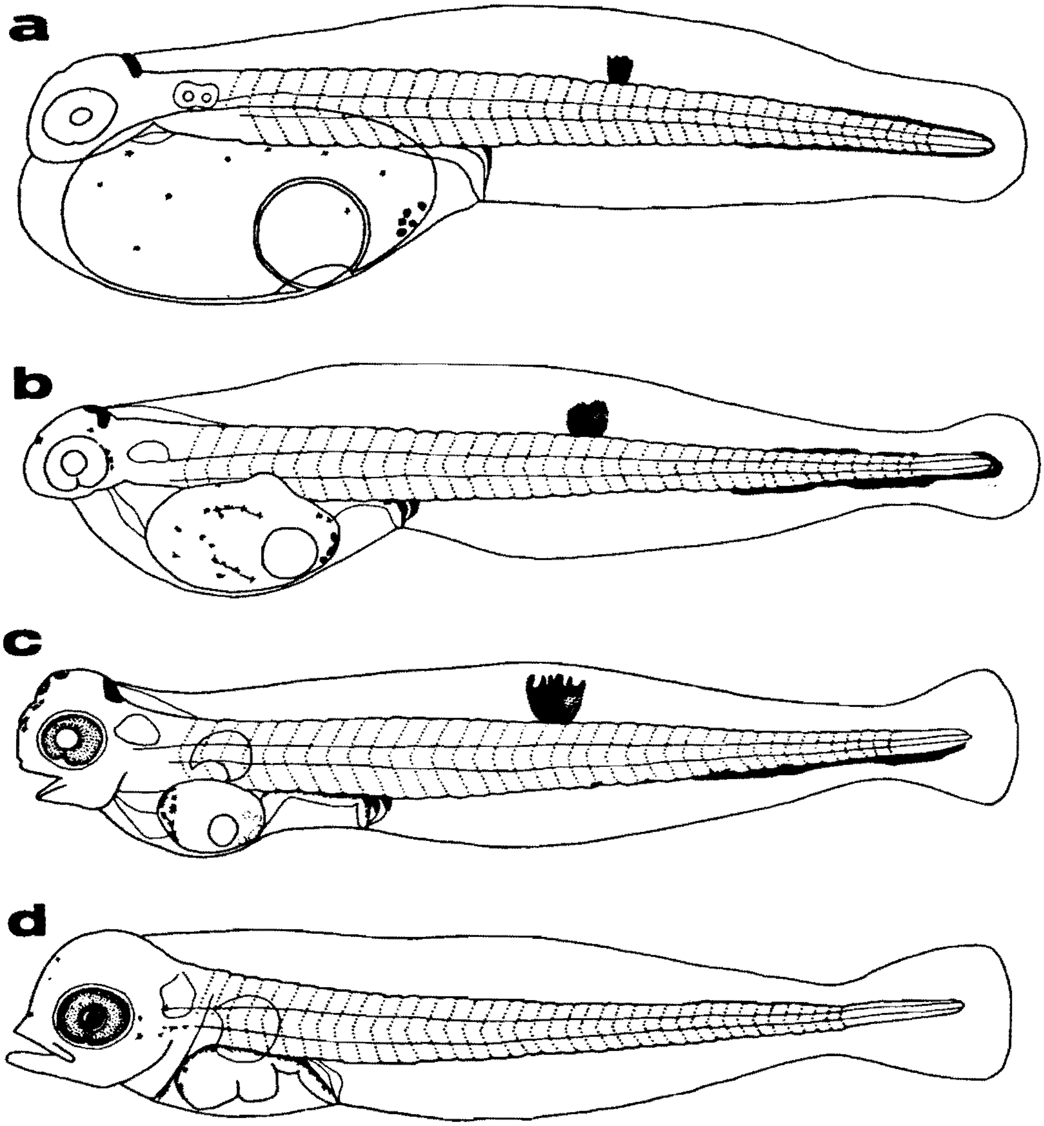


FIGURE 3. Larvae of bigeye tuna: a) newly hatched; b) 24 hours after hatching; c) 48 hours after hatching; d) 86 hours after hatching (from Yasutake, Nishi and Mori, 1973).

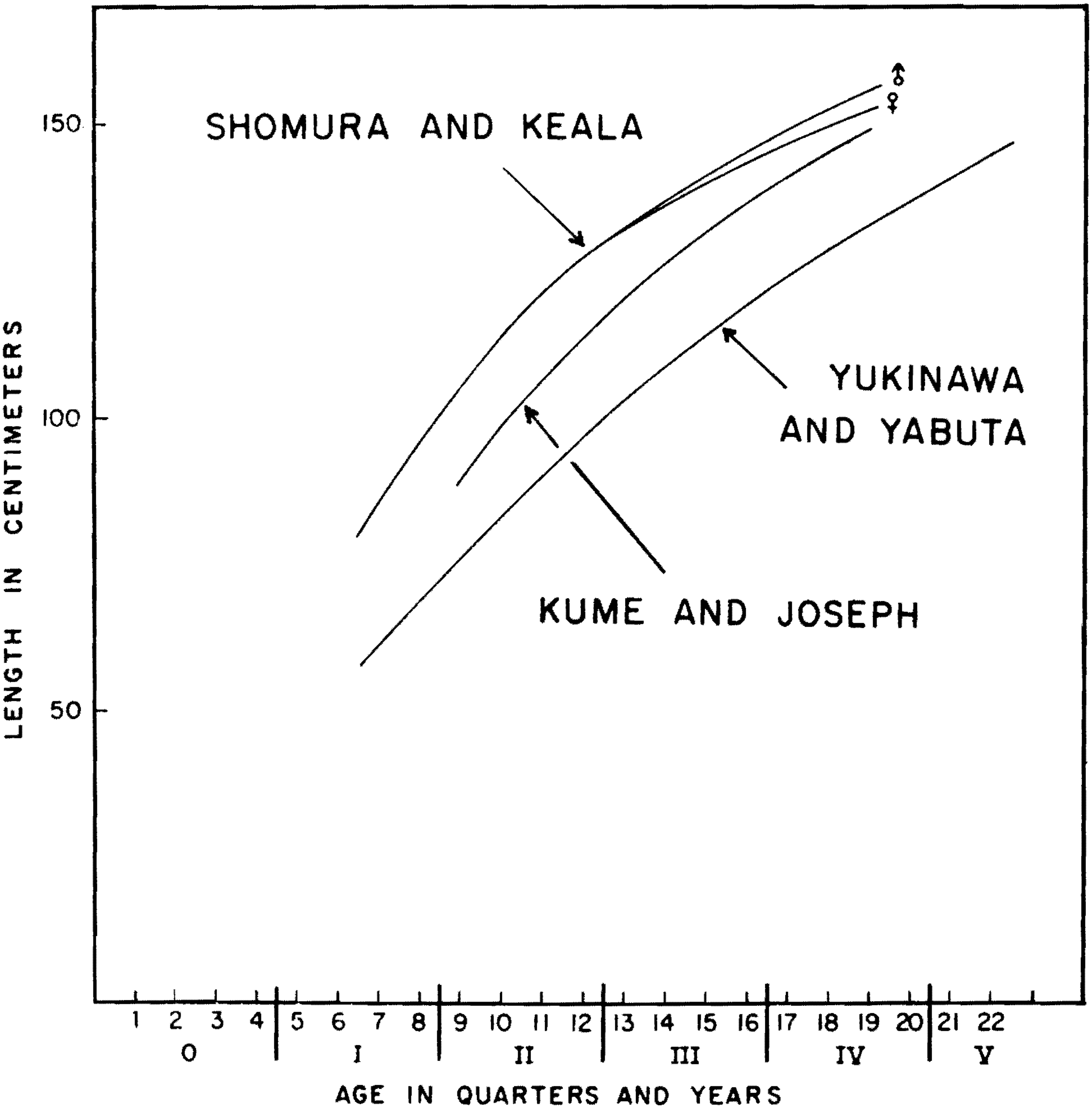


FIGURE 4. Three growth curves of bigeye (from Kume and Joseph, 1966).

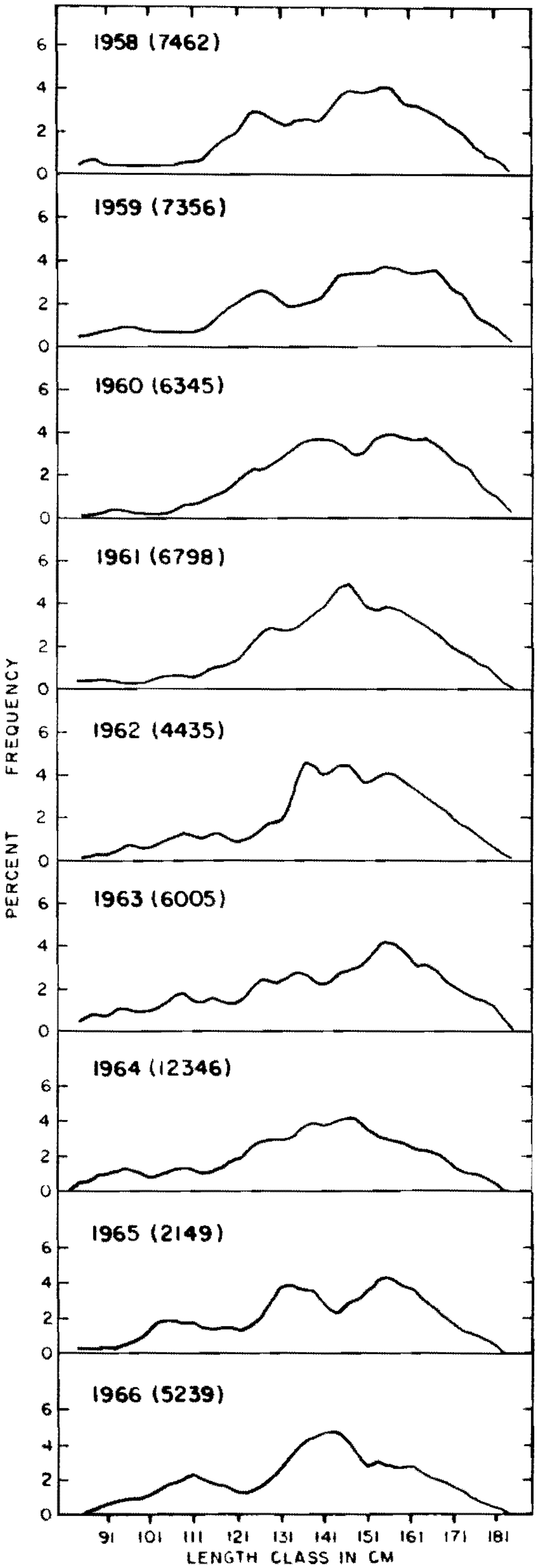


FIGURE 5. Annual length-frequency distributions of bigeye caught by longliners in the "southern area" (between 10°S and 25°S and between 115°W and 130°W) during 1958-1963 (from Kume and Joseph, 1966) and east of 130°W during 1964-1966 (after Kume and Joseph, 1969).

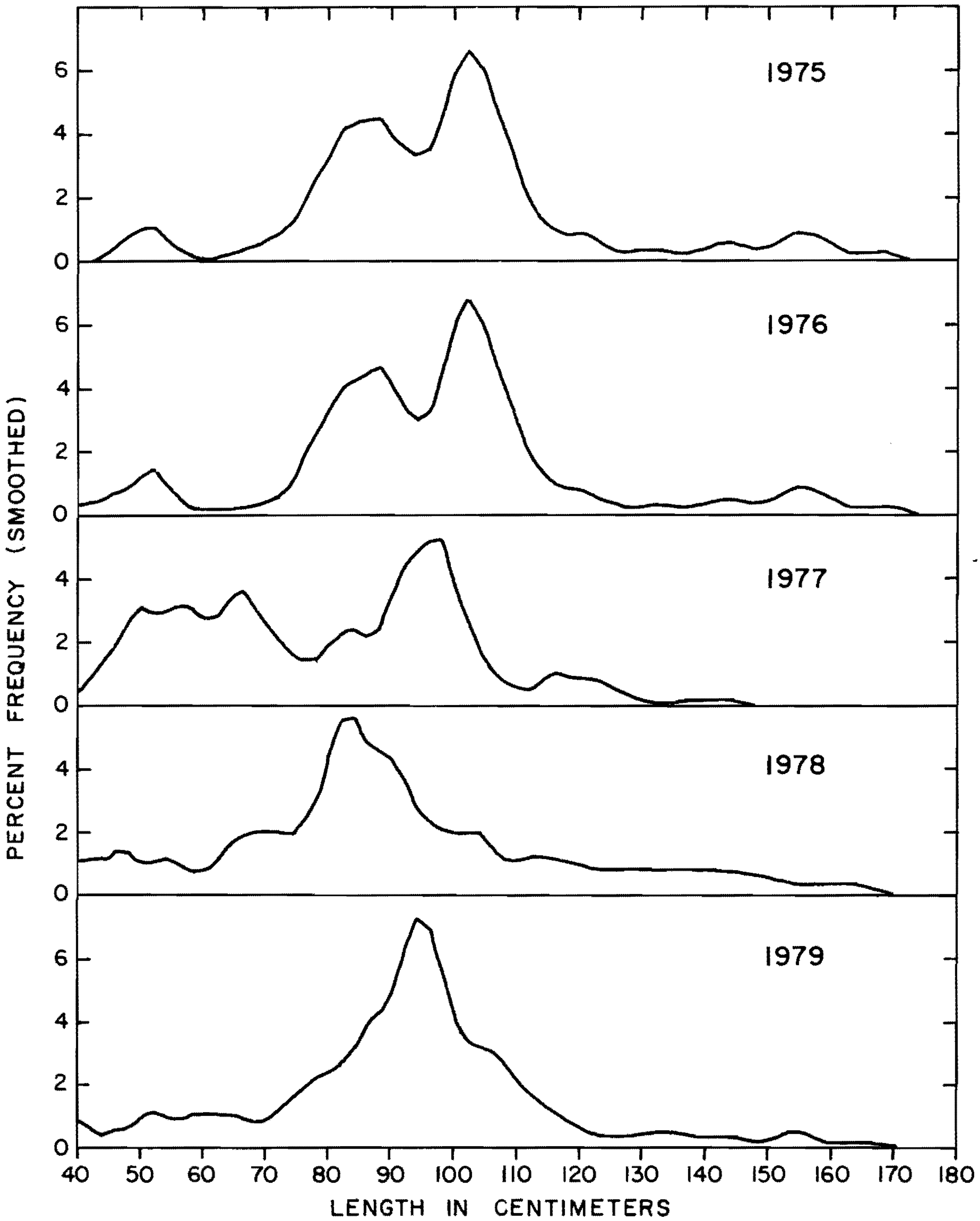


FIGURE 6. Annual length-frequency distributions of bigeye caught by purse seiners in the eastern Pacific Ocean, 1975-1979 (from Anonymous, 1980a).

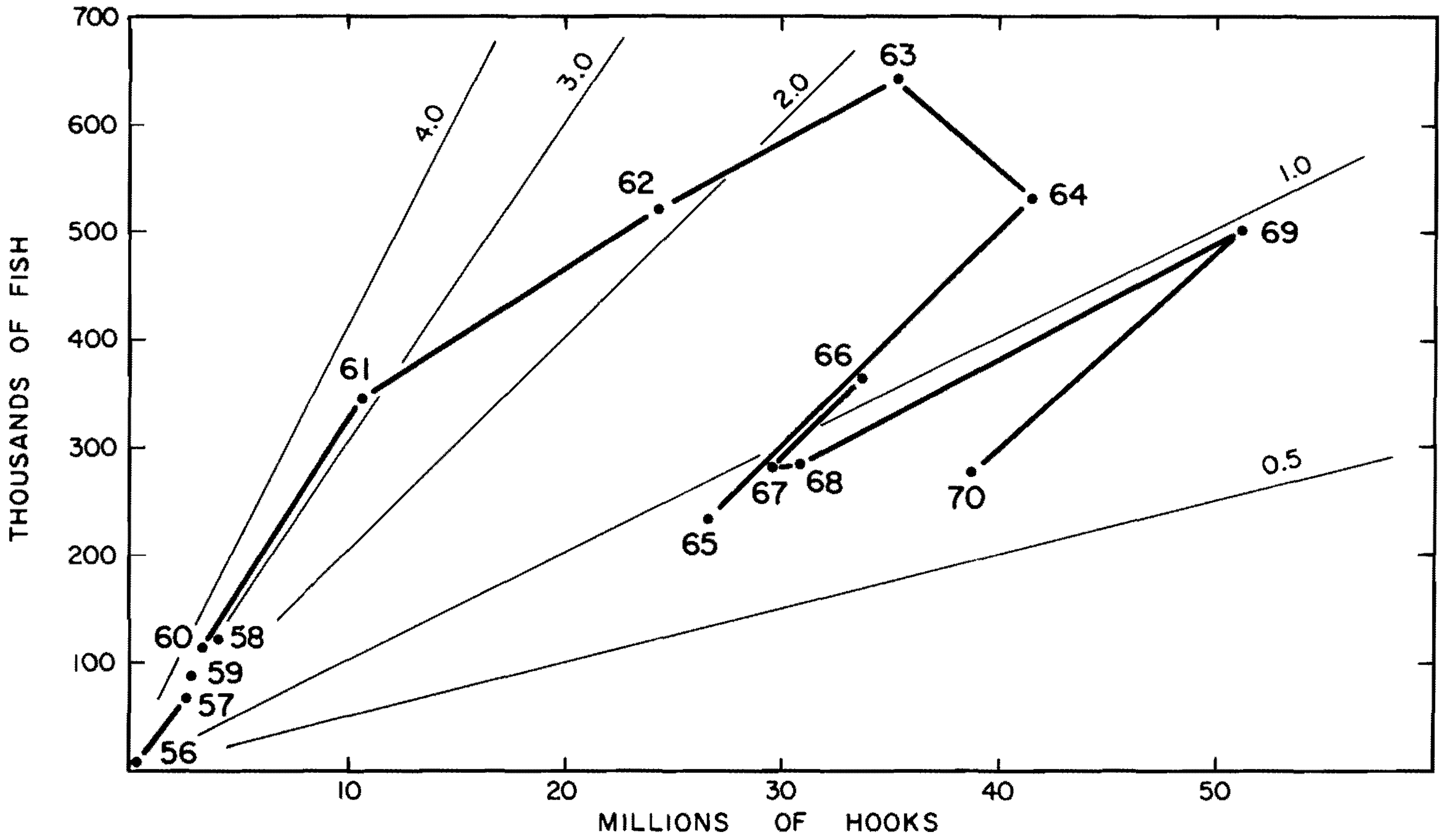


FIGURE 7. Relationship between catch of bigeye and fishing effort in the portion of the eastern Pacific (Areas 7-12 of Shingu, Tomlinson and Peterson, 1974) where most longline catches of bigeye occur, 1956-1970 (from Shingu, Tomlinson and Peterson, 1974). The fine lines denote hook rates of different intensities.

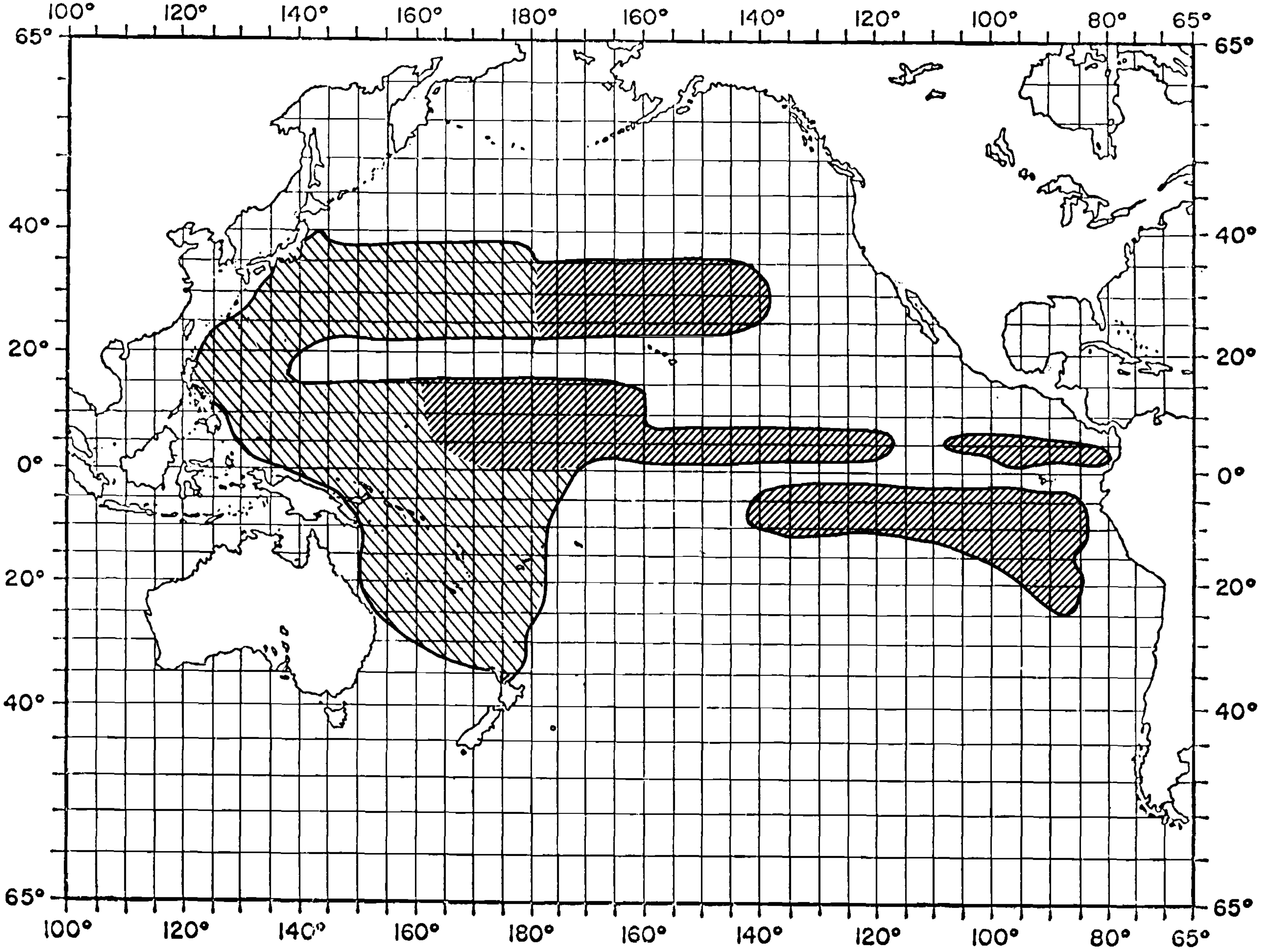


FIGURE 8. Average geographical distribution of the Japanese longline fishery for bigeye in the Pacific Ocean. The darker shaded areas denote areas of higher hook rate.

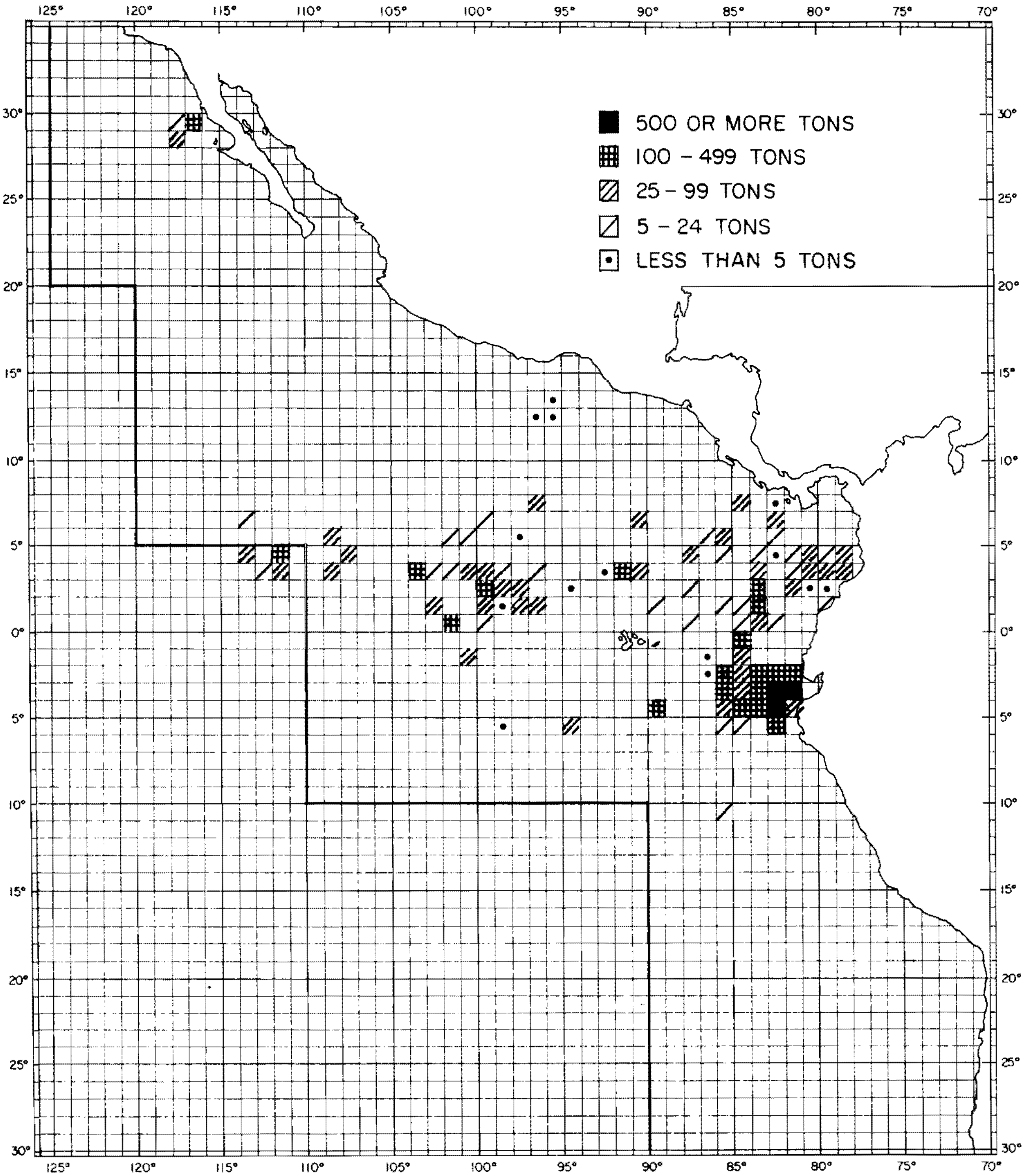


FIGURE 9. Geographical distribution of bigeye catch by purse seiners in the eastern Pacific Ocean in 1978.

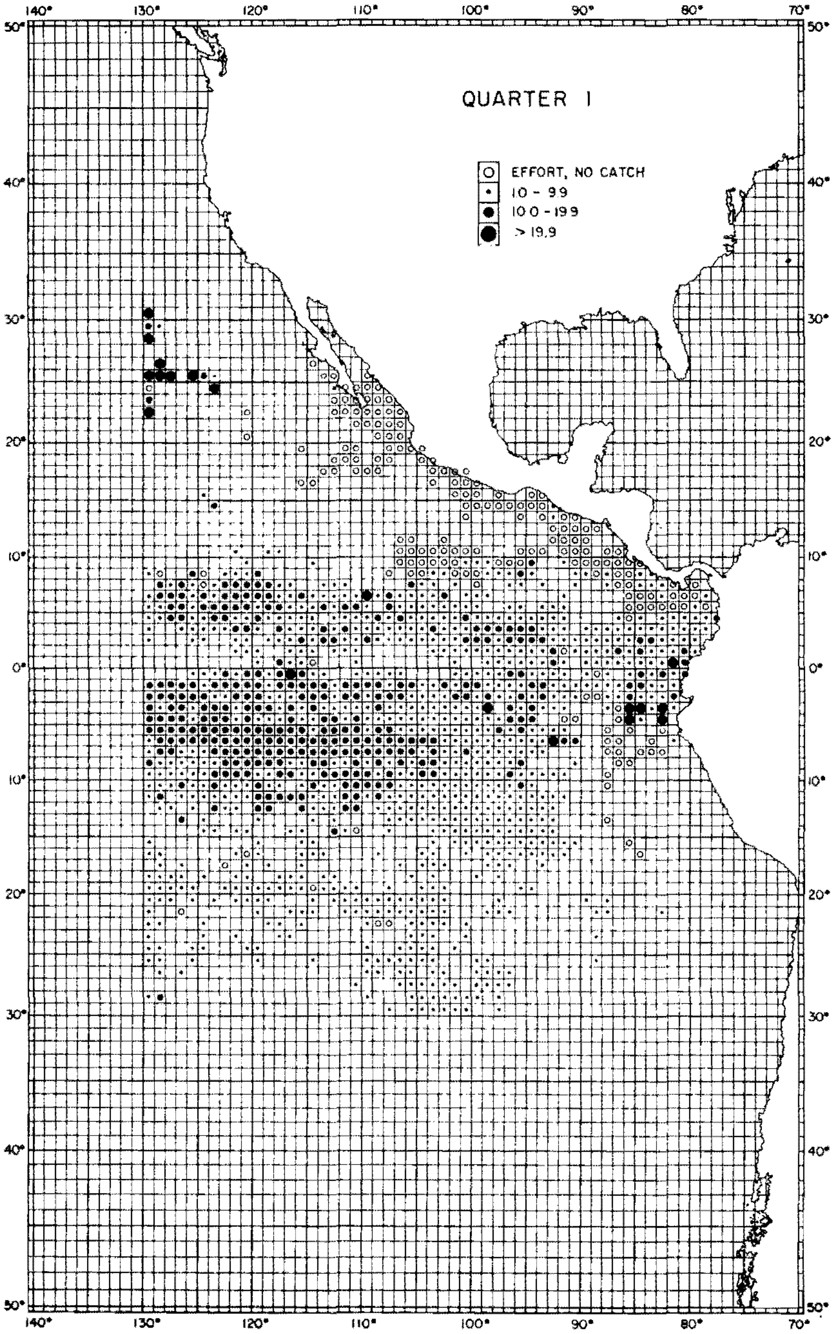


FIGURE 10. Quarterly distribution of bigeye hook rate (catch per 1000 hooks) averaged over 1967-1970 (from Shingu, Tomlinson and Peterson, 1974).

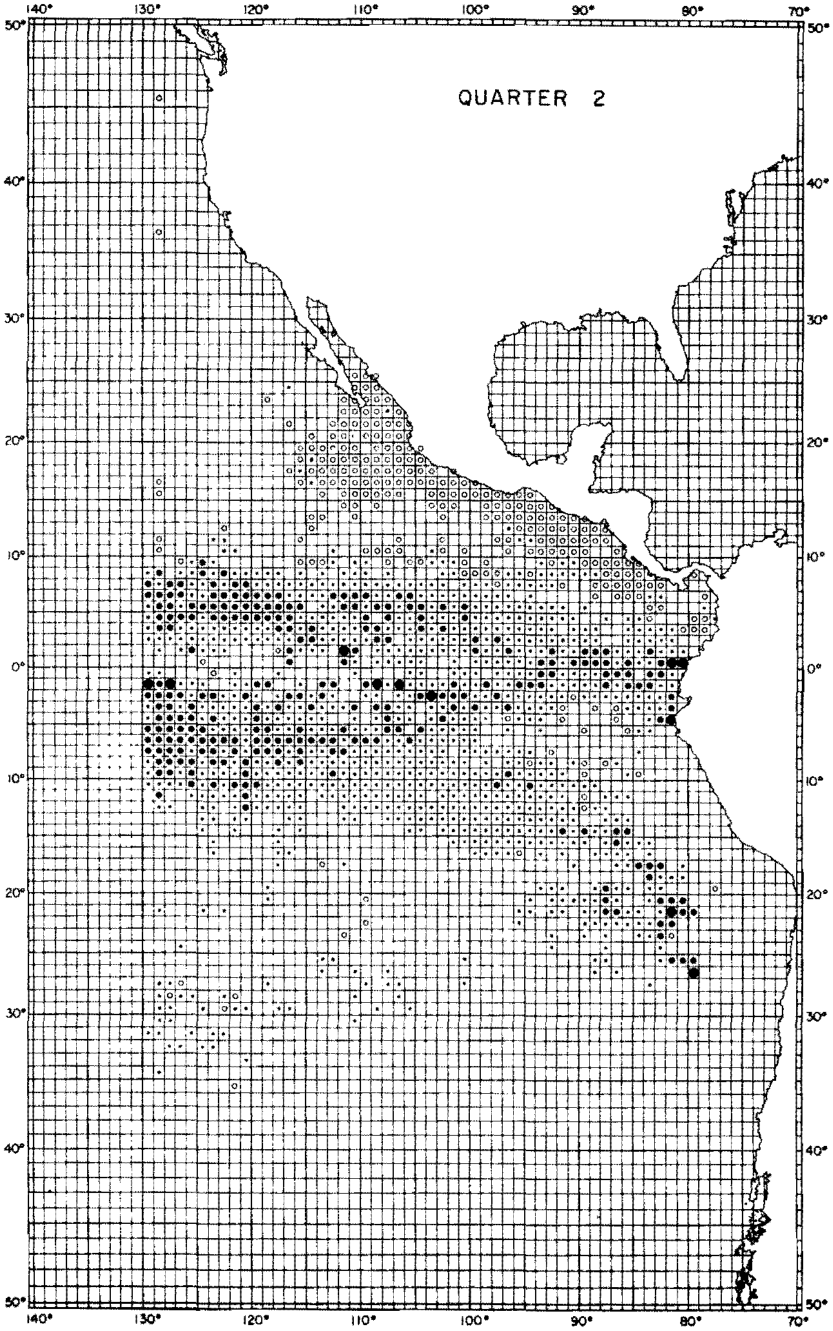
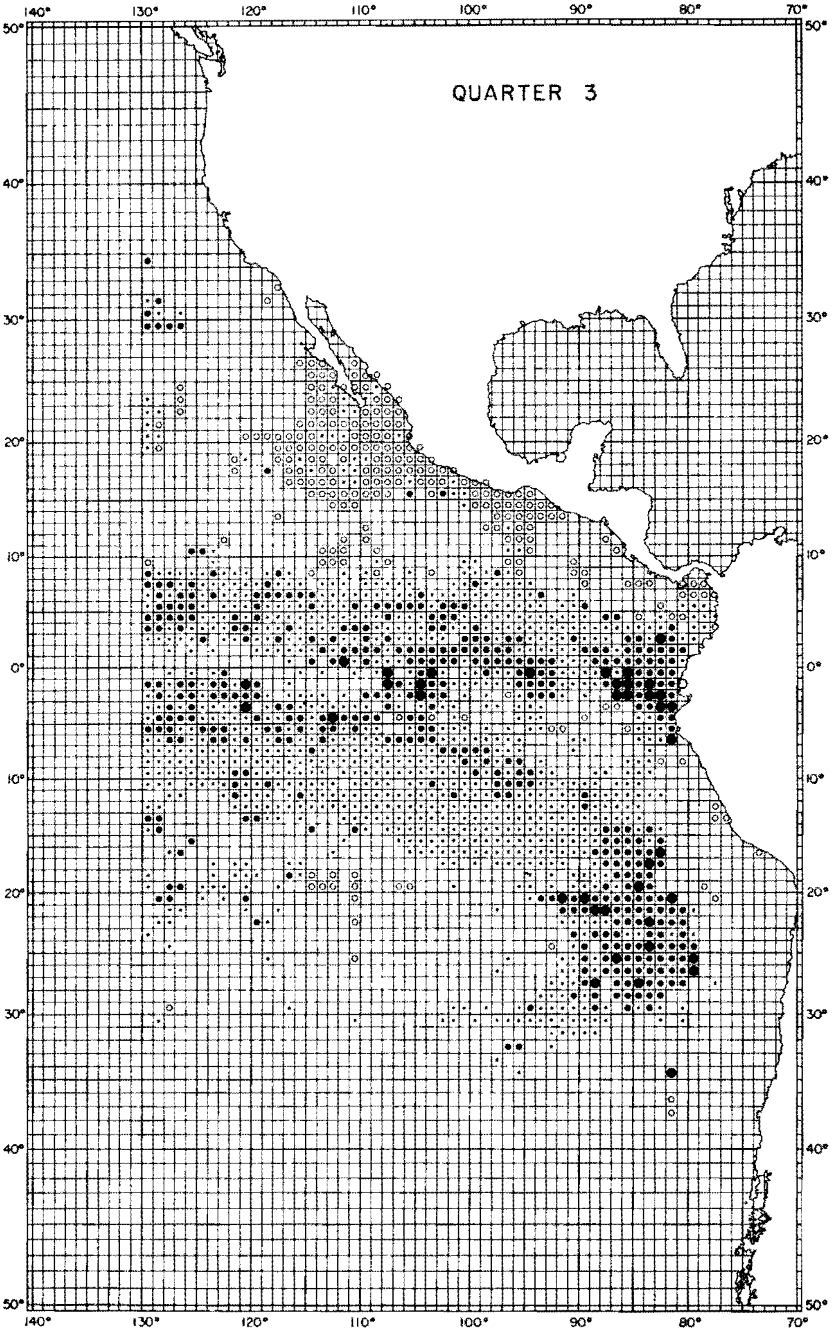


FIGURE 10. (continued)



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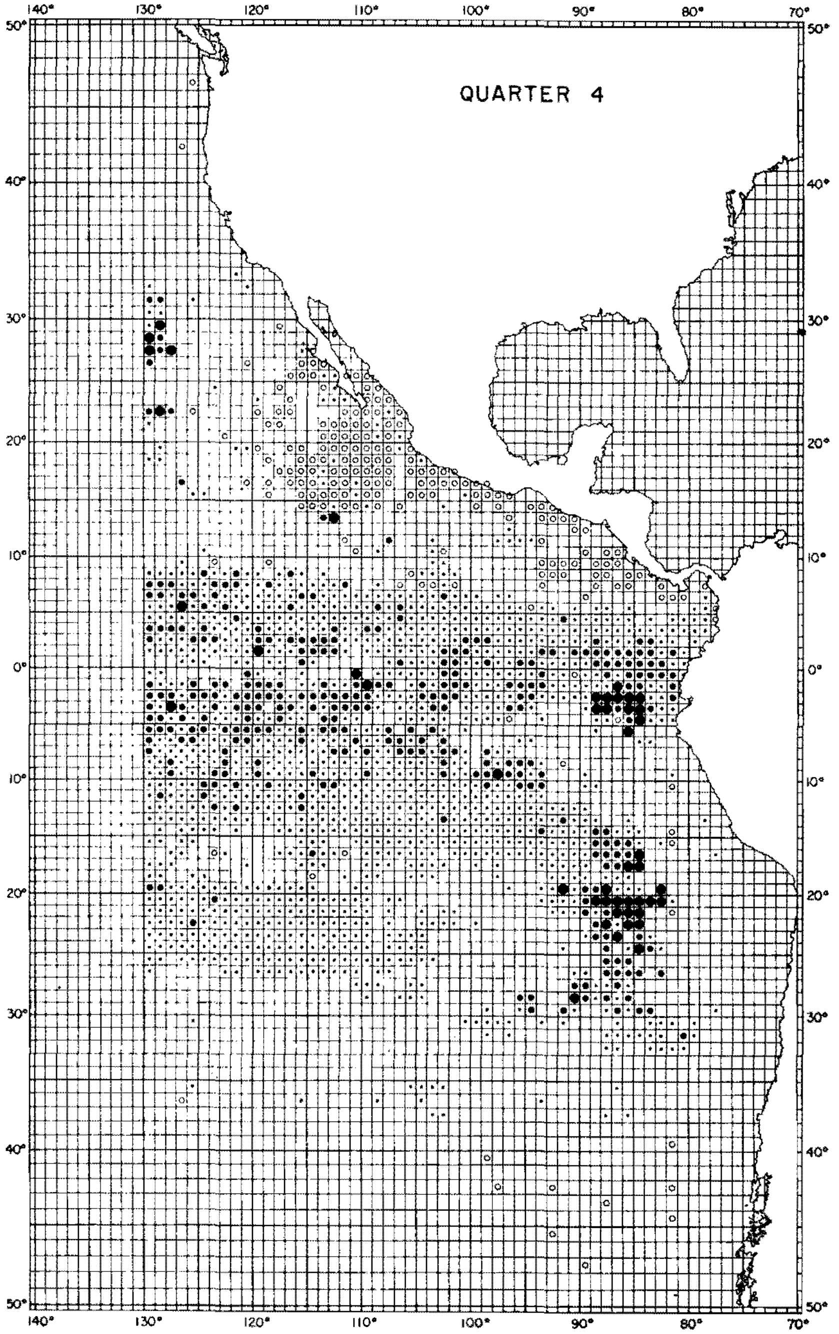

FIGURE 10. (continued)

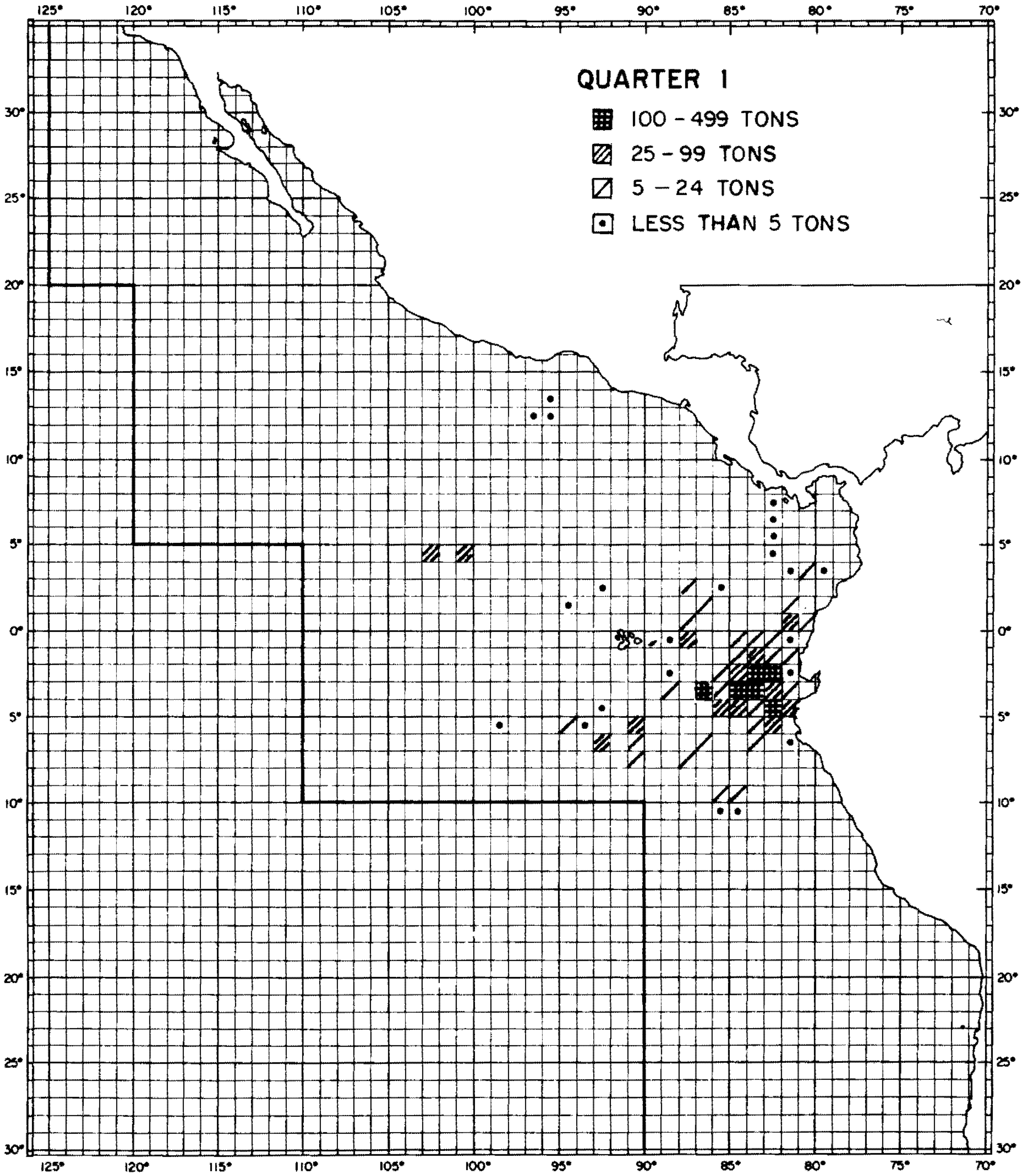

FIGURE 11. Quarterly distribution of bigeye catch by purse seiners averaged over 1976–1978.

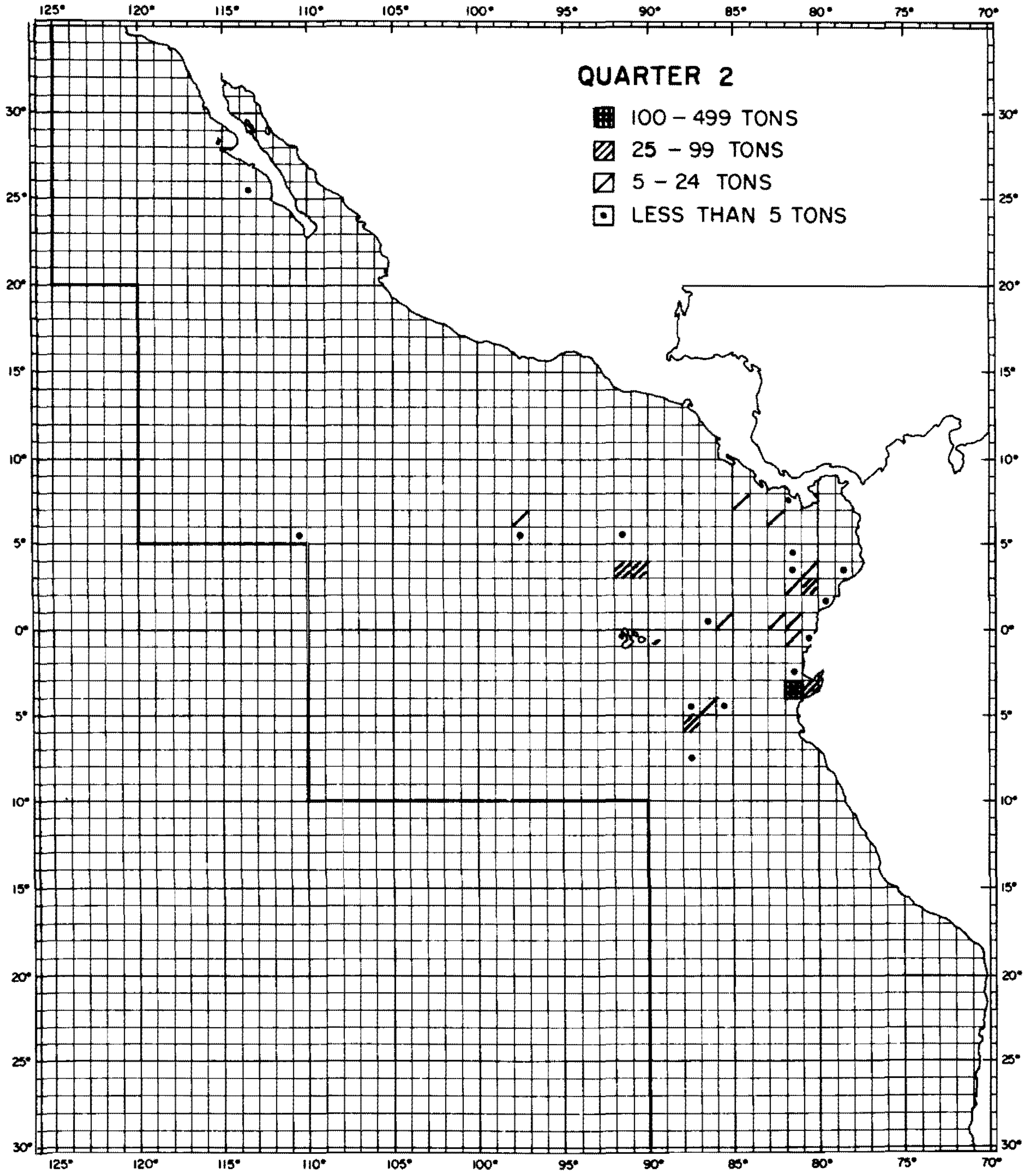

FIGURE 11. (continued)

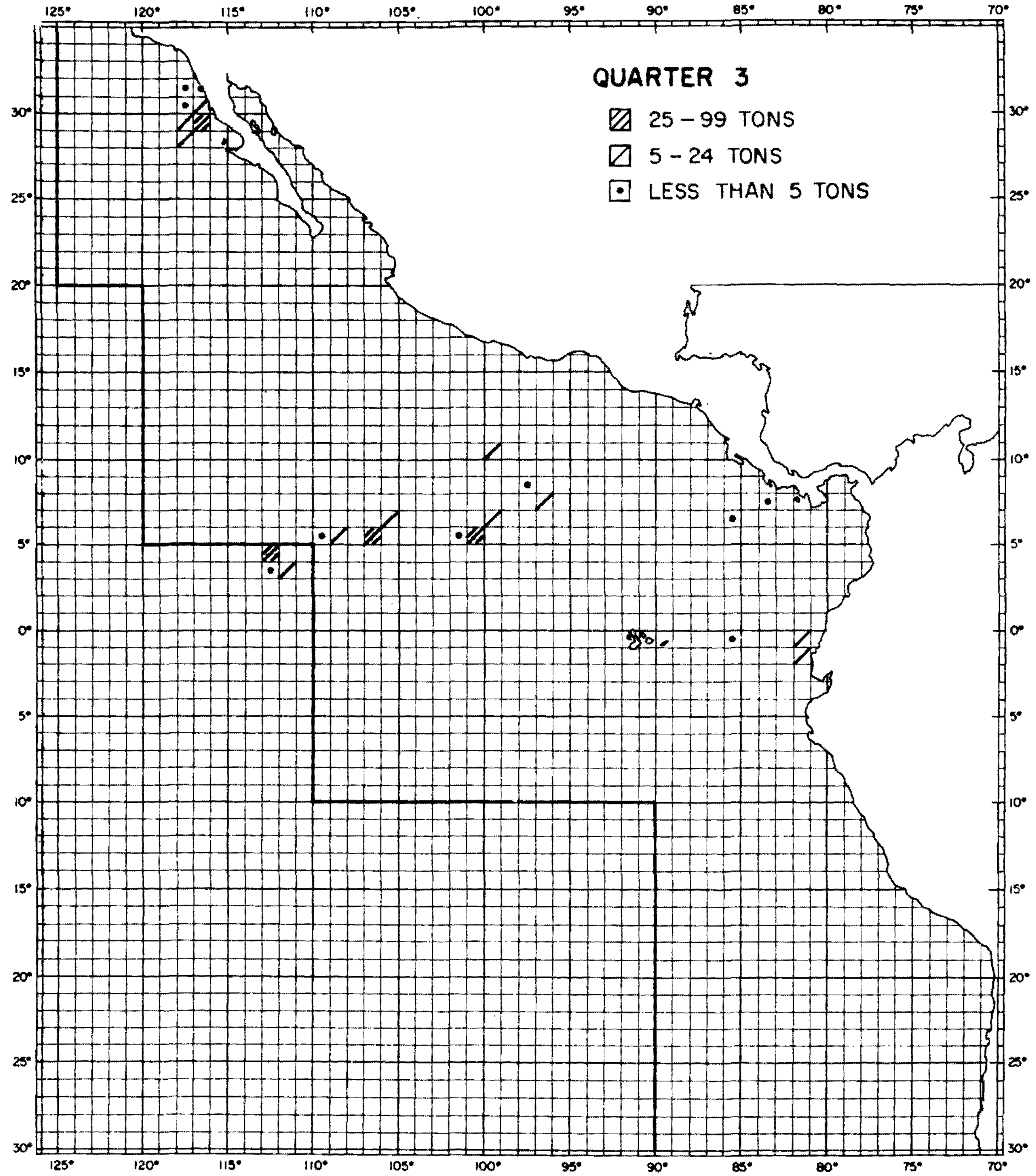

FIGURE 11. (continued)

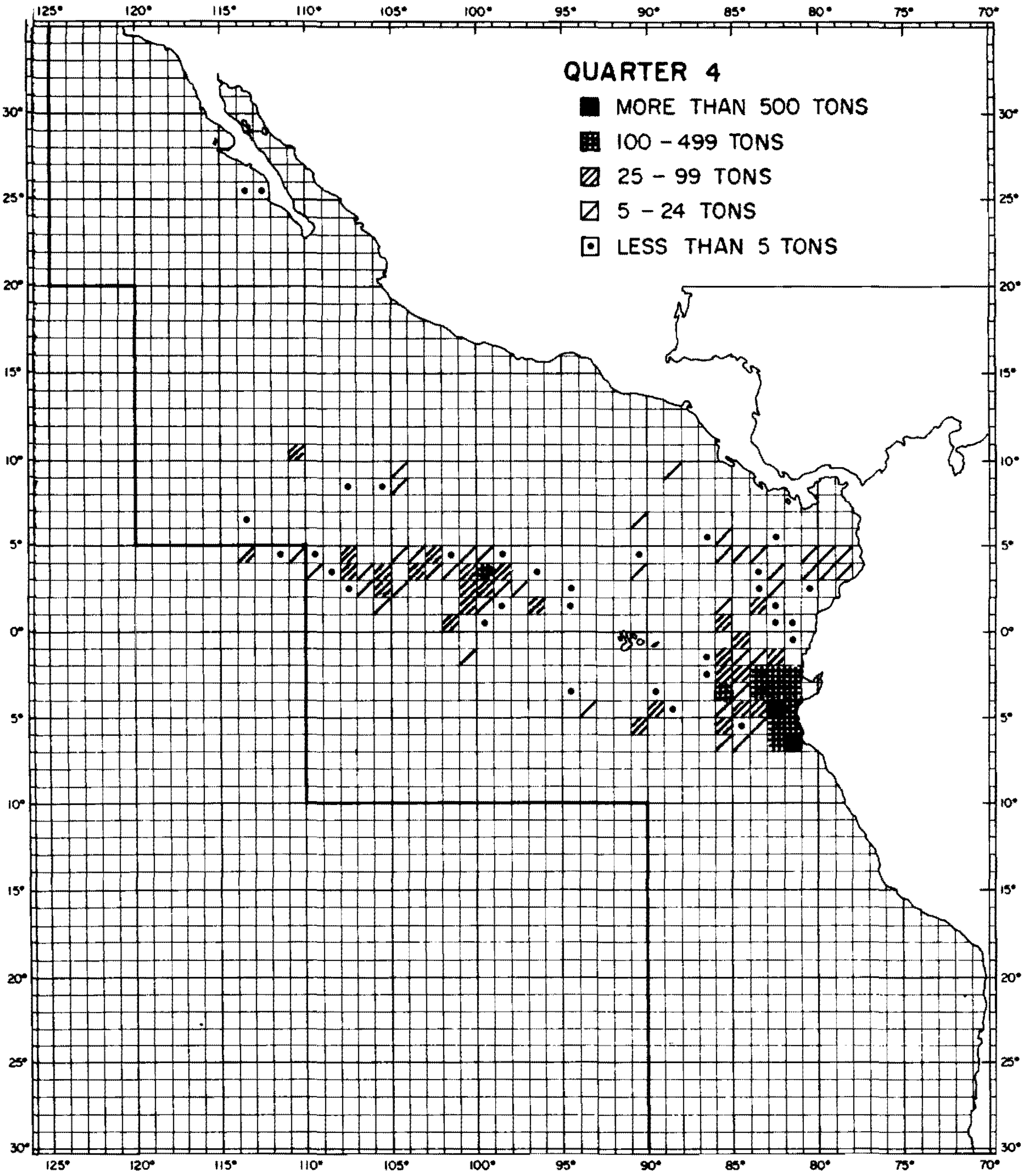

FIGURE 11. (continued)

TABLE 1. Data on tagged bigeye at liberty long periods of time. The distances are given in nautical miles.

Release			Recapture			Dis-tance	Days free	Direc-tion	Reference
Area	Date	Length	Area	Date	Length				
30°59'N- 171°14'W	Jan. 31, 1955	122.3	32°41'N- 155°57'W	Nov. 24, 1955	126.8	785	298	82	Otsu and Uchida, 1956
30°59'N- 171°14'W	Jan. 31, 1955	109.0	29°50'N- 117°50'W	Feb. 2, 1956	127.5	348	368	259	Kume, 1967
32°59'N- 143°19'E	May 31, 1958	82	29°15'N- 133°45'E	Nov. 11, 1959	110-115	540	530	255	Kume, 1967
32°59'N- 143°19'E	May 31, 1958	81	35°27'N- 141°10'E	Jan. 17, 1960	119	182	597	324	Kume, 1967
3°18'N- 90°50'W	May 6, 1967	80	2°12'S- 81°01'W	Jan. 13, 1968	?	664	253	117	IATTC, unpublished
3°18'N- 90°50'W	May 12, 1967	50	4°32'N- 107°50'W	Jun. 18, 1969	128.0	1,020	769	274	Anonymous, 1970

SYNOPSIS OF BIOLOGICAL DATA ON THE NORTHERN BLUEFIN TUNA, *THUNNUS THYNNUS* (LINNAEUS, 1758), IN THE PACIFIC OCEAN

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Inter-American Tropical Tuna Commission
La Jolla, California
1980

CONTENTS

1 IDENTITY

The scientific name for the northern bluefin tuna is *Thunnus thynnus*. Collette (1978) recognizes two subspecies, *T. thynnus thynnus* in the Atlantic Ocean and *T. thynnus orientalis* in the Pacific Ocean.

2 DISTRIBUTION

In the eastern Pacific northern bluefin are caught mostly between Cabo San Lucas, Baja California, Mexico, and Point Conception, California, U.S.A. Within this area the fish tend to be distributed further to the north in years when the sea-surface temperatures are above normal and further to the south in years when those temperatures are below normal (Hester, 1961). On September 24, 1960, a purse seiner caught 50 metric tons of bluefin about 50 miles west of Cape Mendocino, more than 300 miles north of Point Conception. This species has also been caught off Oregon and Washington (Brock, 1938; Radovich, 1961), off British Columbia (Neave, 1959), and in Shelikoff Strait, Alaska (Radovich, 1961). These occurrences far to the north of the usual range of this species in 1957-1959 have been attributed to higher-than-average sea-surface temperatures during that period (Radovich, 1961). One fish thought to be a bluefin was tagged near Roca Partida, Mexico, on June 15, 1976 (Anonymous, 1978a). The tag was later returned, but the fish was not examined to verify its identity. Bluefin are recorded in the vicinity of the Galapagos Islands (Snodgrass and Heller, 1905; Herre, 1936), "but there is no supporting evidence which would eliminate *T. maccoyii* (southern bluefin) or any other species from consideration" (Gibbs and Collette, 1967). Two large (1553- and 1640-mm) bluefin were caught by a purse seiner at 3°23'S-81°09'W on June 14, 1969. Their identity as bluefin was confirmed by the striations on the livers, but it was not determined if they were northern or southern bluefin. De Buen (1953 and 1958) records northern bluefin off the central coast of Chile, and Nakamura and Warashina (1965) record a specimen caught at 37°11'S-114°41'W. Also Kume (1974) gives data for fish caught off the west coast of South America between 80°W and 115°W during 1968-1970, and Anonymous (1975a, 1976a, 1977a, and 1978b) records this species in the same area during 1973 through 1976 (Figure 5).

In the central Pacific Jordan and Jordan (1922), Fowler (1928), and June (1952) record northern bluefin caught near Hawaii, and Kume (1974) and Anonymous (1974a, 1975a, 1976a, 1977a, and 1978b) record other catches of this species made in this area both north and south of the equator. Fowler's (1928 and 1932) records of a 355-mm bluefin from the Society Islands and of bluefin from the Marquesas Islands could be based upon misidentifications, as Klawe (1959) showed that Fowler (1944) had identified juvenile yellowfin, Thunnus albacares, caught in the eastern Pacific as bluefin.

In the western Pacific northern bluefin occur from Sakhalin Island to southeastern Australia and New Zealand (Shimada, 1951a; Isao, 1963; Yamanaka et al., 1963; Kume, 1974; Shingu, Warashina, and Matsuzaki, 1974; Anonymous, 1974a, 1975a, 1976a, 1977a, and 1978b), but are most abundant in the vicinity of Japan. They are much more plentiful off Japan in years when the sea-surface temperatures are above normal than when they are below normal (Uda, 1962 and 1973).

In the Indian Ocean northern bluefin have been caught west of Australia (Nakamura and Warashina, 1963) and north of Borneo (Anonymous, 1977a).

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

Hirota, Morita, and Taniguchi (1976) reported two northern bluefin, a male and a female, both reared in captivity, which matured at 3 years of age. The lengths of these fish (male, 1190 mm; female, 1353 mm) were considerably in excess of the average lengths of 3-year-old fish given in Table 1. Nakamura (1943; cited by Hirota, Morita, and Taniguchi, 1976) states that northern bluefin mature at 3 years of age in nature. Fish of 270 to 300 kg have about 10 million eggs (Yamanaka et al., 1963). Spawning occurs between Japan and the Philippine Islands and southeast of Japan during April through July (Yabe, Ueyanagi, and Watanabe, 1966; Nishikawa, Kikawa, Honma, and Ueyanagi, 1978). Okiyama (1974 and 1979) found larvae in the Sea of Japan, and considered them to have resulted from spawning in that area. In addition, Miller (1979) reports larvae of this species from the Hawaiian Islands.

3.2 Pre-adult phase

The larvae of northern bluefin are described by Matsumoto (1962), Yabe and Ueyanagi (1962), Matsumoto, Ahlstrom, Jones, Klawe, Richards, and Ueyanagi (1972), and Richards and Potthoff (1973). The larvae, postlarvae, and juveniles are carried northward by the Kuroshio Current toward Japan. Fish of age 0+ about 20 to 60 cm in length are caught in the vicinity of Japan during the second half of the year (Yabe, Ueyanagi, and Watanabe, 1966; Yukinawa and Yabuta, 1967). Yokota, Toriyama, Kanai, and Nomura (1961) mention the presence of juvenile northern bluefin in the stomachs of skipjack, Katsuwonus *pelamis*.

3.3 Adult phase

3.31 Longevity

Aikawa and Kato (1938) used vertebrae to estimate the ages of northern bluefin in the western Pacific, and found the maximum age to be 9+ years. Using scales to estimate the ages of fish in the same area, Yukinawa and Yabuta (1967) found fish up to 7+ years old. The oldest fish found in the eastern Pacific by Schultze and Collins (1977), who also used scales to estimate the ages, were 6+ years old.

3.32 Hardiness

Ueyanagi, Mori, Nishikawa, and Suda (1973) mention that small bluefin captured by traps and trolling gear and confined in enclosures are likely to die if roughly handled or subjected to sudden decreases in salinity. Clemens (1961) believed that this species is less resistant than albacore, *Thunnus alalunga*, to the stresses of tagging and handling, but more resistant than bigeye, *T. obesus*, yellowfin, or skipjack.

3.33 Competitors

No specific information is available on this subject, but northern bluefin probably compete for food with other medium and large pelagic predatory fish and mammals with which they share living space.

3.34 Predators

Yamanaka *et al*. (1963) state that: "Tunas are devoured by killer-whales which are said to catch them at the nape and kill them immediately. They fear killers so greatly that they are frightened several miles away from the spots where these ferocious enemies are found. Thus catches made by pound-nets [traps] vary greatly according to the favorable or unfavorable proximity of killers. Sometimes tunas leap recklessly on to beaches to escape their enemies." Man is also a predator of northern bluefin.

3.35 Parasites, diseases, injuries, and abnormalities

Data on parasites of northern bluefin are given by Bell (1963a), Silas (1967), Silas and Ummercutty (1967), Love and Moser (1977), and Cressey and Cressey (1980).

3.4 Nutrition and growth

3.41 and 3.42 Feeding and food

Blunt (1958), referring to surface-caught northern bluefin of the eastern Pacific, stated: "Of 168 bluefin taken off California [during 1957], 70 percent had been feeding on anchovies... Bluefin sometimes feed close inshore near the surf. Tuna captured in shallow water had eaten starfish, kelp, sanddabs [*Citharichthys*], surf perches [Embiotocidae] and white croakers [*Genyonemus lineatus*]." Bell (1963a) lists 14 species of fish found in northern bluefin stomachs. Pinkas (1971) reported that surface-caught bluefin sampled in 1968 and 1969 consumed, in order of importance, anchovies, *Engraulis mordax*, red crabs, *Pleurocodes planipes*, sauries, *Cololabis saira*, squid, *Loligo opalescens*, and hake, *Merluccius productus*. Anchovies made up 80 percent of the stomach contents by volume. In addition, other species of fish, cephalapods, and crustaceans, *Atlanta* (a gastropod), and pieces of kelp were found in the stomachs. He remarked that bluefin occurred further offshore in 1968 and 1969 than they had in 1957, which probably accounted at least partly for the differences in his results and those of Blunt (1958). Scott and Flittner (1972) found that red crabs are a significant part of the diet only south of 29° north latitude, and that boiling and jumping schools of fish are much more common north of that latitude, where fish are the principal item of the diet. They stated that the differences in behavior in the two areas could be due to the differences in the food, *i.e.* "modified filter feeding" might be employed while feeding on red crabs, while "vigorous pursuit" would be required for feeding on fish. Yamanaka *et al.* (1963) summarized the available information on the feeding and food of this species in the western Pacific. Fish 20 to 65 cm in length consume anchovies and other fish, plus crustaceans, while longline-caught (larger) fish eat fish and squid. Fish of unspecified size are reported to consume both pelagic and demersal fish, *Calamarius*, pteropods, *Pyrosoma* (a tunicate), and crustaceans. Mori (1972) found skipjack in the stomachs of longline-caught northern bluefin.

3.43 Growth rate

The age and growth of northern bluefin has been studied by Kimura (1932), Aikawa and Kato (1938), Bell (1963b), Koski (1967), Yukinawa and Yabuta (1967), and Schultze and Collins (1977). Kimura used length-frequency data, Aikawa and Kato used vertebrae, and the others used scales to estimate the ages of the fish. Koski verified that distinctive marks are formed on the scales once each year, with the midpoint in April, and thus that their use to estimate the ages of the fish is valid. The results are summarized in Table 1. l_{∞} and *K* are parameters of the von Bertalanffy growth equation. *K*, which was estimated by the compiler of this report, is expressed on an annual basis.

Data on the length-weight relationship are given by Bell (1964) and Shingu, Warashina, and Matsuzaki (1974).

3.44 Metabolism

The tunas, including the northern bluefin, differ from most fishes in that they maintain their body temperatures at higher levels than the water in which they live. This is accomplished by the *retia mirabile*, networks of arteries and veins in the fish's body in which the relatively cool arterial blood coming from the gills is warmed by the relatively warm venous blood coming from the muscles, brain, and eyes, and *vice versa* (Carey and Teal, 1966 and 1969; Carey, Teal, Lawson, Kanwisher, and Beckett, 1971; Linthicum and Carey, 1972; Carey, 1973; Carey and Lawson, 1973; Stevens and Neill, 1978). Northern bluefin, which apparently tolerate a wide range of temperature, have body temperatures which are much warmer than the water when the latter is cold, but only slightly warmer than the water when it is warm. The mechanisms of thermoregulation are discussed by Dizon and Brill (1979a).

Barrett and Williams (1965) measured the hemoglobin content of the blood of 10 specimens of northern bluefin and found it to range from 18.7 to 21.0 g per 100 ml of blood.

3.5 Behavior

3.51 Migrations and local movements

Date for tagged northern bluefin released in the eastern Pacific (Bayliff and Calkins, 1979) indicate that the fish tend to migrate northward along the coast of Baja California and California from June to September. This pattern of movement can also be discerned from Figure 4, which shows the distributions of the catches by months. In the vicinity of Japan the fish tend to migrate northward along the Pacific coast during the summer and southward during the fall and winter. Smaller fish, weighing less than about 8.3 kg, tend to occur near shore, whereas medium and larger fish usually occur further offshore (Yamanaka *et al*., 1963). Large bluefin enter the Sea of Japan through the Tsushima Channel, west of Kyushu, in the early summer, and migrate northward as far as Hokkaido, or even Sakhalin Island and the Okhotsk Sea. Most of them leave the Sea of Japan through the Tsugara Strait, north of Honshu. Some of the smaller bluefin which occur in the northern Sea of Japan leave through the Tsugara Strait and others migrate to the southwest coast of Honshu in the Sea of Japan (Okachi, 1963a).

Eleven tagged fish have made trans-Pacific migrations, two from the western to the eastern Pacific and nine from the eastern to the western Pacific (Orange and Fink, 1963; Clemens and Flittner, 1969). These are listed in Table 2.

3.52 Schooling

Northern bluefin occur in schools at the surface until they reach roughly 100 to 200 pounds or 40 to 80 kg in weight. Catches in excess of 100 tons of fish have been made from single schools, and Bell (1963a) reports that "in August 1958, 8,000,000 pounds [3,629 metric tons] were removed from a school group off San Benito Island [Baja California]." They tend to school by size, *i.e*. small fish with small fish and medium fish with medium fish. Purse-seine vessels in the eastern Pacific sometimes catch northern bluefin in the same sets with albacore, yellowfin, bigeye, skipjack, bonito, *Sarda chiliensis*, or yellowtail, *Seriola dorsalis*. In the western Pacific Yamanaka *et al*. (1963) report that small bluefin school with frigate or bullet tuna, *Auxis* sp.

3.53 Responses to stimuli

Inoue, Iwasaki, Amano, Aoki, and Yamauti (1970) found positive phototaxis in captive northern bluefin. It is noteworthy that this species is caught frequently by baitboats and trollers in the western Pacific (Tatsuki, Uto, and Kitamura, 1963), but only rarely by such vessels in the eastern Pacific.

4 POPULATION

4.1 Structure

4.11 Sex ratio

Fragmentary information on the sex ratio of northern bluefin is given by Bell (1963a) and Yamanaka *et al*. (1963).

4.12 Age composition

The numbers of northern bluefin of each age group landed in California by commercial vessels during 1963-1969 were estimated by Schultze and Collins (1977) to be as follows:

Age group	0	1	2	3	4	5	6
Number of fish	3,900	3,390,700	2,418,200	250,100	12,100	900	310
Percentage of fish	0.1	55.8	39.8	4.1	0.2	0.0	0.0

4.13 Size composition

The annual length-frequency distributions of northern bluefin caught by commercial gear in the western Pacific during 1963-1969 (Schultze and Collins, 1977) and 1973-1978 (Anonymous, 1979a) are shown in Figure 1. These data are grouped by 2-cm intervals and smoothed by moving averages of three, with the center frequency being given double weight. The monthly length-frequency distributions for 1976, a fairly representative year, are shown in Figure 2. The average size of sport-caught fish is roughly 25 pounds (11 kg), equivalent to a length of about 80 cm, but before the advent of the commercial fishery the incidence of large fish in that fishery is believed to have been greater.

Tatsuki, Uto, and Kitamura (1963) show length-frequency data for fish caught by baitboats and trollers in the western Pacific during January-April 1952-1954 and 1957-1959. The fish ranged from 44 to 70 cm in length, with modes at 50 to 58 cm. Yukinawa and Yabuta (1967) and Maeda and Shiota (1979) show similar data for January-December 1953-1963 (Figure 3) and November-January 1974-1978, respectively. Weight-frequency data for fish caught by purse-seines, longlines, and traps in various years are given by Yamanaka (1958), Okachi (1963a), Yamanaka _et al_.(1963), Watanabe (1968), Nakamura (1969), Shingu, Warashina, and Matsuzaki (1974), and Honma and Suzuki (1978). These fish are considerably larger, many of them weighing more than 80 kg (dressed weight).

4.2 Abundance and density

The best index of abundance and/or density of a species of fish is usually provided by catch per unit of fishing effort. Such data are not easily obtainable for northern bluefin, however, as the vessels which fish for bluefin almost always fish for other species at the same time. Such being the case, the best indications of annual fluctuations in abundance and/or density are provided by annual catch data (Section 5.4, Figure 6, and Table 3). The lower catches of the earlier years may be due to lower effort, or course.

Judging by the world catches of tunas (Joseph, 1973), northern bluefin are considerably less abundant than skipjack, _Katsuwonus pelamis_, yellowfin, _Thunnus albacares_, albacore, _T. alalunga_, bigeye, _T. obesus_, and bonito, _Sarda_ spp., and roughly as abundant as southern bluefin, _Thunnus maccoyii_.

4.3 Natality and recruitment

As the fecundity of northern bluefin is quite high (Section 3.1), obviously only a few of the offspring survive to maturity. Fish are recruited to the troll and baitboat fisheries of the western Pacific during the summer of their first year of life, when they are about 20 to 30 cm in length (Yabe, Ueyanagi, and Watanabe, 1966; Yukinawa and Yabuta, 1967). Fish are recruited to the purse-seine fishery of the eastern Pacific during the spring following their first year of life (Clemens and Flittner, 1969) when they are about 50 to 55 cm long (Table 1).

4.4 Mortality and morbidity

Bayliff and Calkins (1979) used age composition data from Schultze and Collins (1977) and tag return data from Bell (1970) to estimate the annual instantaneous total rate of attrition of northern bluefin in the eastern Pacific. The results were as follows:

Age composition data

Year class	Instantaneous total rate of attrition
1962	1.81
1963	1.62
1964	3.10
1965	1.32

Tag return data

Year of release	Instantaneous total rate of attrition
1962	1.90
1963	1.63
1964	1.69
1966	3.55

It was assumed for these calculations that the fishing effort was constant from year to year and that the fish of the various age groups were equally vulnerable to the fishery. The attrition rate estimated from the tag return data includes mortality due to carrying the tags and losses due to shedding of the tags, whereas that estimated from age composition data does not. These were probably minor, however, relative to fishing and natural mortality and emigration. Six of the estimates are relatively close to one another, and the other two are considerably higher. The tagged fish released in 1966 were 15 to 25 pounds (7 to 11 kg) in weight, which means that they were members of the 1964 and 1965 year classes. Perhaps at the end of the 1966 fishing season a much higher than usual portion of the age-2+ fish emigrated from the eastern to the western Pacific Ocean. If so, this could explain the high rates of attrition for the 1964 year class estimated from age composition data and for the tagged fish released in 1966 estimated from tag return data.

Tauchi (1940) estimated the annual survival rate of young fish to be 0.30 and that for adults to be 0.75 in the western Pacific. These are equivalent to instantaneous total rates of mortality of 1.20 and 0.29, respectively.

4.5 Dynamics of the population

There have been no studies of the population dynamics of northern bluefin, although some of the data which would be useful for this purpose have been collected.

4.6 The population in the community and the ecosystem

Doi (1960) used the catches of northern bluefin and those of squid and five species of smaller fishes as indices of their abundance, and then applied Volterra's predator-prey equations to the data to compare the observed and theoretical abundances. The actual and expected results were fairly close for the bluefin-squid model for 1951-1955 and for the bluefin-squid plus smaller fish model for 1951-1956. Yokota, Toriyama, Kanai, and Nomura (1961) discussed the northern bluefin as a prey species and a predator species.

5 EXPLOITATION

5.1 Fishing equipment

In the eastern Pacific northern bluefin are caught almost entirely by purse seines (McNeely, 1961; De Fever, 1968; Green, Perrin, and Petrich, 1971). The remainder of the catch is made by baitboat, trolling, and sport-fishing gear. The purse seiners range in capacity from less than 50 to more than 1,000 metric tons. Proportionally more bluefin are caught by the purse seiners with capacities of less than about 300 metric tons. In the western Pacific this species is caught at the surface by gill nets, purse seines, traps (set nets), trolling gear, baitboat gear, harpoons, and sport-fishing gear (Yamanaka _et al_., 1963; Anonymous, 1965a; Honma and Suzuki, 1978). The purse seines have been employed with either one or two boats, but during the 1970's the former have largely replaced the latter. Most of these vessels have capacities of about 100 to 500 metric tons. Most of the trolling vessels have capacities of less than 5 metric tons (Hisada, Shingu, and Yonemori, 1979). Northern bluefin are caught beneath the surface in the western Pacific, and to a much lesser extent in the central and eastern Pacific, with longlines (Kanasashi, 1960; Yoshida, 1966b). The longlines are operated near

Japan with vessels of about 20 to 50 gross tons (Yamanaka et al., 1963), and in more distant waters with larger vessels.

5.2 Fishing areas

The monthly distributions of northern bluefin caught by purse seiners in the eastern Pacific during 1969-1978 are shown in Figure 4. The figure includes only data recorded in the vessel logbooks and made available to the Inter-American Tropical Tuna Commission. These represent 72 to 98 percent of the actual catches during the 1969-1978 period. Prior to 1930 fishing was conducted only off California. During that year fish were discovered off Guadalupe Island, Baja California, and about 40 percent of the catch in 1930 was made in that area (Whitehead, 1931). From 1930 through 1947 fishing was conducted off both California and Baja California, but in most years the majority of the catch came from off California. From 1948 to the present, however, most of the catch has been made off Baja California. The average annual catches made off California during the 1960's and 1970's have been considerably less than the average annual catches made in the same area during the 1918-1929 period. It is believed that the principal reason for this is that during more recent years the larger vessels fishing off Baja California have tended to intercept the fish before they reach the waters off California. It should be remembered, however, that the distribution of the fish in the area between Cabo San Lucas and Point Conception is also influenced by sea-surface temperatures (Section 2).

According to Yamanaka et al. (1963), prior to the 1940's northern bluefin were caught by gill nets southeast of Hokkaido and east of northern Honshu and by longlines off the east coast of Japan from northern Honshu to Okinawa, southeast of Taiwan, and northwest of Luzon. Fish were scarce during the 1940's. Since the early 1950's, at least, they have been caught by gill nets and purse seines southeast of Hokkaido and east of northern Honshu and by longliners off the east coast of Japan from southeast of Hokkaido to Okinawa and south of Okinawa to about 18° north latitude. Hisada, Shingu, and Yonemori (1979) state that northern bluefin are caught in traps on both the Pacific and Sea of Japan coasts of Honshu and Hokkaido. The troll fishery is pursued principally west and south of Kyushu and southeast of Kyushu, Shikoku, and Honshu.

The areas in which Japanese longliners have recorded catches of northern bluefin during 1972-1976 (Anonymous, 1974a, 1975a, 1976a, 1977a, and 1978b) are shown in Figure 5.

5.3 Fishing seasons

In the eastern Pacific northern bluefin are caught by purse seines in all months of the year, but most of the catches are made during May through October. The portion of fish longer than 100 cm is higher during November through April than during May through October (Figure 2). Fish are also caught during all months by the surface fishery in the western Pacific. The purse-seine fishery takes place from May to October, and bluefin are caught in traps during about the same period. Bluefin are caught by trolling west of Kyushu during October to January, south of Kyushu from December to April, and southeast of Kyushu, Shikoku, and Honshü during April to September (Hisada, Shingu, and Yonemori, 1979). The offshore longline fishery is also pursued during all months of the year.

5.4 Fishing operations and results

Some catch statistics for northern bluefin are presented in Figure 6 and Table 3. The eastern Pacific data were obtained from Whitehead (1931), Bell (1963a and 1971), Frey (1971), Oliphant (1973 and 1979), Pinkas (1974 and 1977), McAllister (1975 and 1976), and unpublished records of the Inter-American Tropical Tuna Commission. The data for 1918 through 1960 include only the catches landed in California, but it is believed that the catches landed elsewhere prior to 1961 were inconsequential. The eastern Pacific sub-surface catches for all years are omitted, but these are also believed to be inconsequential. The western Pacific data for 1951-1959 were obtained from Yamanaka et al. (1963) and those for 1964-1978 from Anonymous (1971-1979). Yamanaka et al.'s data are for "around Japan" only, but the catches made elsewhere in the western Pacific were probably minor. Their 1951 and 1952 data include southern bluefin, but the catches of this species in the vicinity of Japan are probably inconsequential. Yamanaka et al. also state that fish were scarcer during the 1940's than during the 1930's and 1950's. According to Watanabe (1968) the trap catches in the Sea of Japan were poor during 1922-1927, good during 1928-1939, poor during 1940-1952, and good during 1953-1964.

6 PROTECTION AND MANAGEMENT

A few regulations concerning northern bluefin in the eastern Pacific have been promulgated from time to time (Clemens, no date), but essentially there is no management program in this area. In the western Pacific, according to Yamanaka et al. (1963), there are regulations regarding the numbers of fishing vessels which affect the catch of that species.

7 CULTURE

Northern bluefin have been raised in enclosures in Japan on an experimental basis for periods of up to 5 years (Ueyanagi, Mori, Nishikawa, and Suda, 1973; Harada, Kumai, and Okamoto, 1976; Harada, 1978; Ueyanagi, 1978). The experiments have been carried out at various locations on southern Honshu, Shikoku, Kyushu, and Tsushima Islands. The fish are caught by traps and trolling gear in the late summer and fall and transported to enclosures of wire or synthetic fiber netting. They survive better if they are less than 1 kg in weight when caught and if they are handled with care. The trap-caught fish survive better than do the troll-caught ones. Those which do not die due to the shock of capture and handling survive better in wire enclosures than in synthetic fiber enclosures. This is due to the fact that the wire enclosures do not flex during stormy weather and because the water circulation is better through them. If the enclosure is in an enclosed bay and the salinity decreases suddenly due to heavy rainfall the fish are likely to die.

The fish have been fed various species of smaller fish, including mackerel, horse mackerel, anchovies, sand lance, round herring, saury, and frigate mackerel. They can be induced to feed fairly easily, first beginning to eat about 4 to 6 days after capture. The growth is rapid, fish of about 0.25 to 0.30 kg captured in August growing to about 2.5 to 3.0 kg by December. The feeding decreases considerably in winter, and the growth ceases during that period. If the water temperature goes below 15°C in the winter the growth does not resume in the spring, but otherwise it does. Fish of about 33 cm and 500 g caught in late August 1972 grew to about 140 cm and 50 kg by November 1, 1975.

In June 1979 bluefin were observed to spawn in captivity for the first time, and several hundred thousand eggs were collected and transferred to hatching tanks. When they hatched the larvae were fed with *Chlorella* algae and the rotifer *Brachionus plicatilis*. They grew to about 4 mm in 4 days (Anonymous, 1979h and 1979i).

8 A MODEL FOR NORTHERN BLUEFIN MIGRATION IN THE PACIFIC OCEAN

A preliminary model for the migration of northern bluefin has been formulated for this report. This model is based to a considerable extent upon the ideas of Flittner (1966), Nakamura (1969), and Bell (1970). However, any errors which appear in this section are the responsibility of the compiler of this report. It is anticipated that, as additional data accumulate, or as different interpretations are made of the data presently available, the model will be amplified, modified, or discarded in favor of one that appears to provide a better explanation of what has been observed.

Figure 7 is a diagram of the model. The migrations shown by dashed lines are more speculative than those shown by solid lines. The diagram is intended to show the general areas where the migrations are believed to begin and end, but not the precise routes, as space limitations would make this impractical even if the routes were known. For example, it appears that the route of migration of the juveniles bound for the eastern Pacific is south of the route of migration of the maturing fish bound in the opposite direction, but such is not necessarily the case.

The spawning of northern bluefin occurs between Japan and the Philippine Islands and southeast of Japan during April through July (Yabe, Ueyanagi, and Watanabe, 1966; Nishikawa, Kikawa, Honma, and Ueyanagi, 1978). The larvae, postlarvae, and juveniles are carried northward by the Kuroshio Current toward Japan. Fish of age 0+ about 20 to 60 cm in length are caught in the vicinity of Japan during the summer and fall of the same year (Yabe, Ueyanagi, and Watanabe, 1966; Yukinawa and Yabuta, 1969). Some of these remain in the western Pacific Ocean during the winter and others migrate to the eastern Pacific (Clemens and Flittner, 1969). It is possible that others migrate from the western to the eastern Pacific during their second, third, or even later winters, but there is no evidence of this from tagging. For the 1964 year class there was a shortage of age-1+ fish in the eastern Pacific in 1965, but not a shortage of age-2+ fish in 1966 (Schultze and Collins, 1977). This may be due to the fish of that year class migrating from Japan mostly during their second winter (1965-1966), instead of during their first winter (1964-1965). The fish which migrate from the western to the eastern Pacific form the basis for the fishery in the eastern Pacific, which takes place principally during May through October. It is believed that during the rest of the year the fish remain in the eastern Pacific Ocean, but become less vulnerable and/or available to the fishery at this time. A portion of them apparently spend the winter in the vicinity of Guadalupe Island, as northern bluefin, especially large ones, are caught there during all months of the year. Some of the fish re-enter the eastern Pacific fishery in the following spring, while others return to the western Pacific eventually to spawn. Those which re-enter the eastern Pacific fishery are destined eventually to return to the western Pacific, however. The return journey to the western Pacific may take nearly 2 years, as 674 days is the minimum time recorded between release and recapture of a tagged fish making this migration (Table 2). This fish was 1+ years old when released and 3+ years old when recaptured. Other tagged fish released at age 1+ in the eastern Pacific were recaptured at age 3+ in the same area 2 years later and fish even older than 3+ years occur in that area (Section 3.31), so it is obvious that the length of the sojourn of the fish in the eastern Pacific is not uniform.

In Figure 7 it appears that the fish in the eastern Pacific occur further and further offshore and have an increasingly restricted north-south distribution as they grow older. It was necessary for the sake of clarity to make the diagram this way, but actually such is not necessarily the case.

The fish caught by longline vessels between North America and Japan (Figure 5) are probably en route from the eastern to the western Pacific. Upon arriving in the western Pacific they presumably proceed to the area between Japan and the Philippine Islands and southeast of Japan to spawn, either immediately or eventually.

Northern bluefin are also caught by longline vessels east of the Philippine Islands, northeast of Papua New Guinea, and southeast of Australia, especially in the vicinity of New Zealand (Figure 5). The question arises as to whether these fish come from larvae, postlarvae, and juveniles which went south from the spawning area, from young fish which migrated south from Japan after a brief sojourn there, or from older fish which migrated south from the spawning area after spawning. If either the first or second possibility is the case there should be small northern bluefin south of 20° north latitude. Small numbers of baitboat-caught northern bluefin have been recorded north of Papua New Guinea and in the vicinity of the Solomon and Marshall Islands (Anonymous, 1977f, 1977g, 1977h, 1977i, and 1977j), so it appears that at least some of the northern bluefin caught south of the spawning grounds by longline vessels are the result of movement of larvae, postlarvae, and juveniles from the spawning area or the result of migration of young fish south from Japan. However, this does not mean that none of them are the result of migration of adult fish south from the spawning area after spawning.

Larvae or postlarvae of northern bluefin have not been found in the Australia-New Zealand area, so it is not likely that the fish which are caught there by longlines would have spawned there. Rather, they would have to migrate back to the spawning area or not spawn at all.

After spawning the fish probably disperse from the spawning area to other areas of the western Pacific. Some may even migrate to the eastern Pacific, though this seems unlikely. The following year they presumably return to the spawning area to spawn again.

There might be several subpopulations of northern bluefin in the Pacific Ocean, for example, one which originates in the spawning area, migrates to Japan, and then returns to the spawning area to spawn, one which originates in the spawning area, migrates to Japan, then migrates to North America, and finally returns to the spawning area to spawn, and one which originates in the spawning area, migrates to the area south of 20° north latitude, either directly or by way of Japan, and then returns to the spawning area to spawn. On the other hand, there may be only one subpopulation in the Pacific Ocean, in which case the portions of this which migrate to the eastern Pacific Ocean and the area south of 20° north latitude are presumably determined by oceanographic conditions.

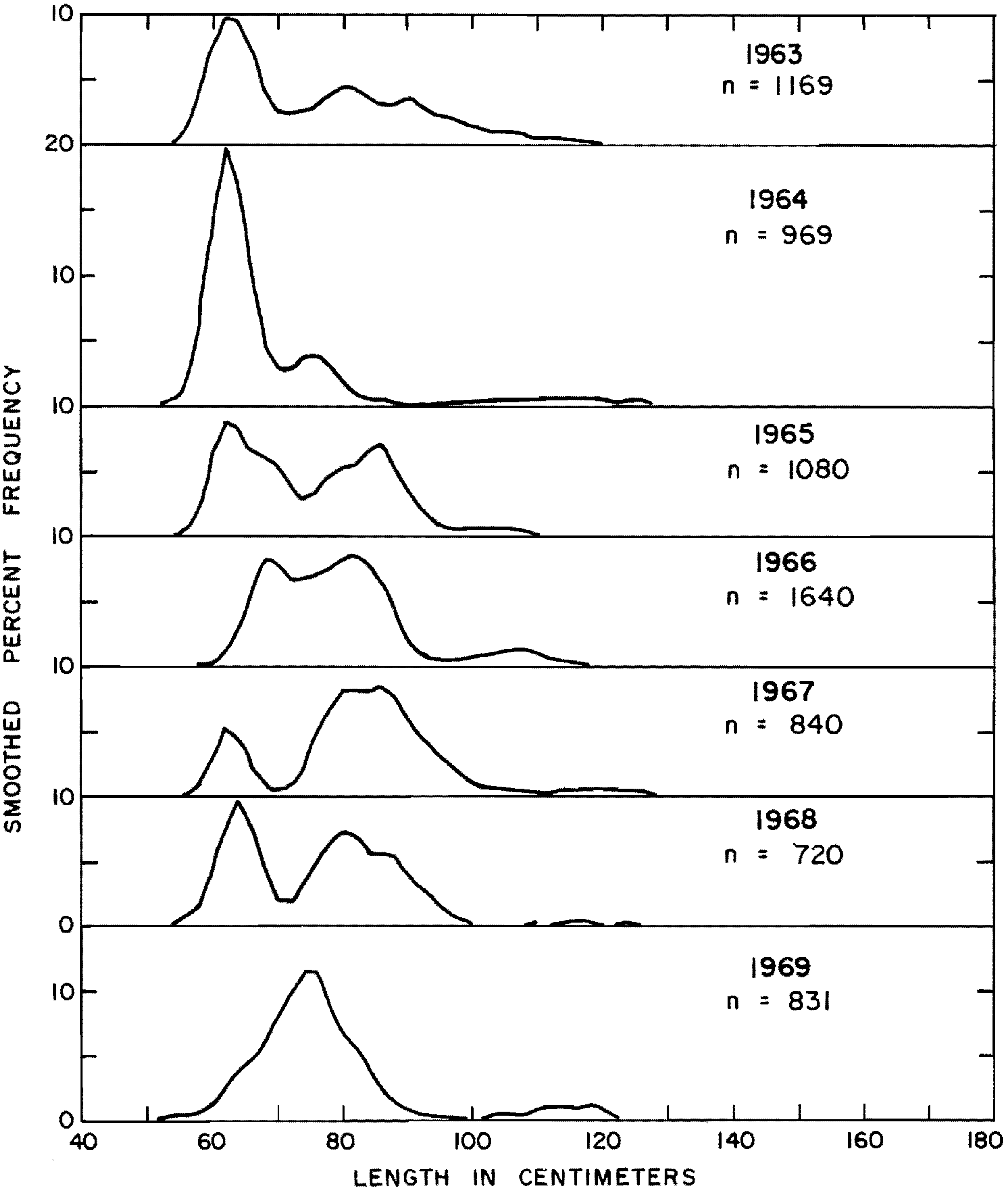

FIGURE 1. Annual length-frequency distributions for surface-caught northern bluefin of the eastern Pacific Ocean during 1963-1969 and 1973-1978.

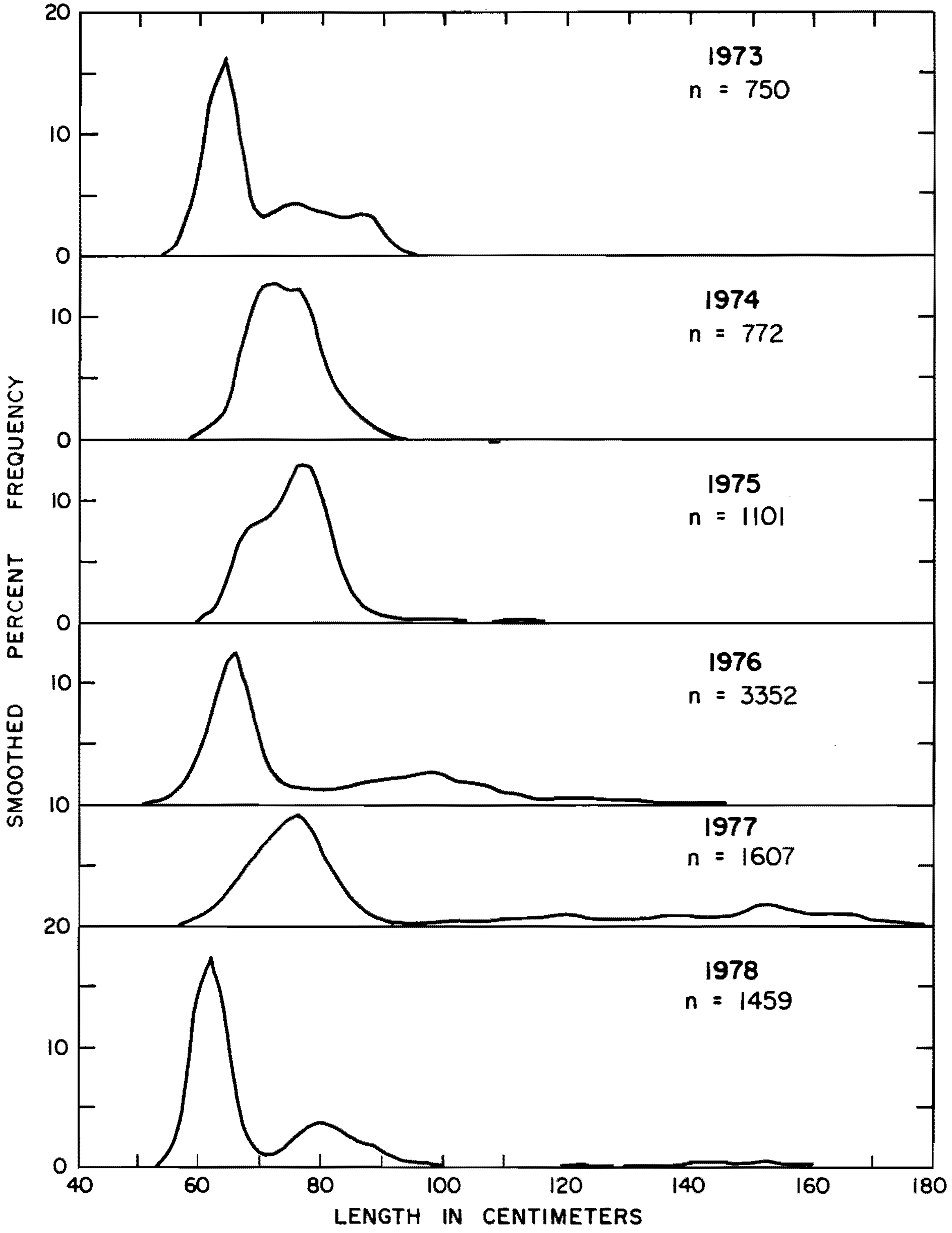

FIGURE 1. (continued)

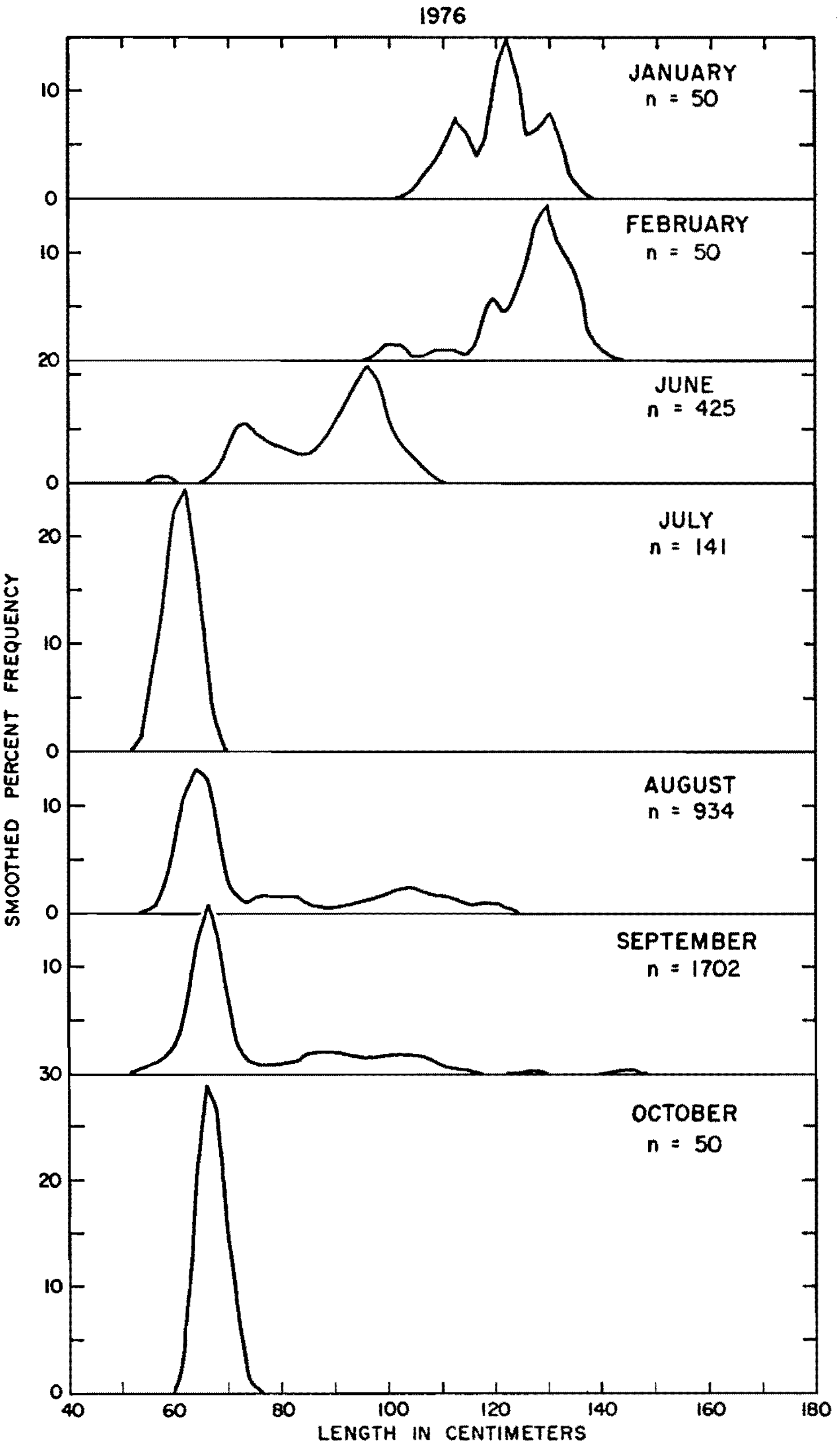

FIGURE 2. Monthly length-frequency distributions for surface-caught northern bluefin of the eastern Pacific Ocean during 1976.

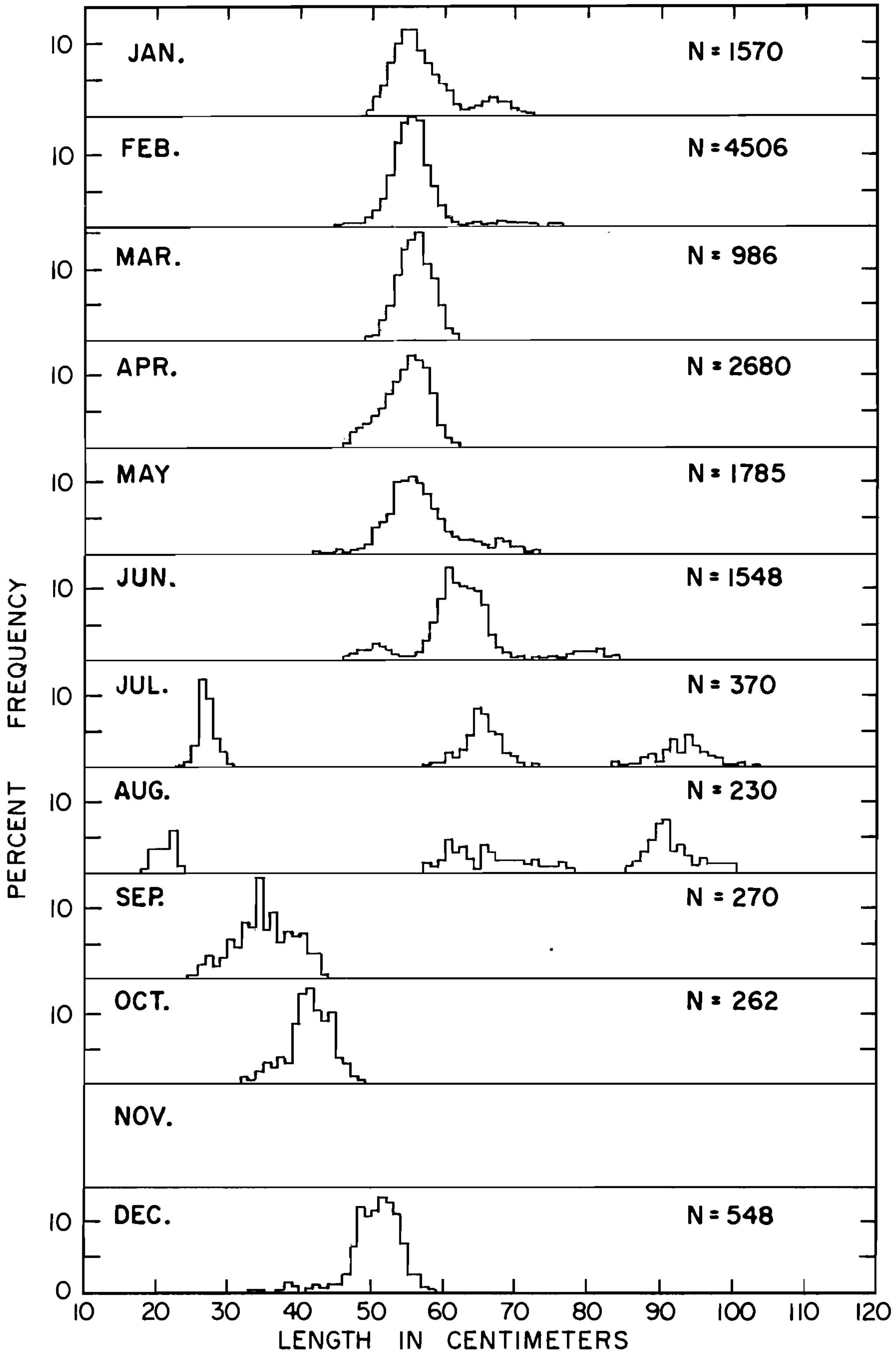

FIGURE 3. Average monthly length-frequency distributions for northern bluefin caught by surface gear north of Satunan during 1953-1963 (after Yukinawa and Yabuta, 1967).

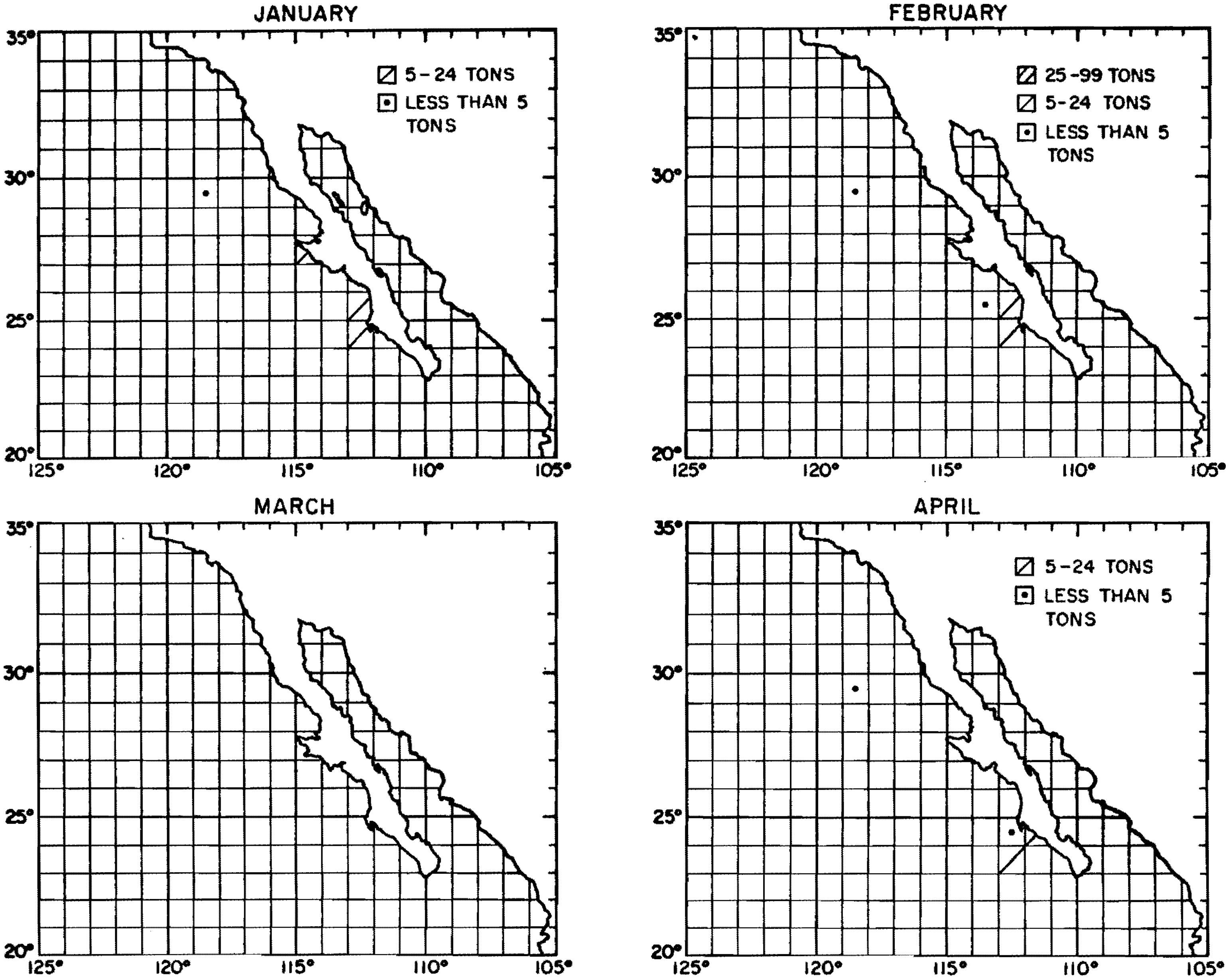

FIGURE 4. Average monthly distributions of northern bluefin caught by surface gear in the eastern Pacific Ocean during 1969-1978. The data are in short tons; 1 short ton = 0.907185 metric ton.

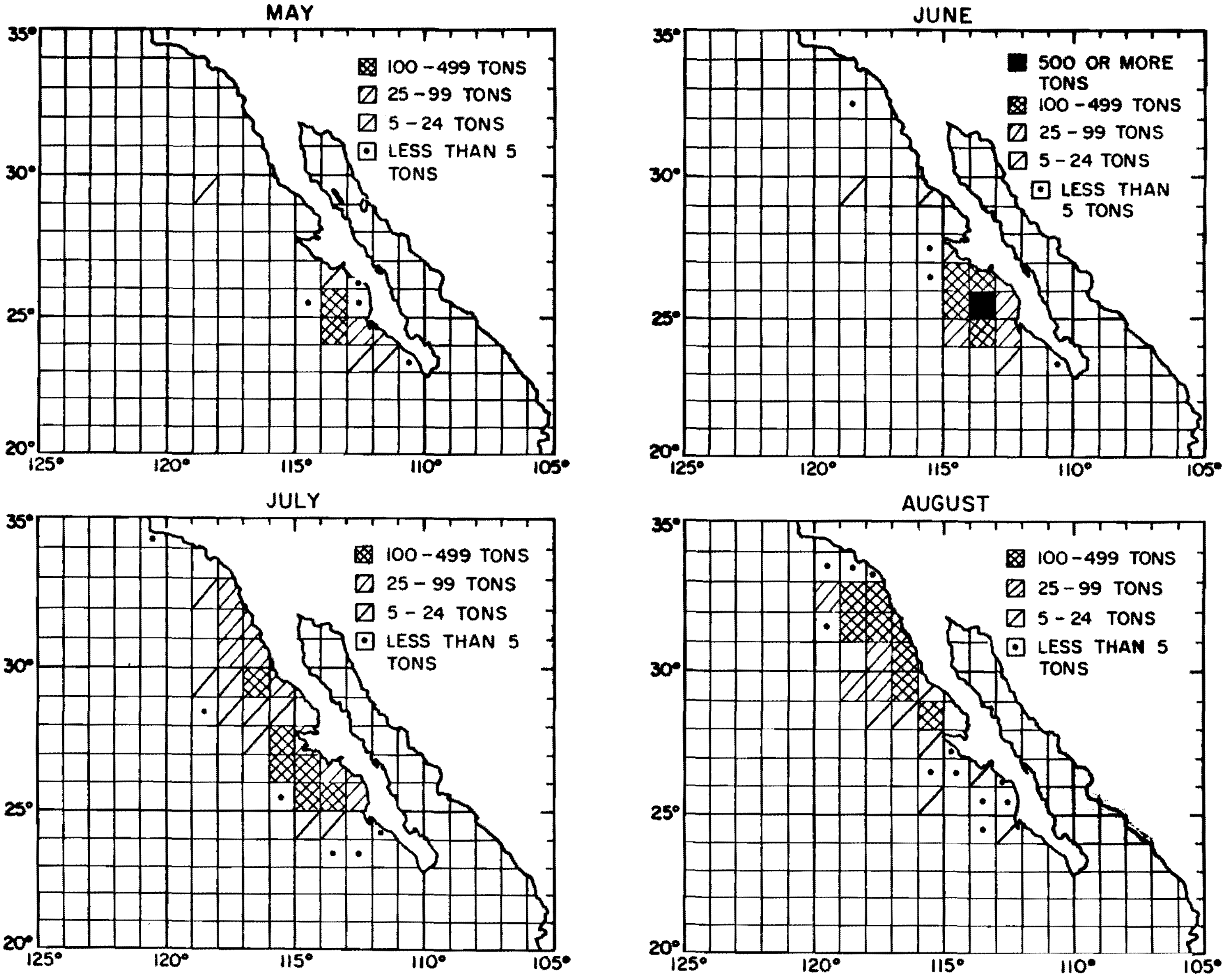

FIGURE 4. (continued)

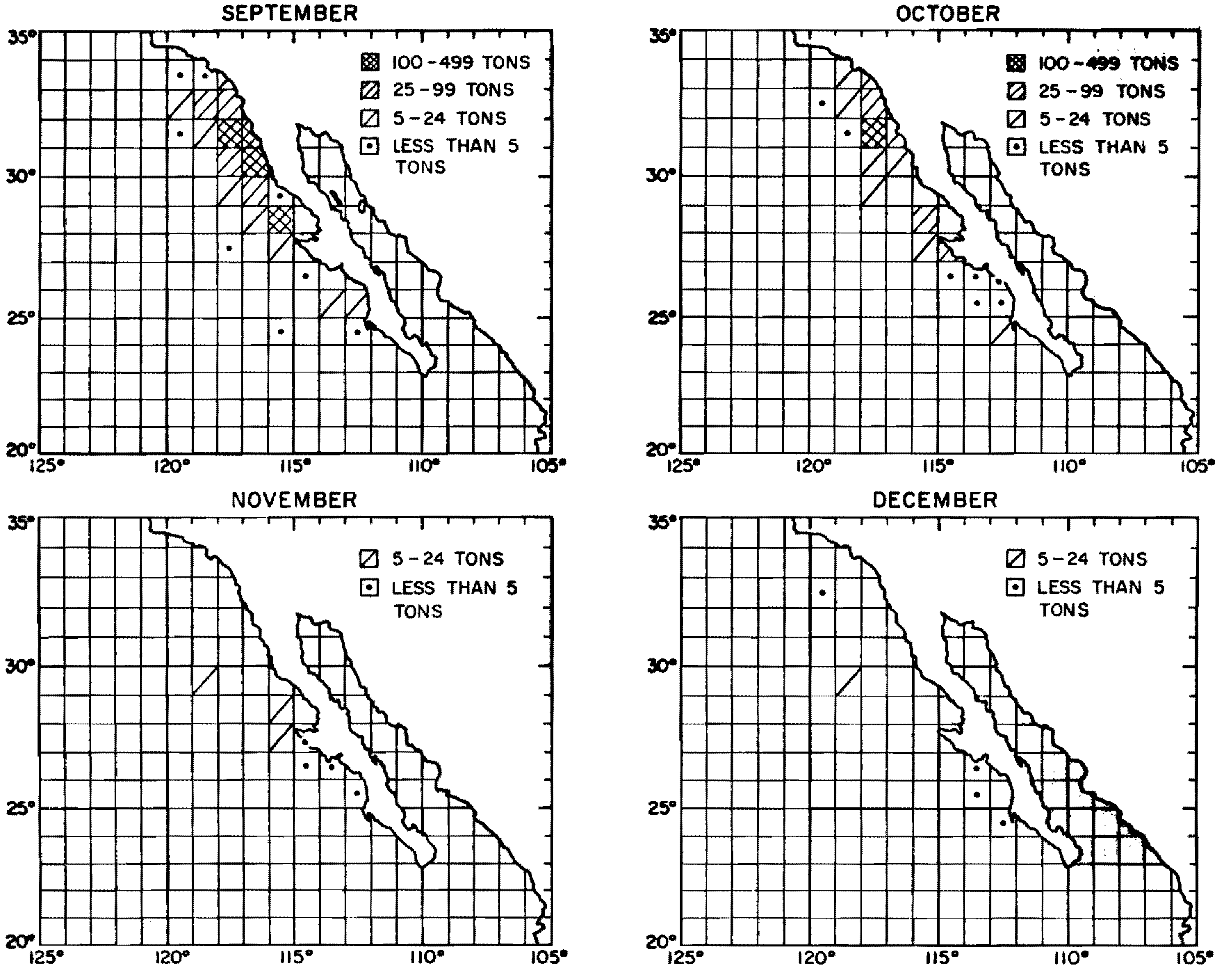

FIGURE 4. (continued)

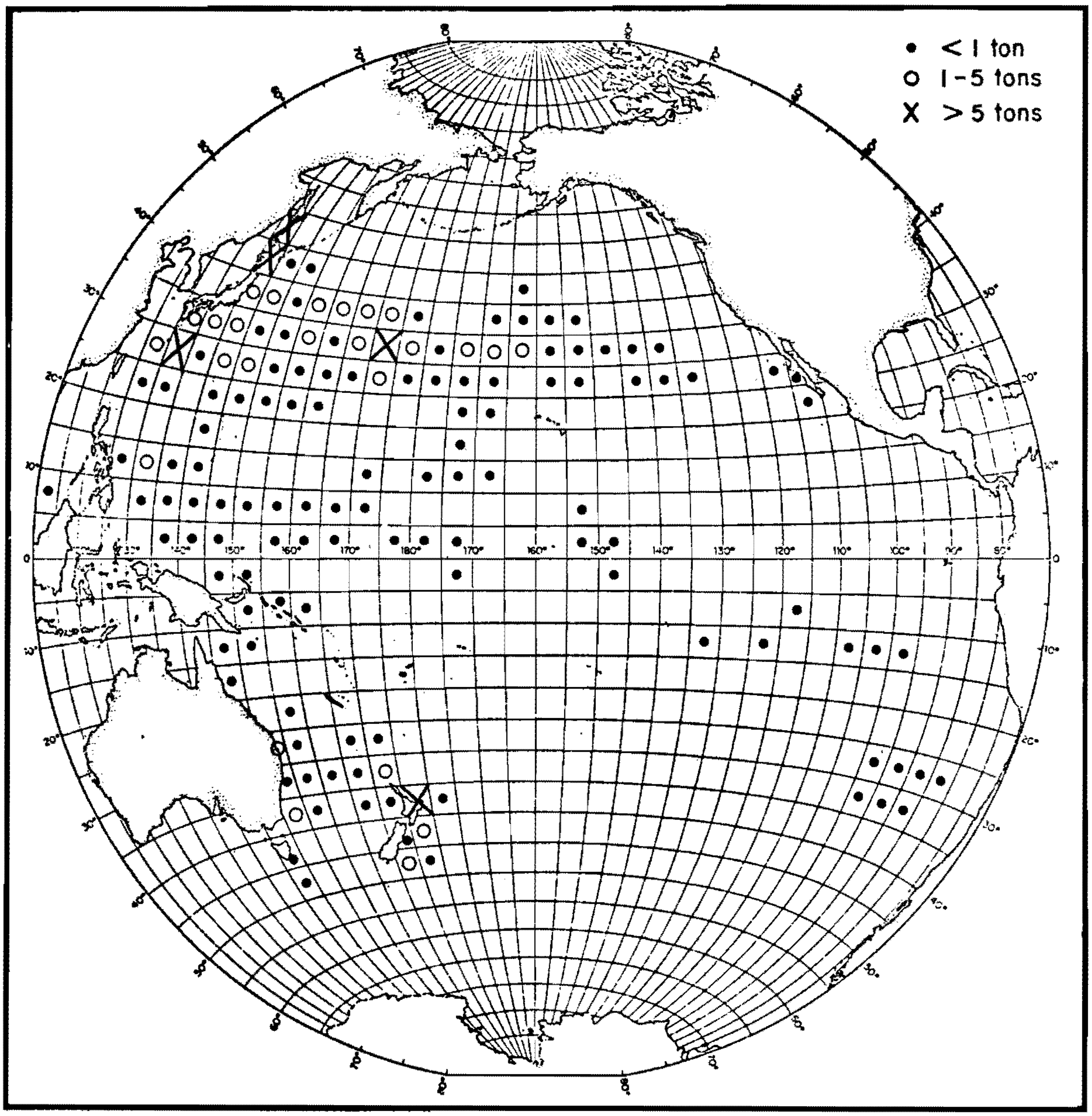

FIGURE 5. Average annual distribution of northern bluefin caught by Japanese longliners during 1972-1976.

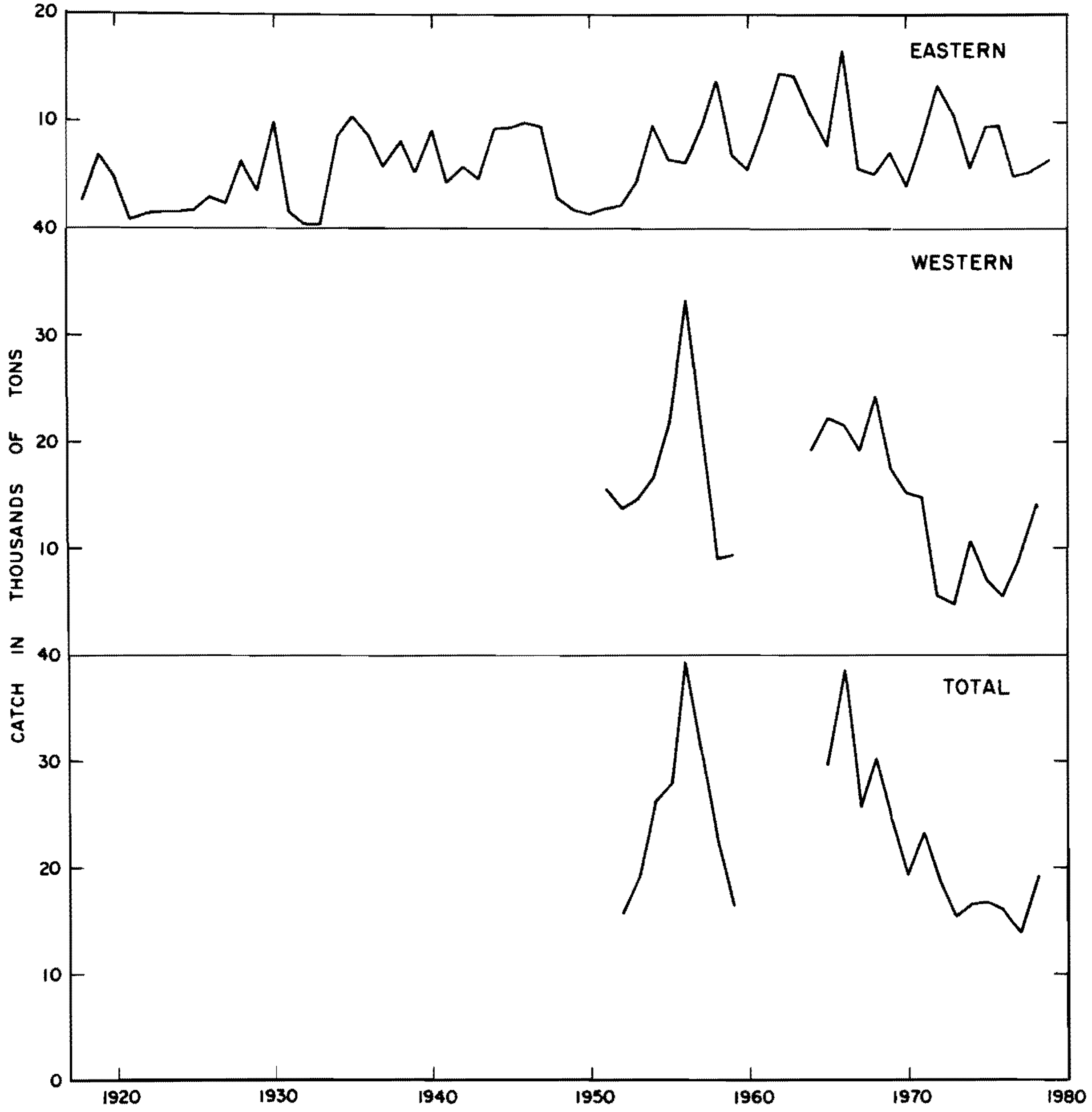

FIGURE 6. Catches of northern bluefin in the Pacific Ocean in metric tons.

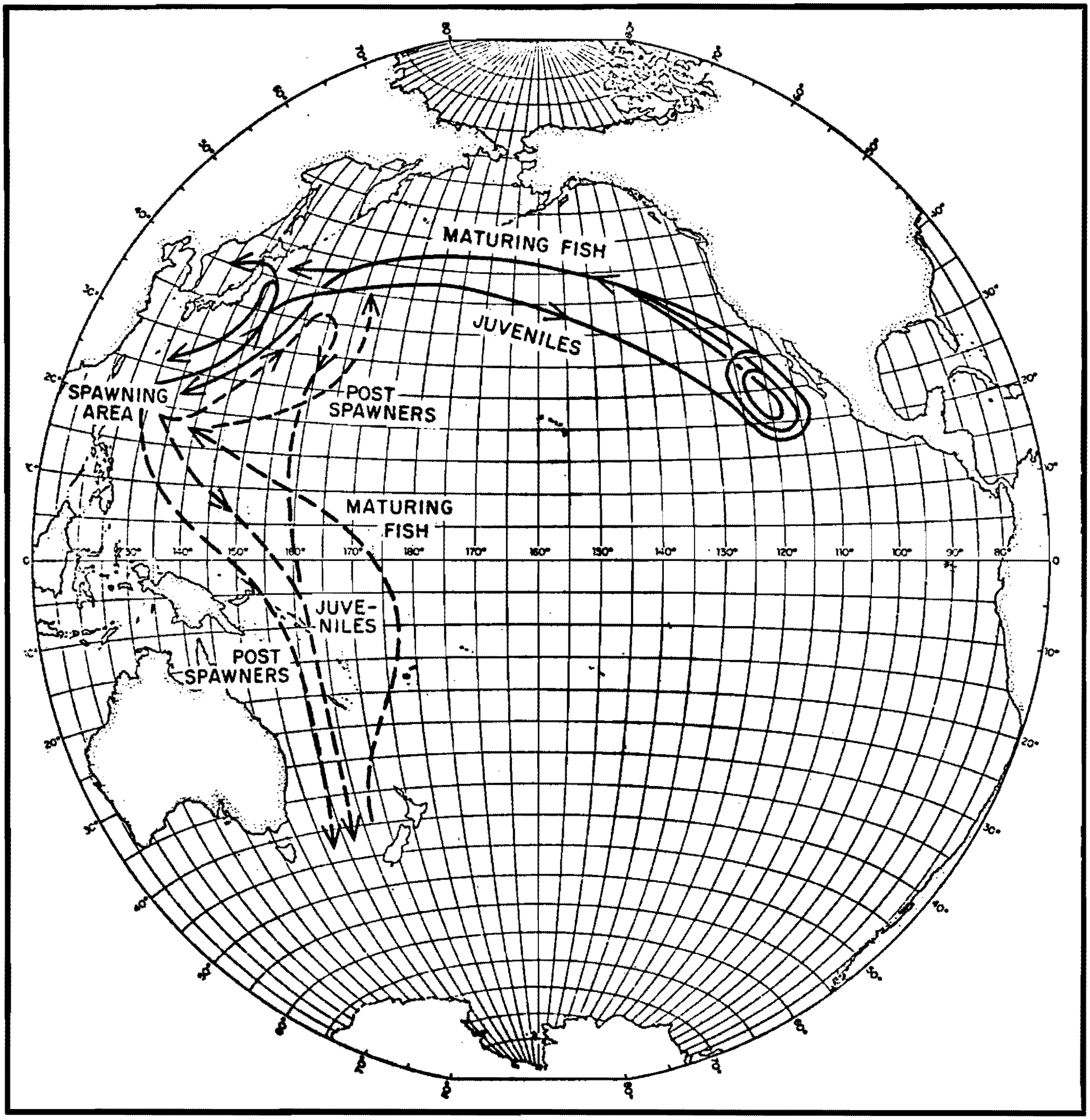

FIGURE 7. A model for northern bluefin migration in the Pacific Ocean.

TABLE 1. Age and growth data for northern bluefin. The sample of Bell consisted of 247 fish, of which approximately half had legible scales.

Reference	Sample size	Age										l_{oo}	K
		1	2	3	4	5	6	7	8	9	10		
Aikawa and Kato, 1938	21	43	69	94	118	145	168	190	210	230	250		
Bell, 1963b	about 124	57.10	72.08	90.65	106.95	128.50	142.00						
Yukinawa and Yabuta, 1967	97	51.8	78.2	102.0	123.5	142.9	160.3	176.1				320.5	0.103
Shultze and Collins, 1977	2,743	53.0	80.4	104.8	126.3	145.5	162.4					295.4	0.120

TABLE 2. Release and recapture data for northern bluefin which have made trans-Pacific migrations.

Release			Recapture			Days	Miles
Area	Date	Length	Area	Date	Length		
28°45'N-118°15'W	Feb. 2, 1958	?	29°03'N-139°42'E	Apr. 23, 1963	182.5	1,907	5,147
29°43'N-117°20'W	Aug. 15, 1962	?	40°44'N-140°00'E	Jun. 18, 1964	?	674	4,781
29°43'N-117°20'W	Aug. 15, 1962	?	41°39'N-141°09'E	Aug. 17, 1964	115	734	4,708
29°50'N-117°13'W	Aug. 16, 1962	?	41°15'N-140°43'E	Aug. 29, 1964	?	745	4,737
29°48'N-116°57'W	Aug. 14, 1962	?	34°16'N-136°54'E	June 23, 1965	138	1,045	5,124
33°21'N-119°01'W	Aug. 21, 1962	?	41°43'N-141°03'E	Aug. 10, 1965	120	1,086	4,514
32°41'N-117°55'W	Aug. 20, 1964	60	38°25'N-139°15'E	Jul. 1, 1966	110	681	4,746
30°30'N-116°45'W	Aug. 13, 1964	85	38°49'N-142°28'E	Jul. 4, 1968	?	1,422	4,734
32°41'N-117°55'W	Aug. 20, 1964	65	39°37'N-143°16'E	Jul. 14, 1968	158	1,425	4,549
35°31'N-140°46'E	Aug. 27, 1965	36	27°00'N-144°34'W	Jul. 15, 1966	68	323	5,124
35°30'N-140°53'E	Aug. 27, 1965	36	30°01'N-116°39'W	Aug. 9, 1966	71	348	4,923

TABLE 3. Catches of northern bluefin in the Pacific Ocean in metric tons. The 1979 value is preliminary.

Year	Eastern Pacific surface fishery		Western Pacific surface and subsurface fishery	Total
	Commercial	Sport		
1918	2,722			
1919	6,800			
1920	4,776			
1921	894			
1922	1,275			
1923	1,460			
1924	1,470			
1925	1,725			
1926	2,960			
1927	2,222			
1928	6,215			
1929	3,414			
1930	9,943			
1931	1,603			
1932	486			
1933	254			
1934	8,327			
1935	11,418			
1936	8,584	33		
1937	5,758	46		
1938	8,041	135		
1939	5,369	112		
1940	9,058	78		
1941	4,318			
1942	5,826			
1943	4,617			
1944	9,228			
1945	9,341			
1946	9,993			
1947	9,452	25		
1948	2,961	1		
1949	1,991	22		
1950	1,242	0		
1951	1,752	81	15,400	17,233
1952	2,076	2	13,700	15,778
1953	4,433	48	14,600	19,081
1954	9,537	11	16,600	26,148
1955	6,173	93	21,700	27,966
1956	5,727	388	33,100	39,215

TABLE 3. (continued)

Year	Eastern Pacific surface fishery		Western Pacific surface and subsurface fishery	Total
	Commercial	Sport		
1957	9,215	73	21,100	30,388
1958	13,934	10	9,000	22,944
1959	6,914	15	9,300	16,229
1960	5,422	1		
1961	9,603	26		
1962	14,651	28		
1963	14,189	8		
1964	10,642	8	19,300	29,950
1965	7,556	1	22,200	29,757
1966	16,846	23	21,800	38,669
1967	6,601	36	19,100	25,737
1968	6,063	14	24,300	30,377
1969	7,172	17	17,500	24,689
1970	4,024	21	15,200	19,245
1971	8,415	8	14,800	23,223
1972	13,390	17	5,400	18,807
1973	10,576	61	4,800	15,437
1974	5,748	65	10,629	16,442
1975	9,578	38	7,126	16,742
1976	9,822	23	5,387	15,232
1977	5,233		8,897	14,130
1978	5,355		14,158	19,513
1979	6,117			

SYNOPSIS OF BIOLOGICAL DATA ON THE SKIPJACK TUNA, *KATSUWONUS PELAMIS* (LINNAEUS, 1758), IN THE PACIFIC OCEAN

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FOREWORD

The first synopsis of biological data on skipjack in the Pacific Ocean was compiled by Waldron (1963) and presented in 1962 at the World Scientific Meeting on the Biology of Tunas and Related Species at La Jolla, California, sponsored by the Food and Agriculture Organization of the United Nations. Much of the information in the present paper was obtained from a synopsis of biological data on skipjack from all oceans by Matsumoto and Skillman (in press), and the writer is indebted to these investigators for the use of their manuscript. The present synopsis, however, includes considerable additional information from recent investigations and reports.

The reviews by Blackburn (1965) and Sund, Blackburn, and Williams (1980) of the known and hypothesized relationships between environmental properties and tunas, including skipjack, are valuable to those readers interested in the ecology of skipjack. Useful bibliographies have been compiled by Klawe and Miyake (1967) on the biology and fisheries of skipjack in the Pacific, and by Richards and Klawe (1972) on the eggs and young of tunas, including skipjack.

The writer is grateful for critical reviews of the manuscript by A. W. Argue, Maurice Blackburn, Thomas P. Calkins, and Ronald G. Rinaldo.

CONTENTS

1 IDENTITY

The scientific name for the skipjack tuna is Katsuwonus pelamis.

2 DISTRIBUTION

2.1 Total area

Skipjack are distributed across the Pacific in tropical and sub-tropical latitudes, usually in waters exceeding 20°C at the surface. In the western Pacific, because of poleward-flowing warm currents, they occur commonly from about 40°N to about 40°S, whereas in the eastern Pacific, because of cold equatorward currents, they occur commonly from about 30°N to about 30°S (Brock, 1959; Kearney, 1978; Matsumoto and Skillman, in press). Rare occurrences of skipjack are shown by Matsumoto and Skillman (in press) as far north as 50°N in the western Pacific and 49°N in the eastern Pacific, and as far south as 49°S at 180° and 35°S in the eastern Pacific. Off Tasmania skipjack have been recorded as far south as 43°S (Blackburn and Serventy, 1981).

In the western Pacific skipjack fisheries occur in the vicinity of Japan, the Ryukyu Islands, Taiwan, the Bonin Islands, the Mariana Islands, the western Caroline Islands, the Philippine Islands, Indonesia, Papua New Guinea, the Solomon Islands, Australia, and New Zealand. In the central Pacific fisheries occur near the Hawaiian Islands and in French Polynesia. In the eastern Pacific fisheries occur near Baja California, the Revillagigedo Islands, Clipperton Island, Central America, northern South America, Cocos Island, and the Galapagos Islands. Incidental catches of larger skipjack by longliners fishing for tunas and billfishes show that skipjack are widely distributed throughout the Pacific (Miyake, 1969; Matsumoto, 1975).

2.2 Differential distribution

2.21 Spawn, larvae, and juveniles

The eggs of skipjack cannot yet be differentiated from those of other tunas, so that the distribution of the spawn is unknown.

"In the Pacific Ocean, the known distribution of skipjack larvae now extends from near lat. 35°N off Japan to as far south as lat. 37°S off the southeastern part of Australia. The distribution remains wide eastward until slightly past the Hawaiian Islands in the northern and the Society Islands in the southern hemisphere. The distribution then narrows abruptly toward the equator at about long. 145°W and remains within 10° to 15° of latitude on either side of the equator to the Central and South American coasts" (Matsumoto and Skillman, in press).

Ueyanagi (1969b) and Nishikawa, Kikawa, Honma, and Ueyanagi (1978) show the distribution of skipjack larvae captured in net tows by Japanese research vessels (Figure 1). Klawe (1963) found few larvae in the eastern Pacific (see Matsumoto, 1966).

Unpublished data from the Far Seas Fisheries Research Laboratory, Shimizu, Japan, and data from Ueyanagi (1969b) and Ueyanagi, Mori, and Nishikawa (1969a) show that larvae are concentrated in the equatorial regions and that the abundance increases from east to west. Matsumoto (1975), however, after making adjustments for differences among net tows, found the greatest abundance of skipjack larvae between 160°E and 140°W. Skipjack larvae occur above the thermocline (Klawe, 1963; Matsumoto and Skillman, in press). The Japanese data for the Pacific west of 180° show that skipjack larvae were captured in 22% of surface tows and 55% of subsurface tows (Forsbergh, 1980a). Skipjack larvae are scarce at the surface during the day; they are more common at the surface at night, but are still fewer than at deeper levels (Ueyanagi, 1969b).

Juvenile skipjack are rarely seen or captured by fishermen (Kearney, 1978). In 1979, however, near Oroluk Atoll and Ponape in the Pacific Islands Trust Territory, a research baitboat using very small lures captured juvenile skipjack from schools where the average length was less than 30 cm. Large amounts of skipjack with an average weight of less than 0.5 kg were also reported in the area from 6°N to 8°N and 151°E to 153°E (Kearney and Hallier, 1980).

Most juvenile skipjack have been collected from stomachs of larger tunas and billfishes, from experimental mid-water trawls, and by dipnetting at night under a light. Higgins (1967) defined juvenile tunas as those between 12 mm and 30 cm in length, and compiled all records from the Pacific for the 1916-1966 period: 372 juvenile skipjack were listed from west of 180°, 135 from 180°-140°W, and only 11 east of 140°W.

Yoshida (1971b) examined 1,742 juvenile skipjack from the stomachs of billfishes caught by longline near Hawaii and in the south central Pacific (5°S-32°S, 180°-135°W) and concluded that the juveniles were as widely distributed as the larvae. Mori (1972) defines juvenile skipjack as those less than 15 cm long, and young skipjack as those between 15 and 35 cm long. He examined the data from 3,778 juveniles and young skipjack from the stomachs of billfishes and tuna caught on longlines in the Pacific and showed the relative apparent abundance of juveniles to be greatest west of 180° between 10°N and 10°S and lowest east of 120°W. Mori observed that the distribution of juveniles was similar to that of the larvae, with the juveniles prevailing in areas with surface temperatures greater than 24°C, and that the young were more widely distributed and more common in areas with surface temperatures less than 24°C. He suggested that the young skipjack leave the nursery ground to disperse themselves when they reach a length of around 30 cm. The seasonal distributions of juveniles and young are shown in Figure 2.

From the distribution of baitboat-caught tunas, mostly skipjack, with juvenile skipjack in their stomachs, Conand and Argue (1980) concluded that the apparent abundance of juveniles in a vast area of the central Pacific was greatest between the equator and 25°S. No juvenile skipjack were found in large numbers of stomachs from temperate waters off northern New Zealand and southeastern Australia.

Predation on juvenile skipjack is discussed in Section 3.34.

2.22 Adults

Fishing by longliners is widespread throughout the western and central Pacific, but in the eastern Pacific it is less intense and occurs only in some areas. Although few skipjack are captured by longline, occurrences indicate the range of the larger adults in the western and central Pacific, the longline gear being selective for the larger skipjack (Miyake, 1968). The latitudinal limits by quarters for skipjack caught by longliners are shown in Figure 3.

Maps of the distributions of catches of adult skipjack by Japanese baitboats in the western Pacific for the 1972-76 period have been made by Kasahara (1978). The quarterly catches for 1975 and 1976 are shown in Figure 4. Catches have been made off Japan as far north as 35°N in the first quarter and 44°N in the third quarter. Catches in the southern hemisphere have been made as far south as 23°S off Australia. There appear to be more fish caught south of the equator in the first and fourth quarter, but this is caused by the fact that more boats fish in this area when the northern areas are too cold for skipjack. Japanese baitboats have made catches as far east as 160°W in 1976.

Honma and Suzuki (1978) have made maps of the distribution of catches of skipjack by Japanese purse seiners during the 1968-1974 period. Off Japan, catches were highest from May to August, and north of the island of New Guinea catches were highest from October to March. Skipjack occur from October to April off northern New Zealand (Clement, 1976 and 1978). Large concentrations of skipjack have been seen as far south as southeastern Tasmania (Robins, 1952).

Skipjack have been fished along the west coast of the Americas from 34°N off southern California to 27°S off northern Chile. The northern extent of the range fluctuates with sea temperature from 25°N in February, March, and April to 34°N in August, September, and October (Williams, 1970). Maps of the distributions of catches of skipjack in the eastern Pacific are shown in Calkins and Chatwin (1967 and 1971), Calkins (1975), and Anonymous (1976b, 1977b, 1978a, 1979a, and 1980a).

2.3 Determinants of distribution changes

Summaries of the determinants of distribution changes of tunas, including skipjack, have been made by Blackburn (1965) and Sund, Blackburn, and Williams (1980).

2.31 Larvae and juveniles

Skipjack larvae are seldom found below 70 m and are most common above the thermocline (Matsumoto, 1958; Strasburg, 1960; Klawe, 1963; Matsumoto and Skillman, in press). They are generally limited to water ≥ 24° C although they have been found in water of 22.1° C (Matsumoto, 1974). Data from net tows reported by Ueyanagi (1969b), and Ueyanagi, Mori, and Nishikawa (1969a) show that the percent occurrence (presence or absence) of skipjack larvae in subsurface net tows increases with temperature while the percent occurrence in surface net tows increases with temperaure to about 28° C and then decreases with further increases in temperature (Forsbergh, 1980). Because many more skipjack larvae are found below the surface than at the surface, the cumulative effect in the water column is for the occurrence to increase with temperature (Anonymous, 1972a).

Juvenile skipjack (7–47 mm in standard length) were collected by midwater trawl near Hawaii by Higgins (1970) with deep (100 m) and shallow (20 m) tows during the day (1200-1800 hours), night (2000–0200), and morning (0400-1000). He stated that: "Shallow tows at night tended to catch the most juvenile skipjack tuna and deep tows at night, the fewest. Catches during the morning were not significantly different from those at night, but shallow-morning tows tended to be less productive and deep-morning tows to be more productive than the corresponding tows at night. Daytime catches are about the same in shallow and deep tows. The differences in the catch rates for skipjack tuna between shallow and deep tows, at different times are assumed to be the result of diel vertical migration... Skipjack tuna were significantly larger in deep tows (average 14.4 mm) than in shallow tows (average 11.1 mm) during all three towing periods. Although the apparent tendencies were not significant, night and morning tows at the deeper depth also tended to catch larger skipjack tuna than day tows. It was tentatively concluded that the smaller skipjack tuna live primarily in the upper isothermal layer, whereas the larger individuals tend to occur in deeper water."

2.32 Adults

2.321 Surface temperature

Temperature ranges for skipjack in the Pacific have been summarized by Williams (1970). Off Japan Uda (1957) gave ranges of 17.5°–30° C for occurrence and 20°–24° C for fisheries. In the eastern Pacific Broadhead and Barrett (1964) and Blackburn (1969) showed that fishable concentrations occasionally were found as low as 17° C and as high as 30° C, but usually were found between 20° and 28° C; Williams (1970) found that the catch-per-standardized-day's-fishing greater than one ton/day "is normally limited to 20°–29° C water, except in two areas in certain years; from the Gulf of Tehuantepec to

Cape Mala rates of 1-9 tons/day are relatively common at 29°-30°C, and off Chimbote (Peru) occasionally>9 tons/day are recorded down to 18°C." At the northern range of the eastern Pacific fishery the occurrence of skipjack off western Baja California follows the seasonal movements of the 18°-21°C isotherms; while at the southern range off Ecuador, Peru, and sometimes northern Chile, seasonal temperature changes do not have such a clear effect on skipjack distribution (Williams, 1970). Although there has been no commercial fishery for skipjack off southeast Tasmania, Robins (1952) reported experimental catches between 14.7° and 20.8°C, with most occurring between 16.0° and 18.0°C. Blackburn and Serventy (1981) showed that the southern range limits for captures of skipjack off southeastern Australia and Tasmania closely follow the seasonal movements of the 16°C surface isotherm.

The optimum range for commercial fishing for five hypothesized subpopulations of skipjack was submitted by Sharp (1978) as follows:

Northeastern Pacific	20°-26°C
Southeastern Pacific	20°-28°C
New Zealand	17°-23°C
Papua New Guinea	28°-30°C
Northwestern Pacific	20°-28°C

Blackburn (1965) concluded that though surface temperature determines the limits of tuna distribution, including that of skipjack, is does not determine the distribution of the abundance within those limits.

2.322 Surface salinity

According to Blackburn (1965) salinity, *per se*, does not determine the distribution of tunas, including that of skipjack, but may indicate oceanic conditions which are associated with tunas.

In the Hawaiian skipjack fishery Seckel (1972) found that the landings were high in those years when the sea-surface temperatures began increasing before the end of February and the mean spring salinities were between 34.6 and 34.8 o/oo, indicating that favorable conditions are limited to the high-salinity part of the California Current Extension as it moves through the Hawaiian Islands in the summer (see also Seckel, 1963). Donguy, Bour, Galenon, and Guererdrat (1978) showed that the catches of skipjack by Japanese baitboats in the southwestern tropical Pacific appear to be greater in waters with salinites of 35 o/oo or less, because the 35 o/oo isohaline in this region can be associated with the presence of convergences where forage may be concentrated.

2.323 Surface currents

Surface currents indirectly influence the distribution of tunas by modifying the distribution of sea-surface temperature limits (Brock, 1959; Blackburn, 1965). The warm North and South Equatorial Currents flow westward at low latitudes and are deflected poleward along the western shore. The cold North Pacific Current flows eastward at higher latitudes and most of it is deflected to the southeast on reaching the eastern shore; while in the southern hemisphere the West Wind Drift flows eastward at high latitudes, mostly into the Atlantic but with a part deflected northward along the coast of South America. The latitudinal distribution of skipjack is thus related to currents through the poleward expansion of warm water in the western Pacific and the equatorward intrusions of cool water in the eastern Pacific (Figure 3).

The investigations of the relationship of skipjack and currents off Japan has been summarized by Uda (1962) and Kawasaki (1965). Uda stated that: "A study of oceanographic conditions showed that good catches were made during years with warm water temperatures, whereas poor catches were made during years with cooler water temperatures. These differences in temperatures were primarily related to the relative strengths of the warm Kuroshio and the cool Oyashio.

"It was postulated that recruitment of skipjack is favored by the enriched zones associated with upwelling in the Equatorial Countercurrent and near the Equator. From these tropical waters there is a migration of skipjack (composed mainly of medium-sized fish) into Japanese waters. When the warm Kuroshio water spreads over a broad area, more skipjack become available to the Japanese fishery.

"Conversely a strong Oyashio current (cold water) hinders the migration, and catches are low. However, good catches may also be made when both the Oyashio and Kuroshio are strong. Under the latter conditions skipjack are concentrated along the boundary between the warm and cold water (Polar Front)."

Models for the migration of skipjack in the currents of the eastern and central Pacific proposed by Seckel (1972) and Williams (1972) are described in Section 3.51.

2.324 Fronts, convergences, and upwelling areas

"Fronts are probably best considered as boundaries (lines of convergence) between surface waters of different densities, recognizable by strong horizontal gradients of temperature and/or salinity, and accompanied by some sinking of one or both of the types of water involved. Drifting or weakly swimming biota (zooplankton) are believed to be carried towards a front from one or both sides and aggregated there, and strongly swimming biota (nekton) are thought to move into the front to feed on the aggregations" (Blackburn, 1965).

During six cruises off Baja California, however, no evidence was found of tuna prey aggregating in the front off Cabo San Lucas (Blackburn, 1969).

One of the most intensely fished areas in the eastern Pacific skipjack fishery has been the Gulf of Guayaquil area. "Most of the skipjack fished in the area has been captured east of 83°N between 0° and 5°S. These fishing grounds lie in the equatorial thermal front between the cold upwelled waters of the Peru Current and its extension and the warm waters north of the equator. Sea-surface temperatures change very rapidly with latitude in the frontal area, and the intensity of the gradient and the position of the front vary with season and among years" (Anonymous, 1978a). No significant correlations were found between apparent abundance of skipjack and the intensity of the temperature gradient or mean temperatures in the area.

In the western equatorial Pacific, skipjack catches by Japanese baitboats are said to be concentrated on the warm, low-salinity, side of convergences located near 5°N and 5°S (Donguy, Bour, Galenon, and Gueredrat, 1978). Good fishing for skipjack and other tunas is found at the front between the warm Kuroshio Current and the cool Oyashio Current (Uda, 1953; Uda and Ishino, 1958).

Skipjack are frequently caught around floating objects (Hunter and Mitchell, 1967; Greenblatt, 1979) which may sometimes be associated with fronts (Blackburn, 1965).

Off western Baja California, skipjack and yellowfin (Thunnus albacares) prey heavily on the red crab (Pleuroncodes planipes), a herbivore, which is found in great abundance in the cool upwelling areas where phytoplankton is concentrated. When surface temperatures are less than 20°C the tunas generally feed on red crab at the edges of these areas, and move into these areas where red crab is concentrated when temperatures increase (Blackburn, 1969; Sund, Blackburn, and Williams, 1980).

In the northern part of the Panama Bight the abundance of skipjack appears to be related to upwelling which occurs from January to April, while catch rates of skipjack peaked from April to July, the lag being attributed to the time required for the production of forage organisms (Forsbergh, 1969).

2.325 Vertical distribution

Skipjack were observed from a small submarine off the Hawaiian Islands at depths of around 600 ft (183 m; Anonymous, 1965b) and at 98 to 152 m (Strasburg, Jones, and Iversen, 1968).

The movements of three skipjack approximately 70 cm long equipped with ultrasonic transmitters were followed by Dizon, Brill, and Yuen (1978). The three fish spent 85% of their time in water warmer than 20°C, but dove into water colder than 16°C for short periods. The fish which was tracked the longest time (24 hours) spent the night between the surface and 75 m, but during the day and the twilight ranged from the surface to 263 m.

The vertical distribution of skipjack is limited by the vertical distribution of temperature and oxygen concentrations necessary for their survival.

Skipjack from Hawaii require a minimum temperature of 18°C and a minimum oxygen concentration of 3.0-3.5 ml l^{-1} for long-term survival, though they have survived at lower values for several hours; the upper temperature limit decreases with increasing size from 30°C or more for small fish to as low as 20°C for large fish (Barkley, Neill, and Gooding, 1978). These investigators suggested that: "... only young skipjack tuna can inhabit tropical surface waters, and that the habitat of adult skipjack tuna in the tropics is the thermocline and not the warmer surface layer, as has generally been thought. Since the thermocline in many areas is too oxygen-poor to support these active fish and the well-oxygenated surface layer is too warm for adult skipjack tuna, only heat-tolerant young skipjack tuna can live in those areas. As they grow, these fish are forced to move into areas where well-oxygenated water of the proper temperature is more readily available." Maps of the geographic distribution of the hypothesized skipjack habitats in the Pacific based on vertical distributions of the limiting properties are shown in the above paper and in that of Sharp (1978). Sharp, however, used lower values for minimum tolerance limits: 15°C for temperature and 2.5 ml l^{-1} for oxygen concentration. According to these maps the habitat available to skipjack is more vertically restricted and shallower in the eastern Pacific than in the western and central Pacific.

2.4 Hybridization

Hybridization has not been found in skipjack.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

Skipjack are heterosexual. The rare occurrences of hermaphroditism that have been reported are mentioned by Thomas and Raju (1964).

Results of investigations on the sexual maturity of skipjack have been summarized by Matsumoto and Skillman (in press). From the Marshall Islands area, Marr (1948) found the smallest fish with spent ovaries to be 400 mm in fork length; off southern Japan, Yabe (1954) found that the smallest fish with mature ova was 468 mm long; off Hawaii, Brock (1954) found that the smallest fish with maturing ova were about 400 to 450 mm long; Yoshida (1966) found that the smallest fish from the Marquesas and Tuamotu Islands with advanced or developing ovaries was 430 mm long; Hu and Yang (1972) determined that fish of both sexes caught off Taiwan were mature at 430 mm. Wade (1950a), however, reported a fish from off the Philippine Islands in the 340- to 349-mm size class with ripe ovaries; Matsumoto and Skillman, (in press) suggested that this could be an anomaly or an error in the determination of gonad development.

Iversen, Nakamura, and Gooding (1970) reported on a pair of skipjack that appeared to be courting, observed by scuba divers in an underwater sled in Hawaiian waters, as follows: "The two fish observed from the sea sled were noticed because they were not feeding on the live bait that had been chummed into the water. After watching them for 20–30 seconds, during which time they remained close together while swimming back and forth in front of the sled several times, it became obvious these two fish were paired. Twice while swimming side by side the ventral portions of their bodies almost touched. They were tilted about 30° from the vertical in opposite directions when this occurred. Once we saw what appeared to tail nosing... by the following (*i.e.*, rearmost) fish. The following fish was slightly below the lead fish and approached it closely from the rear, its snout coming to within a few centimeters of the caudal fin of the lead fish. At the closest point of approach, the following fish displayed dark vertical bars on its sides for several seconds." This behavior has also been described by commercial fishermen in Hawaii.

Artificial fertilization of skipjack eggs was first accomplished in 1972 using fish caught by purse seine off Japan (Inoue, Tutumi, Nagaoka, and Nagata, 1974; Ueyanagi, Nishikawa, and Matsuoka, 1974).

The literature on gonads of skipjack has been reviewed by Batts (1972) and Matsumoto and Skillman (in press). The latter proposed a new classification of maturity stages based on descriptions of the ova and ovaries.

In order to avoid measuring ova, some authors have used gonad indices, which are ratios of ovary weight to body weight or length used as measures of maturity. Yoshida (1966a), however, found that ova diameter was not related to gonad index at higher indices. Matsumoto and Skillman (in press) concluded that for skipjack the gonad index did not appear to be a good measure of maturity.

The fecundity of tunas is roughly 100,000 eggs of the largest mode per kilogram of body weight (Joseph, Klawe, and Murphy, 1979). Investigations of the fecundity to length relationship in skipjack from all oceans have been reviewed by Matsumoto and Skillman (in press), who showed that the relationships differed among sources and regions. The fecundity estimates ranged from about 100,000 to 2,000,000.

"It would be most difficult to estimate the total annual egg production of the skipjack tuna because of (a) the extremely large variation in number of ova among fish of the same size, (b) the uncertainty in the number of times a fish spawns during the year..., (c) the possibility of reduced fecundity at successive spawnings in the same year (Joseph, 1963), and (d) incomplete knowledge concerning the size composition and total abundance of the spawning stocks" (Matsumoto and Skillman, in press).

It is generally agreed that skipjack spawn several times in a spawning season (Brock, 1954; Buñag, 1956; Raju, 1964; Matsumoto and Skillman, in press). For skipjack caught in the Atlantic off North Carolina, Batts (1972) found three distinct modes (0.15 mm, 0.50–0.60 mm, and 0.95 mm) in the egg diameter of nearly ripe fish, and residual eggs in fish having a new ripening group of eggs, and concluded that skipjack were multiple spawners.

"Gonadal studies in the Pacific Ocean... indicated that skipjack tuna spawn throughout the year in tropical waters near the equator and from spring to early fall in subtropical waters with the spawning period becoming shorter with increasing distance from the equator. Because sampling for gonads required the capture of adults, these studies have generally been done on a commercial basis or in waters subjected to heavy experimental fishing. These areas include waters south of Japan, Philippine Islands, Marshall Islands, Hawaiian Islands, New Caledonia, Marquesas-Tuamotu Archipelago and off Central America... Larval captures, also indicative of spawning activity, have occurred not only in the areas mentioned above and in similar months, but also in intervening waters" (Matsumoto and Skillman, in press).

On the basis of gonad indices, Naganuma (1979) concluded that smaller adult skipjack (40–60 cm) in the western Pacific between 15°N and 20°S spawn from October to March, which is the warmer season in this area, both north and south of the equator, and that the larger fish (>60 cm) north of 15°N spawn in the northern summer.

The ripe eggs of skipjack are spherical and transparent and about 1 mm in diameter, with a yellow oil globule (Yoshida, 1966a). Spawned eggs collected at sea cannot be distinguished from those of other scombrids.

3.2 Preadult phase

A bibliography of the eggs, larvae, and juveniles of tunas, including skipjack, is given by Richards and Klawe (1972).

The development of skipjack embryos from artificially fertilized eggs has been described by Inoue, Tutumi, Nagoaka, and Nagata (1974) and Ueyanagi, Nishikawa, and Matsuoka (1974). The latter investigators found that around 27°C hatching occurred 22 to 27 hours after fertilization.

Larval skipjack have been described by Matsumoto (1958) and Ueyanagi, Mori, Nishikawa, and Suda (1973). Newly hatched larvae from artificially fertilized eggs were about 2.6 mm in total length. At temperatures of 24° to 26.5°C the larvae required about 2 days to absorb their yolk sacs. None survived more than 5 days because of unsuccessful initial feeding just after the yolk sac was absorbed (Ueyanagi, Nishikawa, and Matsuoka, 1974).

Biologists of the U.S. National Marine Fisheries Service in Honolulu, Hawaii, have succeeded in artificially fertilizing eggs from skipjack caught by baitboats. The first group of eggs hatched in 30 hours and the larvae began feeding on rotifers about 2 1/2 days later, but the mortality was high and none survived more than 8 days after hatching. Larvae from the second group of eggs had a much lower mortality, and at the time of writing were feeding well 7 days after hatching (Anonymous, 1980d). Female skipjack kept in tanks at the Kewalo Research Facility at Honolulu, Hawaii, produced ripe eggs and released them, apparently as a response to the stress of captivity. A supply of fertilized eggs is thus available for experimentation, at least during the summer months (Anonymous, 1980e).

On reaching a length of 12 mm, the larvae are considered to be juveniles.

The information available on the adolescent phase of skipjack had been discussed in Section 2.21.

3.3 Adult phase

3.31 and 3.32 Longevity and hardiness

A reliable method for determining the age of skipjack has not yet been developed. Crude estimates of age based on size, and on growth rates derived from tagging and modal progressions of length-frequency data are all that are available.

Miyake (1968) showed one fish caught by longline to be in 106.5- to 108.4-cm size class and Matsumoto and Skillman (in press) estimated that it would have been at least 12 years old.

The growth rate of skipjack is discussed in Section 3.43.

Skipjack are less tolerant to the stresses of confinement in purse seines than are yellowfin and other larger species of tuna. For this reason attempts to tag skipjack captured by purse seines have been discontinued by the Commission.

The tolerance of skipjack to temperature and oxygen concentrations has been discussed in Section 3.44.

3.33 Competitors

Waldron (1963) lists the following fish which have been seen feeding with aggregations of adult skipjack; whale shark, Rhincodon typus; yellowfin, Thunnus albacares; albacore, T. alalunga; kawakawa, Euthynnus affinis; bullet or frigate tuna, Auxis sp.; mahi-mahi, Coryphaena hippurus; and rainbow runner, Elagatis bipinnulatus. He adds that seabirds also may be considered competitors, as they feed on some of the same organisms at the surface as do skipjack.

3.34 Predators

Waldron (1963) lists the following species as predators on juvenile or adult skipjack in the Pacific: skipjack; yellowfin; albacore; bigeye, Thunnus obesus; wahoo, Acanthocybium solandri; Chinese seerfish, Scomberomorus sinensis; black marlin, Makaira indica; blue marlin, M. nigricans; striped marlin, Tetrapturus audax; sailfish, Istiophorus platypterus; thresher shark, Alopias sp.; and snake mackerel, Gempylidae.

Investigations of stomach contents of tunas caught in the central Pacific showed that skipjack occurred in 1.5% of 1,097 yellowfin stomachs (Reintjes and King, 1953), in 3.9% of 439 yellowfin and none of 166 bigeye stomachs (King and Ikehara, 1956), and 7.8% of 707 skipjack stomachs (Waldron and King, 1963). From 603 skipjack caught near the Marquesas and Tuamotu Islands, 9.5% of the stomachs contained juvenile skipjack ranging from 4 to 15 cm long (data in Nakamura, 1965). Stomach contents of 5,956 skipjack and 751 yellowfin caught throughout a vast area of the Pacific from 134°E to 140°W and 25°N to 42°S showed that 3.3% of the skipjack and 2.3% of the yellowfin contained juvenile skipjack, most of them ranging from 2 to 14 cm in length, and comprising about two-thirds of all species of juvenile tunas found in the stomachs (Conand and Argue, 1980). In the eastern Pacific fishery, no skipjack were found in 2,317 skipjack stomachs, and only one was found in 3,763 yellowfin stomachs (Alverson, 1963). Cannibalism is apparently prevalent in the central and western Pacific, but not in the eastern Pacific, which is not surprising in view of the fact that juvenile skipjack are rare in the eastern Pacific (Section 2.21). "Small skipjack are common in the stomachs of larger fish of this species and may represent one of the major food items. This suggestion can be carried further, for there is no doubt that adult skipjack represent the greatest biomass of recognizable predators in the area of known distribution of skipjack larvae in the Pacific (i.e., the surface layers of the most tropical waters), therefore the hypothesis that skipjack are potentially their own greatest predators, at least numerically, has great credibility" (Kearney, 1978).

A total of 1,742 juvenile skipjack were found in the stomachs of 6,867 billfishes caught in the central Pacific: 12% of the stomachs from Hawaii contained skipjack, while 19% of those from the south Pacific contained skipjack (Yoshida, 1971b). Mori (1972) found 5,019 skipjack in 6,504 stomachs of 10 species of billfishes, and 832 skipjack in 6,088 stomachs of 5 species of tunas caught in the Pacific, Indian, and Atlantic Oceans. The size of the skipjack ranged from 3 to over 70 cm in standard length, with most measuring between 6 and 20 cm. The average number of skipjack per stomach was highest for sailfish, shortbill spearfish (Tetrapterus angustirostris), and blue marlin with values of 2.06, 1.24, and 1.06, respectively, for fish from the tropical western Pacific (Mori, 1972: Table 4).

3.35 Parasites, diseases, injuries, and abnormalities

Parasites found in skipjack are listed by Waldron (1963), Silas (1967), Silas and Ummerkutty (1967), and Chen and Yang (1973). Thirty-six species of trematodes, 12 species of parasitic copepods, 6 species of nematodes and acanthocephalids, and 1 species of cestode are listed by Love and Moser (1977). Only five species of copepods parasitic on skipjack are listed by Cressey and Cressey (1980), who used only data where both the host and the copepod could be identified.

3.4 Nutrition and growth

3.41 Feeding

Observations on the feeding behavior of skipjack in their natural environment have been reviewed by Nakamura (1969) and are summarized in Section 3.53.

From examination of stomach contents of skipjack from the central Pacific, Waldron and King (1965) concluded that the feeding peaked from 0700 to 0900 hours, was low from 1300 to 1600, and increased again in the late afternoon. Nakamura (1965), reported that the volume of stomach contents of skipjack from the Marquesas and Tuamotus was highest from 0900 to 1000 and from 1600 to 1700 and was low from 1110 to 1400. He suggested that: "This feeding pattern may be related: (1) to the distribution and abundance of forage organisms and zooplankton and their diurnal movements; or (2) to a satiation of the food drive during midday." Matsumoto and Skillman (in press) suggested that the second hypothesis may not be the case, based on data from Yuen (1959) showing that catches of skipjack by Hawaiian baitboats were highest around midday.

It is generally assumed that skipjack do not feed at night because of inadequate illumination.

Skipjack kept in a pool were observed for 5 1/2 months. Schooling was disrupted during feeding and light and dark vertical bands were seen on their backs and sides which disappeared when the fish were satiated. (This response has also been observed at sea by Strasburg and Marr, 1961.) Food consumption was 10% of the body weight per day when the fish were fed to satiation once a day and double that when they were fed to satiation every hour (Nakamura, 1962).

"Skipjack tuna were fed at 15-minute intervals throughout the day. Alhough a period of intense feeding occurred between 0630 and 0830 hours, the fish did not fill their stomachs to capacity the first or even the second or third time they were offered food, but filled their stomachs slowly over the 2-hour period. Maximum capacity of the stomach was about 7 percent of the fish's weight, but during the whole day they ate an equivalent of 15 percent of their body weight. Skipjack tuna ate more food and digested it more rapidly than other fishes for which data are published" (Magnuson, 1969a). Recent studies show that a skipjack weighing 1.4 kg may consume up to 28 to 35% of its body weight per day (Kitchell, Neill, Dizon, and Magnuson, 1978).

3.42 Food

The most comprehensive studies of food eaten by skipjack are those by Hotta and Ogawa (1955), Alverson (1963), Waldron and King (1963), and Nakamura (1965), according to Matsumoto and Skillman (in press). The last investigators have listed the taxonomic groups found in the stomachs of skipjack from all sources. They show that in the western and central Pacific the volume of stomach contents consists mainly of fish, with molluscs ranking second and crustaceans last, while in the eastern Pacific the stomach contents were found to be 59% crustaceans, 37% fish, and 3% squids (Alverson, 1963). "The wide variety of food organisms and the variations in the order of importance of the major food groups have led to the conclusion that skipjack tuna do not exhibit food preference, but will feed on whatever prey organisms are available to them. The incidences of cannibalism exhibited by the skipjack tuna bears this out" (Matsumoto and Skillman, in press).

Examination of the stomach contents of skipjack showed that the percent occurrence of crustaceans increased with the size of the skipjack, while the percent occurrence of fish decreased with size (Nakamura, 1965). In the central Pacific, Magnuson and Heitz (1971) showed that the crustaceans in the stomachs of various species of tuna are much smaller than the fishes or squids. They found that skipjack, which have a smaller gill raker gap than all other species of the same size that were investigated, tended to consume a larger porportion of crustaceans by volume because they were able to filter out smaller organisms. Skipjack 35 cm long had a mean gill raker gap of 0.51 mm, and skipjack 50 cm long had a mean gap of 1.0 mm. Stomach contents of skipjack caught in the eastern Pacific fishery consist mostly of organisms between 0.5 cm and 10 cm long (Blackburn and Associates, 1962).

3.43 Growth rate

A review and critique of the methods and results of numerous investigations of growth rate in adult skipjack has been made by Josse, Le Guen, Kearney, Lewis, Smith, Marec, and Tomlinson (1979). Of the various methods that have been used to estimate the growth of skipjack, they conclude that counting seasonal marks on vertebrae, scales, and dorsal spines and following modal progressions of length-frequencies are the least reliable, that counting daily increments on otoliths is more reliable, and that measuring the growth between tagging and recapture is the most reliable. Comparing tagging data from Joseph and Calkins (1969) for the eastern Pacific and tagging data from the Papua

New Guinea area for fish of similar size (40-60 cm) which had been free for 2 to 5 months before recapture, they found no significant difference in growth rate; from a length of 40 cm the fish grew 18.4 cm in 12 months in the eastern Pacific, and 15.6 cm during the same time off Papua New Guinea. Kearney (1978), however, estimates an annual increment of only 7 cm from tagging studies off Papua New Guinea. An estimate of 17.4 cm per year from modal progressions was obtained for the eastern Pacific (Anonymous, 1976b), similar to that obtained from tagging data.

Matsumoto and Skillman (in press) have tabulated the growth parameters for the von Bertalanffy growth equation and calculated the lengths at various ages for various investigations of skipjack growth. Their table shows the growth rate of fish caught off Hawaii to range from 20 to 28 cm per year for fish increasing in age from 12 to 24 months; this appears to be considerably greater than the rates in the eastern and western Pacific. From daily growth increments on otoliths, Uchiyama and Struhsaker (1979) estimated that skipjack from the central Pacific grew 28.2 cm between 1 and 2 years of age, and 10.8 cm between 2 and 3 years of age, and that skipjack from the eastern Pacific grew 23.6 cm between 1 and 2 years of age. These apparent differences in growth rates among areas are probably not statistically significant (Josse, Le Guen, Kearney, Lewis, Smith, Marec, and Tomlinson, 1979).

Increments on otoliths of skipjack from the Revillagigedo Islands and off Baja California that had been tagged, injected with tetracycline, released, and recaptured, have been counted by Wild and Foreman (1980). The number of observable increments that had been deposited after the tetracycline mark on the otolith averaged 24% less than the number of days at liberty, so that growth could not be estimated from the increment count.

Otoliths were examined from larval skipjack reared in captivity at the Kewalo Research Facility at Honolulu, Hawaii. The otoliths from larvae up to 4 days old which had been examined showed growth increments of one per day (Anonymous, 1980f).

3.44 Physiology

Results of recent investigations on the physiology of skipjack can be found in Hoar and Randall (1978) and in Sharp and Dizon (1978). Experiments and hypotheses on body temperature relations have been reviewed by Stevens and Neill (1978). They believed that the temperature in the muscles of skipjack is usually 2°-4°C higher than ambient temperature; but when feeding or swimming rapidly these values may be up to three times as large. "An adaptive value of being warm after severe exercise then is that it speeds recovery, thereby permitting more frequent feeding frenzies with concomitant increases in the rate of food capture and perhaps of growth" (Stevens and Neill, 1978).

"The heat comes from metabolic activity associated with the remarkable swimming activity of tuna. Some tuna have been clocked at speeds of over 20 body lengths/sec for very short periods. Speeds greater than 10 lengths/sec are well verified. In addition they swim continuously, never stopping to rest. The slowest that many can swim exceeds one body length/sec... The proportion of dissolved oxygen removed from water passing over the gills of tuna is the highest known in the fish world. This is perhaps not surprising because the metabolic rate of tuna is higher than for other fishes for which estimates are available. Also, the digestion rate of tuna is the highest known and the concentration of blood hemoglobin is as high as that of humans. The tuna are, without a doubt, the most highly specialized fishes in regard to sustained, high levels of locomotory activity" (Magnuson, 1978a).

Tunas are unusual in that their circulatory anatomy includes counter-current heat exchangers where heat is transferred from venous to arterial blood. In skipjack a large portion of the blood flows through the exchanger and the efficiency of the exchanger has been estimated to lie between 90 and 100% (Stevens and Neill, 1978). Chang and Dizon (1976) estimated that the rate of heat exchange between the deep tissues of skipjack and the surrounding water is about 60% as fast as in most teleosts, and that minimum and maximum metabolic rates for red muscle were about 4 and 25 cal g^{-1} hr^{-1}. Dizon, Brill, and Yuen (1978) suggested that skipjack thermoregulate physiologically by conserving heat under certain conditions and by releasing heat through the gills under other conditions. Investigations on thermoregulation in tunas, including skipjack, have been reviewed by Dizon and Brill (1979b).

Skipjack require high concentrations of dissolved oxygen for long-term survival. Barkley, Neill, and Gooding (1978) mention experiments with skipjack in tanks where the fish appeared to be under stress at 2.8 ml l^{-1}, and only one out of six survived over 4 hours at 2.5 ml l^{-1}, at temperatures of 23° to 24°C. They selected a conservative lower limit of 3.5 ml l^{-1} for their model of the habitat available to skipjack.

Skipjack are extremely efficient at extracting oxygen from the water. Free-swimming skipjack in a tank used an average of 56% of the oxygen in the water passing over the gills (Stevens, 1972). The rate of metabolism in skipjack increases with increasing size. Brill (1979) measured the standard metabolic rate of 33 skipjack ranging in weght from 0.3 to 4.7 kg and calculated the best fitting allometric equation to be:

$$SMR = 412.0\ W^{0.563}$$

where SMR = standard metabolic rate in mg O_2 hr^{-1} and

W = body weight in kg.

The digestive rate of skipjack is rapid, the exoskeletons of shrimp passing through the digestive tract of skipjack held in tanks in 1 1/2 hours (Nakamura, 1962).

In most animals physiological rates double to triple for every 10°C increase in temperature (Q_{10} = 2-3). Dizon, Neill, and Magnuson (1977), from experiments using fish swimming in tanks having variable water temperatures, estimated that yellowfin had a Q_{10} averaging 2.2, while skipjack and kawakawa (*Euthynnus affinis*) both had remarkably low values of Q_{10} averaging 1.0. This indicates that there is virtually no increase in physiological rate with temperature in skipjack and kawakawa because of their ability to rapidly compensate for changes in temperature. They suggested that: "the actual habitat of adult skipjack tuna is the upper thermocline. Since much forage for the adult tunas is likely to be in the upper mixed layer, frequent forays into warmer, upper waters must be made. Most animals whose metabolism is instantaneously temperature-compensated live in an environment in which temperature fluctuates dramatically (*i.e.*, intertidal forms...). The habitat of the adult skipjack tuna could be similarly constituted. Consider also that they lack a swim bladder, which frees them from effects of changing pressure. Skipjack tuna are thus well suited to exploit fully the environment extending from the upper thermocline to the surface; rapid movements through extremes of temperature and depth pose no particular problems to these highly adapted animals. Rapid temperature compensation contributes to the ability to fill this niche." They also presented data from other sources showing estimates of Q_{10} values for both skipjack and bigeye to range from 1.0 to 1.2.

Brill and Dizon (1979b) studied the effect of temperature on white muscle of skipjack in isotonic solution and found that various parameters of muscular activity have mean Q_{10} values ranging from 1.47 to 1.72. They concluded that white muscle in skipjack "appears not to be physiologically unique, in comparison with other teleosts, with respect to contraction time, or the effect of temperature on contraction time." They made no comment on the lower values of Q_{10} given by Dizon, Neill, and Magnuson (1977).

Swimming speeds of skipjack increased when dissolved oxygen dropped below about 4.0 ppm (2.8 ml l^{-1}); the increase in swimming speed may be an escape response to remove the fish from an unfavorable environment, rather than a response to increase ram ventilation (Dizon, 1977). Minimum speeds for maintaining hydrostatic equilibrium are higher for skipjack than for any of the six other scombrids of similar size (Magnuson, 1973). It was estimated that a skipjack 44 cm in length must swim at a minimum speed of 70 cm sec^{-1} or 60 km day^{-1} to maintain hydrostatic equilibrium (Magnuson and Weininger, 1978).

Working with 40 restrained skipjack, Rayner and Keenan (1967) measured the electrical activity of red and white muscle in relation to the frequency of tail beats. In all but three fish deep red muscle was active at all frequencies, but white muscle was inactive at low frequencies and showed increased activity at higher frequencies. They concluded that red muscle was used for basal swimmimg and that white muscle appeared to be used only "... for short bursts of high activity as in feeding or escape behaviour." Using similar methods but forcing skipjack to swim against a current, Brill and Dizon (1979a) found that white muscle activity in five of eight fish tested began at speeds of 3.0 to 4.7 body lengths per second (l sec^{-1}), somewhat above the minimum speed of about 1.5 l sec^{-1} required for maintaining hydrostatic equilibrium (Magnuson, 1978b) but below the estimated maximum sustainable speed of 6 l sec^{-1} (Dizon, Brill, and Yuen, 1978) and well below the estimated maximum speed of 15 l sec^{-1} (Brill and Dizon, 1979b) at the temperatures used in the experiment. In the other three fish white muscle activity began near minimum speeds required for maintaining hydrostatic equilibrium, but this was regarded as possibly abnormal because these fish were weak swimmers.

Swimming speeds of skipjack clocked from a fishing vessel averaged 700 cm sec^{-1}, or about 14 l sec^{-1}, at a sea-surface temperature of 25.4°C (Watanabe, 1942). Using underwater cinematography at sea Yuen (1966) measured a maximum speed of 690 cm sec^{-1}, or about 14 l sec^{-1}, in water of 24 to 27°C. From measurements of white muscle contraction in skipjack, Brill and Dizon (1979b) predicted the mean maximum swimming speed to be 14.3 l sec^{-1} at 27°C, assuming a stride length coefficient of 0.7. From data given in Yuen (1970), it was calculated that a skipjack 44 cm in length swam at a minimum average speed of 435 cm sec^{-1}, or about 10 l sec^{-1}, for 107 minutes (Beamish, 1978). Skipjack 55 cm in length were made to swim at speeds exceeding 550 cm sec^{-1}, or 10 l sec^{-1}, by chasing them (Neill, Chang, and Dizon, 1976). Skipjack, yellowfin, and wahoo have been recorded as swimming faster than maximum speed predicted from data for non-scombrid teleost species (Stevens and Neill, 1978). Wardle and Videler (1980) have suggested that this is accomplished by doubling the wavelength of the swimming movement, thereby doubling the distance travelled for each tail beat, but requiring much more power. Brill and Dizon (1979b), however, stated that: "Skipjack tuna are apparently not capable of exceptionally high maximum swimming speeds when compared to other teleosts of equal fork length and similar muscle temperatures."

The effects of temperature and oxygen requirements of skipjack on limiting their habitat has been discussed in Section 2.325.

3.5 Behavior

3.51 Migrations and local movements

Kawasaki (1964 and 1965a) proposed that skipjack caught in the fisheries of the

Northwestern Pacific, the Hawaiian Islands, and the eastern Pacific all belong to one population that is spawned in the central equatorial Pacific, that the young fish migrate into the fishing areas, and that the older fish return to the central equatorial Pacific to spawn.

Investigators working with blood specimens have proposed the existence of two, three, and five subpopulations of skipjack in the Pacific (Fujino, 1970a; Richardson, 1978b; and Sharp, 1978).

On the basis of serological studies Fujino (1970a, 1970b, and 1972), believed "that there are at least two subpopulations of skipjack in the Pacific Ocean, the western Pacific subpopulation and the central and eastern Pacific subpopulation(s). The western Pacific subpopulation results from spawning in the Philippine Sea and to a lesser extent near the Ryukyu and Bonin Islands. The fish of catchable size occur in the vicinity of Japan, the Ryukyu Islands, Taiwan, the Bonin Islands, the Mariana Islands, the western Caroline Islands, the Philippine Islands, Papua New Guinea, Australia, and New Zealand. The boundary between the range of this subpopulation and that of the central and eastern Pacific subpopulation(s) in the northern hemisphere appears to occur in the area between Japan and the Bonin and Mariana Islands in the west and 165°E in the east. The boundary seems to shift eastward in the spring and westward in the fall. Off northeastern Japan central and eastern Pacific fish have been observed to replace western Pacific fish within a few days in September, and the reverse has been observed east of the Izu Islands in late May and early June. More recent studies, however, indicate the presence of fish in the western Pacific subpopulation near the Hawaiian Islands. In the equatorial region the boundary appears to occur at about 165°E between the eastern Caroline Islands and the Marshall and Gilbert Islands and does not seem to shift very much seasonally" (Anonymous, 1979a). "More recent genetic studies on blood specimens from the southwestern Pacific Ocean indicate that the boundary between ranges of the above two subpopulations stays within the Tasman Sea all the year round and suggest that the western limit of the range of the central-eastern Pacific subpopulation(s) extends to the west close to the east coast of New South Wales in early winter in the southern hemisphere" (Fujino, 1976). There are no data to determine the extent, if any, the western Pacific subpopulation penetrates the Indian Ocean.

Fujino (1972) recognized two groups of skipjack in the western Pacific Ocean, A and B (Figure 5). The fish of Group A probably originate from spawning in the northern summer and those of Group B from spawning in the northern winter. The fish of the two groups appear to belong to the same subpopulation, which indicates interchange of genes. This may be because all, most, or many skipjack spawn twice each year or because spawning by any individual occurs only once a year, but the spawning seasons overlap sufficiently to prevent genetic isolation. Group A is dominant off Tohoku and near the Izu, Bonin, and Ryukyu Islands. Group B is dominant near the Goto Islands. Near the Mariana Islands Group B dominates in winter. Near Palau Group A dominates in winter and Group B during the other seasons.

From electrophoretic studies of the blood of skipjack, Richardson (1978b) has shown that the gene frequency of the most common form of esterase protein varies with different areas of the Pacific. In the western Pacific (Japan, Palau, and Papua New Guinea) it is greater that 0.55, while in the eastern Pacific it is less than 0.55. He suggested that this indicates at least two different genetic subpopulations. Near Hawaii both subpopulations appear to be present. Off New Zealand the gene frequency suggests a third subpopulation from the south central Pacific differing from the others.

From the geographic distribution of esterase-2 frequencies in the blood of skipjack, Sharp (1978) hypothesized that there were at least five genetically different populations in the Pacific.

From data on the captures of skipjack by Japanese longliners, Matsumoto (1974 and 1975) has hypothesized that there are several semi-independent stocks of skipjack which originate in the different regions of the equatorial Pacific. "The apparent movement of groups of skipjack tuna in the Pacific appeared to coincide with the circulation of the major ocean currents. The movement was counterclockwise in the southern hemisphere and clockwise in the northern hemisphere, except in the eastern Pacific where the movement appeared counterclockwise, corresponding with the flow in the north equatorial water mass" (Matsumoto, 1975).

Rothschild (1965) proposed that skipjack from the eastern Pacific fishery are recruited from the central equatorial Pacific and return there to spawn. Skipjack "apparently arrive in the eastern Pacific when they are about 1 to 1 1/2 years old and return to the central and central-western Pacific when they are about 2 to 2 1/2 years old. Evidence for the latter is provided by the fact that 25 skipjack tagged in the eastern Pacific have been recaptured near the Hawaiian and Line Islands and 1 other has been recaptured between the Marshall and Mariana Islands" (Anonymous, 1979a).

Fink and Bayliff (1970) noted that there appear to be two main groups of skipjack in the eastern Pacific: a northern group off the west coast of Baja California, in the Gulf of California, and around the Revillagigedo Islands; and a southern group from off Central America to off northern Chile. In most years skipjack are excluded from the southern coast of Mexico by a cell of warm water in that area (Rothschild, 1965). There is little interchange of fish between the northern and southern areas, but considerable mixing of fish within the areas. From data on 90,412 skipjack tagged in the eastern Pacific and 4,381 recaptures of these, Fink and Bayliff (1970) believed that fish from the northern group first appear near the Revillagigedo Islands around April, then move north along the coast of Baja California during the spring and summer and return south during the fall, and then migrate to the central Pacific during the fall and/or winter; and that fish from the southern group first appear in the Panama Bight around April and move rapidly northwest to the waters off Central America and south to the Gulf of Guayaquil (Figure 6).

Williams (1972) hypothesized three possible models for the migration of fish from the central Pacific to the eastern Pacific: an active migration model where the fish swim eastward in the westward flowing North and South Equatorial Currents; a passive migration model where the fish are carried eastward by the North Equatorial Countercurrent; and a gyral migration model where the fish of the northern fishery are carried in the counterclockwise gyre of the northern equatorial water mass of the eastern Pacific, and most of the fish of the southern fishery are carried in a clockwise gyre formed by the Northern Equatorial Countercurrent and the South Equatorial Current. Using a numerical model, Seckel (1972) showed that skipjack could migrate from northern Mexico to Hawaii by drifting with the currents. He stated that: "Floating objects introduced in the model ocean at long. 120°W and lat. 10° to 20°N converge toward the northern edge of the North Equatorial Current near Hawaii in 21 to 23 months. The time of freedom of skipjack tagged in the eastern North Pacific and recovered in Hawaiian waters is of the same magnitude."

Some of the long-distance migrations which have been recorded for tagged skipjack in the Pacific Ocean are shown in Figure 7 (Fink and Bayliff, 1970; Anonymous, 1979a; Joseph, Klawe, and Murphy, 1980). The long-distance migrations of skipjack tagged in the western Pacific by the South Pacific Commission are shown by Kearney (1980: Figure 2).

Local movements of skipjack have been investigated by equipping them with ultrasonic transmitters and tracking them. A skipjack tracked for 8 days swam away from a bank at night and returned in the morning, with one exception, and spent the day there. Each night the fish travelled from 25 to 106 km (Yuen, 1970). Three skipjack travelled both horizontally and vertically 142 km in 24 hours, 50 km in 11 hours, and 25 km in 10 hours before becoming undetectable (Dizon, Brill, and Yuen, 1978).

3.52 Schooling

A description of the various types of schools of tuna recognized by fishermen in the San Diego-based purse seiner fleet has been made by Scott (1969). A summary of the information available on the schooling of skipjack is given in Matsumoto and Skillman (in press). They list the various types of schools as follows:

(1) Schools without birds
  (a) Milling or swirling in slow circular paths
  (b) Breezing or travelling
  (c) Jumping
(2) Schools with birds or bird flocks
  (a) to (c) above
(3) Schools with drifting objects
(4) Schools with sharks
(5) Schools with whales

"Among these, the last three types may be accompanied occasionally by birds or bird flocks, and all types could be of either pure or mixed schools, i.e., schools made up entirely of skipjack tuna or mixed with other tuna species or other fishes."

In the eastern Pacific fishery, Broadhead and Orange (1960) found that 71% of the skipjack caught by baitboats and 80% of those caught by purse seiners were from pure schools, with no yellowfin or other species present. In Hawaiian waters, Brock (1954) found a strong tendency for skipjack to school according to size, and suggested that it was related to the maximum speed attainable by fish of similar size, as smaller fish would not be able to keep up with larger fish if the sizes were sufficiently different. Strasburg and Yuen (1960) observed skipjack from beneath the surface and saw that small fish (~ 20 cm) maintained closely spaced schools of several thousand individuals, even while feeding. Medium and large fish did not school while feeding.

3.53 Responses to stimuli

Observations on the behavior of skipjack in their natural environment have been reviewed by Nakamura (1969). It has been observed that: skipjack respond better to live bait than to dead bait, but when in a "feeding frenzy" will sometimes ingest inedible materials such as pieces of paper and wood; skipjack do not respond to blood or extracts of fish; skipjack are attracted by the motion of edible and inedible lures; skipjack with empty stomachs tend to bite better than those with full stomachs; skipjack frequently congregate around floating objects. Some fishermen believe that water sprays increase the biting response of skipjack. In the tuna purse-seine fishery of the eastern Pacific hammering on the hull of the vessel and explosives are used in the belief that the sound will drive the fish away from the opening of the net. York (1972) observed that skipjack near a trolling vessel sounded after sudden and irregular noises from the boat, but were less easily frightened when in a "feeding frenzy." Strasburg and Yuen (1960), on the other hand, said that sound does not affect skipjack behavior.

Three skipjack kept in a tank showed no change in swimming speed when salinity was decreased from 34 to 29 o/oo (Dizon, 1977).

Nakamura (1968) estimated that a skipjack in water of the same transparency as in the experimental tank could see its prey at a maximum distance of 36 m with the sun at an altitude of 65° and an illumination of 107,600 lux at the surface. The smallest prey organism a 41-cm skipjack can retain in its gill rakers is wider than 0.9 mm, and he estimated that it could see a prey organism of this size at a maximum distance of 54 cm. The transient vertical marks observed on feeding skipjack could be seen by another skipjack at 12.4 m, while the permanent horizontal stripes could be seen at 3.1 m.

In the Hawaiian fishery, Yuen (1977) observed that the species of live baitfish which are most attractive to skipjack are those which swim with fast, short, darting movements, reflect light well, and are large enough to be seen at a distance, but small enough to be ingested. He found the largest baitfish in the stomach of a skipjack 60 cm long to be 20 cm long. Because a greater number of smaller baitfish can be carried than can larger ones, and because the skipjack will tend to be satiated sooner with larger baitfish, he estimated that the optimal size for fishing is from 2 to 6 cm long. The use of live baitfish in the skipjack fisheries of the tropical Pacific has been reviewed by Baldwin (1977) who listed a total of 160 species from 31 families in 12 major areas of the Pacific.

"In the Japanese pole-and-line fishery, the Japanese anchovy, Engraulis japonicus, is the most important bait species used. The more important bait species utilized in the eastern Pacific fishery are anchoveta, Cetengraulis mysticetus, northern anchovy, E. mordax, California sardine, Sardinops caerulea, Galapagos sardine, S. sagax, and southern anchovy, E. ringens. The Hawaiian skipjack tuna fishermen primarily use an anchovy called nehu, Stolephorus purpureus" (Yoshida, Uchida, and Otsu, 1977).

The responses of skipjack to temperature and salinity have been discussed in Sections 2.3 and 3.44.

4 POPULATION

4.1 Structure

4.11 Sex ratio

From 2,172 skipjack sampled throughout the year in the eastern Pacific, Schaefer and Orange (1956) found only 40% males in fish longer than 55 cm, at which length the sex of most fish could be determined, and found no evidence of a change in the sex ratio in the largest size classes, such as occurs in yellowfin. Waldron (1963) summarized data on the sex ratios of skipjack from various sources: 51% of the fish in samples from the western Pacific and near the Marquesas Islands were males, while in Hawaiian waters, depending on the season, 51 to 59% were males.

4.12 and 4.13 Age and size composition

A reliable and practical method for determining the age of skipjack has not been developed (Section 3.43).

The size composition of skipjack in different areas of the Pacific may be influenced by the volume of the habitat available to fish of varying size, determined by the upper physiological temperature limits which decrease with increasing size, according to the hypothesis of Barkley, Neill, and Gooding (1978) discussed in Section 3.325. Their charts show that the habitat for large skipjack is restricted in the eastern Pacific and more spacious in the central Pacific, which may explain why large skipjack are scarce in the eastern Pacific fishery but common in the fisheries of the Hawaiian Islands and French Polynesia.

The smallest skipjack caught in significant numbers are around 30-40 cm, but in some Japanese fisheries fish of 25 cm are sometimes caught (Matsumoto and Skillman, in press). Kawasaki (1964 and 1965a) shows length-frequency distributions of skipjack caught off Japan; there was usually one mode between 40 and 50 cm during May to August, and usually two to three modes in September to April, ranging from 25 to 70 cm. Length-frequency distributions of skipjack measured by the South Pacific Commission in a vast area of the central and western Pacific can be found in its Interim reports of the activities of the skipjack survey and assessment programme, a list of which is given by Kearney and Gillett (1980). In the Bismarck Sea in 1972 Lewis, Smith, and Hallier (1974) found 77% of the fish to be from 53 to 58 cm long. In the Papua New Guinea baitboat fishery most of the fish are from 46 to 69 cm long (Wankowski, 1980). In the New Zealand purse-seine fishery during the 1978-1979 season 74% of the skipjack were from 43 to 48 cm long (from data in Habib, Clement, and Fisher, 1980). In the Tahitian pole-and-line fishery 81% of the skipjack were under 59 cm long, 16% were 59 to 75 cm long, and 3% were over 75 cm long during the 1975-1978 period (Marcille, Asine, Marec, and Mariterangi, 1979: Tables 2-5). Length-frequency distributions of skipjack from the Hawaiian fishery are trimodal or bimodal, with modes around 35, 50, and 70 cm in the winter and around 45 and 70 cm in the summer (Rothschild, 1965). Broadhead and Barrett (1964) showed length-frequency distributions of skipjack by quarters for the eastern Pacific fishery north of 15°N. There was usually one mode between 45 and 55 cm, and the fish caught off Baja California were smaller than those caught off the Revillagigedo Islands. In 1972 and 1973, however, a second mode appeared between 60 and 70 cm (Figure 8).

Annual length-frequency distributions for the eastern Pacific from 1967 to 1979 are shown in Figure 8. It is evident that there was a higher proportion of larger fish in the catches from 1971 to 1977 than in other years with the exception of 1968, but this is apparently a result of the lower catch rate for smaller fish from 1971 to 1977 rather than of an influx of larger fish (Anonymous, 1980a: Figure 33).

Marked changes in length-frequency distribution of skipjack have been observed during different periods in the eastern Pacific fishery, particularly in the southeastern region (south of 5° N, and north of 5° N and east of 85° W). Distributions for the combined data from the 1965-1970 period in this region were peaked with clearly defined modes at 47, 50, 51, and 52 cm in the first to the fourth quarters, respectively, and with minor modes at 60 cm in the first quarter and at 40 cm in the third quarter. For the 1971-1975 period the distributions were flattened, showing a greater proportion of larger fish as well as of smaller fish than during the earlier period: in the first quarter modes were found at 45 and 57 cm; in the second quarter modes were at 47 and 62 cm; in the third quarter there were poorly defined modes from 36 to 67 cm; and in the fourth quarter modes were at 44 and 57 cm (Anonymous, 1977b: Figure 13).

Various estimates of the length-weight relationship for skipjack from the Pacific Ocean have been summarized by Nakamura and Uchiyama (1966). The equation is:

$$W = aL^b$$

where $\underline{W}$ is body weight in pounds, $\underline{L}$ is fork length in millimeters, and $\underline{a}$ and $\underline{b}$ are constants. For the eastern Pacific skipjack, $\underline{a} = 5.623 \times 10^{-9}$ and $\underline{b} = 3.336$ (Hennemuth, 1959); for central Pacific fish, $\underline{a} = 4.546 \times 10^{-9}$ and $\underline{b} = 3.36836$ (Nakamura and Uchiyama, 1966).

From physiological calculations, Kitchell, Dizon, and Magnuson (1978) estimated that skipjack cannot grow much larger than 25 kg (55 pounds). Larger skipjack, however, have apparently been caught. Some fish weighing as much as 75 pounds (34 kg), and requiring 3-pole fishing were reported in the central Pacific in 1949 (Anonymous, 1950). According to the length-weight equation for central Pacific fish, a 75-pound skipjack would be about 108 cm long. Miyake (1968) lists a single skipjack caught by longline in the 106.5- to 108.4-cm size class. According to the equation for the central Pacific such a fish would weigh about 73 pounds (33 kg). The largest skipjack measured by the Commission from the eastern Pacific fishery was in the 87.0- to 87.9-cm size class and would have weighed about 37 pounds (16 kg); a mounted skipjack at the office of Bumble Bee Seafoods in San Diego, California, caught by purse seine off Baja California in 1967, weighed 40 pounds (18 kg) and was 88.9 cm long; a skipjack weighing 36 pounds (16 kg) was caught off Costa Rica in 1980 (Silva, 1980). Off Tahiti, however, such large fish are more common; 86 skipjack in the 90.0- to 90.9-cm size class and 1 in the 91.0- to 91.9-

cm size class were measured during the 1973-1978 period (Marcille, Asine, Marec, and Mariterangi, 1979: Tables 20-25).

4.2 Abundance and density

Shimada and Schaefer (1956) developed the first measure of apparent abundance for the skipjack fishery of the eastern Pacific. The catches per day's fishing by baitboats of different carrying capacities were compared to obtain standardization factors among vessel size classes, and these were used to standardize the effort to that of a single size class. The method, modified for purse seiners, is still in use today; it is the logged catch divided by the logged effort standardized to Class-3 seiners (vessels of 101-200 short tons of carrying capacity). It is biased in that it includes effort directed primarily at yellowfin. This index of abundance for the 1960-1979 period is shown in Figure 9. Joseph and Calkins (1969) developed a method of estimating abundance of skipjack in the eastern Pacific by eliminating areas of low catch where most of the effort was directed at yellowfin. There appeared to be no relation between the indices of abundance in the areas north and south of 15°N (Figure 10).

Pella and Psaropulos (1975) adjusted the catch-per-unit-of-effort data for purse seiners in the eastern Pacific from 1960 to 1972 for increases in efficiency and time in sets, stating that: "Skipjack abundance was indexed in three subareas [see their Figure 22]. In the northern area, average abundance appeared to increase during the early part of the series of years, and thereafter fluctuated at a generally lower level. In the southern region, skipjack seemed to show general decline in average annual biomass over the series, interrupted by major increases in 1963 and 1967. The central region had low abundance of skipjack in all years" (Figure 11). They also found that the Gulf of Guayaquil area, where much of the skipjack from the southern area had been caught, showed a great decline in the biomass index between 1960-1961 and 1970-1971 (Figure 12).

A simple method of eliminating some of the effort on yellowfin to obtain an index of abundance for skipjack in the eastern Pacific was described in Anonymous (1977b). Twenty-two 5-degree areas were selected where most of the skipjack has been caught in recent years, but only data from area-quarter (3 months) strata having ≥100 standardized days of logged effort and ≥200 short tons of logged skipjack caught were used. For purse seiners, during the 1961-1979 period, this eliminated an average of 43% of the effort while retaining 89% of the skipjack catch. In Figure 13 are shown the indices of abundance for three areas. The catch per unit effort by purse seiners shows a downward trend south of 5°N, but no clear trends are apparent for the central and northern areas. The trend in the southern area is largely due to reduced abundance in the Gulf of

Guayaquil area, as Pella and Psaropulos (1975) have shown. Because changes in the thermal front between the cold upwelled waters of the Peru Current and the warm waters north of the equator were regarded as possible factors influencing the apparent abundance of skipjack in the Gulf of Guayaquil area, mean quarterly values of sea-surface temperature and of the north-south temperature gradient on the fishing grounds during the 1961-1976 period were examined, but no significant correlations were found with indices of skipjack abundance in the area (Anonymous, 1978a).

For the Hawaiian skipjack fishery Uchida (1976) recalculated the effort for the 1948-1964 period to include days during which no skipjack was caught. He found no relation between catch per unit of effort and the relative fishing effort, and concluded that the abundance of skipjack in Hawaiian waters is probably determined by year class strength and availability and not by the fishery. The fluctuations of the index of abundance for the 1948-1970 period are shown in Figure 14; no trend is apparent.

About 90% of the Japanese catch of skipjack in the western Pacific is taken by baitboats. The catch per day's fishing by Japanese baitboats from 1957 to 1973 is shown in Figure 15 from Ishida (1975); no trend is apparent. Kasahara (1977) shows the catch per day's fishing in the Japanese "southern water" skipjack fishery (south of 15°N) from 1968 to 1975 (Figure 16); again, no trend is evident.

The catch per day's fishing by baitboats based in Papua New Guinea is shown in Figure 17; no trend is evident.

4.3 Natality and recruitment

Reproduction rates and factors affecting reproduction have been discussed in Sections 3.13 to 3.16.

Kasahara (1977) suggested that an exceptional number of adults in a year class recruited to the fishery was related to an unusual abundance of larvae of that year class, assuming that natural mortality at the various stages of development were average.

Possible environmental effects on year classes of skipjack caught in the eastern Pacific have been investigated by the Commission in an attempt to explain some of the variation in the catches (Anonymous, 1979a and 1980a). Significant correlations have been found between indices of skipjack abundance in the eastern Pacific and sea-surface temperatures in the spawning areas of the central tropical Pacific (180°-130°W) approximately 1 1/2 years earlier, and between skipjack abundance and meteorological variables which are related to sea-surface temperatures in the spawning areas, such as wind speeds in the spawning areas, and barometric pressure differences at stations far from the spawning areas which are related to winds in those areas.

Lasker (1975, 1978, and 1980) has proposed that the survival of anchovy larvae in the California Current is dependent, in part, on the upper mixed layer in the inshore waters where food is available being in a stable condition for a sufficient time. The food required by the larvae when they first begin to feed is found in aggregations and layers when stability is high during periods of calm weather or weak upwelling. In periods of rough weather or strong upwelling the layering is destroyed and the food organisms dispersed so that concentrations become too low for many of the larvae to feed, resulting in high mortalities. The amount of turbulent mixing caused by wind is roughly proportional to the cube of the wind speed. It appears that weak winds and suitable food during the larval stages result in strong year classes of anchovies, and that strong winds, upwelling, or unsuitable food result in weak year classes (Lasker, 1980).

It was thought that the effects of the wind might also influence the survival of skipjack larvae in the spawning areas of the central Pacific, and ultimately have an effect on the recruitment of adult skipjack into the fisheries of the eastern Pacific. Recent investigations (Anonymous, 1980a) indicate that approximately 47% of the variation ($r = -0.69$, $P < 0.01$) in the annual catch rate (numbers of fish per standardized day's fishing) of skipjack in the eastern Pacific estimated to be between 12 and 24 months of age may be explained by the wind-mixing index in the spawning areas of the central Pacific approximately 1 1/2 years earlier. Though significant, the correlations are not sufficiently high for making reliable predictions of skipjack catches in the eastern Pacific.

Recruitment has also been discussed in Sections 3.51 and 4.13.

4.4 Mortality and morbidity

From length frequencies of skipjack larvae in plankton nets, the apparent mortality rate of the larvae has been estimated to average 30% per day (Anonymous, 1979a).

Previous studies on the mortality of larger skipjack in the eastern Pacific have been reviewed by Bayliff (1977). From tagging data he estimated the rates of attrition (fishing and natural mortality, shedding of the tags, mortality due to carrying the tags, and emigration). He calculated the coefficient of monthly attrition exclusive of fishing mortality to be less than 0.25, but stated that the estimate was too crude to be of much use. "The great fluctuations in natural mortality responsible for the fluctuations in abundance are the result of variability in the magnitude and productivity of the environment (habitat) available to skipjack of any specific size; I further believe that the magnitude of these mortalities can be so great as to apparently eliminate certain size cohorts in a very short time period (of the order of weeks)" (Kearney, 1978).

4.5 Dynamics of the population

"The relation between indices of abundance and total effort and total catch and total effort was examined for 1951 through 1965 in both the north and the south. There was no apparent relation between abundance and effort, but a positive relation between total catch and total effort was apparent. It was concluded that fishing was not sufficiently intense to measurably affect the abundance of subsequent generations contributing to the eastern Pacific fishery. It was further observed that the variability noted in the abundance of skipjack among years was most likely due to fishery-independent causes" (Joseph and Calkins, 1969). "It appears certain that at the present levels of fishing effort, the mortalities induced by man on the skipjack resources of the Pacific are completely overshadowed by those from natural causes" (Kearney, 1979).

In the eastern Pacific skipjack fishery the yields per recruit generally "... are highest with a size at entry of 35 cm (about 1.7 pounds) and fishing effort considerably greater that has been the case so far... This is because the losses to the total weight of a cohort of fish by natural mortality and emigration exceed the gains to it by growth... Neither the general production models nor the age-structured models applied so far indicate any need so far for the management of skipjack" (Anonymous, 1979a).

Estimates of the potential yield of skipjack in the Pacific have been reviewed by Matsumoto (1974), who warned that they are tentative and must be used with caution. Following the method of Beverton and Holt (1957), Rothschild (1966) estimated the potential yield of skipjack from the central Pacific that have returned from the fishing areas of the eastern Pacific. Using 70,000 mt as an average steady-state yield in the eastern Pacific at that time, and assuming a sojourn time of 6 months in the fishing areas of the eastern Pacific, he estimated the potential yield in the central Pacific to be 5 to 17 times greater than the yield in the eastern Pacific, or 350,000 to 1,190,000 mt. Assuming a sojourn time of 6 months he estimated the yield to be 2 to 6 times greater, or 140,000 mt to 420,000 mt. He qualified these estimates as probably low, since they do not include fish that have not moved through the fishing areas of the eastern Pacific. Silliman (1966), using a population simulation method, estimated a potential yield of 180,000 to 225,000 mt for the eastern Pacific fishery and the unexploited areas of the central and eastern Pacific. Joseph and Calkins (1969), however, stated that their own data could not be used to estimate the potential yield of skipjack from the eastern Pacific, and that "Before substantial improvement can be made to the estimates of Silliman and Rothschild, some knowledge of the stock structure of skipjack tuna and the effect of their sizes on subsequent recruitment must be obtained."

The Fisheries Agency of Japan estimated in 1968 that the potential yield of skipjack for the entire Pacific Ocean was at least 1,000,000 mt (Kawasaki, 1972). Suda (1972) estimated the potential yield to range from 800,000 to 1,000,000 mt. He assumed that the skipjack spawning stock was about twice that of the other tunas, on the basis of a ratio of 1.7 to 1.8 for the number of skipjack larvae to those of other tuna larvae collected in nets, and on the basis of the high proportion of juvenile skipjack relative to other juvenile tunas found in the stomachs of large tunas and billfishes. Since 400,000 to 500,000 mt of other tunas were being captured annually at that time, he obtained his estimates of potential skipjack yield by multiplying these catches by two (Kawasaki, 1972). Matsumoto (1974) speculated that the estimate by the Fisheries Agency of Japan was obtained by a similar method, and also pointed out the weaknesses of this method of estimating the potential yield. Nevertheless, these values are now being approached, with the nominal catch for the entire Pacific reaching 662,000 mt in 1978 (Table 3).

4.6 The population in the community and the ecosystem

"Skipjack tuna inhabit the epipelagic zone of the world's major oceans. As such, they live generally in the upper mixed layer having uniform temperatures and salinities with oxygen being at or near saturation. Latitudinal and longitudinal variations in temperature and depth of mixed layer determine to a great extent the distribution of skipjack tuna... The major water masses or their associated currents also influence the distribution of the species both through drift of the larvae and possibly the adults as well, but also through the availability of food associated with current boundaries and areas of upwelling. Except for these latter areas of high productivity, the epipelagic zone is characterized by low productivity" (Matsumoto and Skillman, in press).

"Within the marine community the skipjack may be listed both as prey and predator, although as a large adult it may be only one step removed from a climax predator. In its larval and juvenile stages it serves as food for larger fish, including adult skipjack. As an adult it serves as food for larger tunas and spearfishes, and at the same time preys upon small to moderate-sized pelagic crustaceans, molluscs, and fish. Skipjack compete for food with tunas and other fish of similar size and habits. They might even be considered as competing with sea birds, for the food organisms are often apparently driven to the surface of the water, where they are preyed upon by both skipjack and various sea birds" (Waldron, 1963).

The species composition of the most visible members of the community has been summarized by Matsumoto and Skillman (in press). These include some sharks, several scombrids, marlins, swordfish, mahi-mahi, opah, flying fishes, and many other species.

The habitat of skipjack delineated by temperature and oxygen concentration has been discussed in Section 3.44.

5 EXPLOITATION

5.1 Fishing equipment

The fishing boats and gear used in the various skipjack fisheries of the Pacific have been described by Yoshida (1966b) and Uchida (1975). The live-bait fisheries necessary to the baitboat fisheries for tuna in the Pacific have been described by Yoshida, Uchida, and Otsu (1977). In the eastern Pacific about 80 to 95% of the skipjack is caught by purse seiners, while in the western Pacific most of the catch is made by baitboats (Anonymous, 1979a). Only small amounts of skipjack are caught by longliners. The development, technology, and operation of the purse-seine fishery for tunas in the eastern Pacific by United States vessels has been described by Green, Perrin, and Petrich (1971). The literature on the development of skipjack fisheries in the central and western Pacific has been reviewed by Hester and Otsu (1973). Skipjack are caught at the surface in all baitboat fisheries. Purse seines are basically a surface gear, but fish from the surface to a depth between 50 and 80 m in the eastern Pacific (Sharp, 1978). Purse seines are more successful at catching skipjack when the thermocline is shallower, presumably because the fish are reluctant to dive into colder water to escape under the net (Green, 1967; Sharp, 1978).

The numbers of vessels fishing for tropical tunas in the eastern Pacific since 1961 and their total carrying capacity are given in Table 1. The number of smaller purse seiners (<401 short tons of carrying capacity) in the 1960's ranged from 99 to 125; in the 1970's the numbers ranges from 78 to 105. The number of larger purse seiners (≥401 short tons of carrying capacity), however, increased gradually from 9 in 1961 to 24 in 1967, then increased rapidly, reaching 158 in 1976, and remained at this level through 1979. The number of baitboats remained fairly constant from 1961 to 1976, ranging from 91 to 116, but decreased rapidly to 45 by 1979. The total carrying capacity of all gears in the fleet increased from 36,600 mt in 1961 to 169,900 mt in 1979. The 1979 fleet consisted of 97.7% purse seiners, 2.1% baitboats, 0.2% bolicheras (small purse seiners with <50 short tons of carrying capacity), and less than 0.1% jigboats in terms of capacity; and 80.7% purse seiners, 14.0% baitboats, 4.4% bolicheras, and 0.9% jigboats in terms of numbers (Anonymous, 1980a).

In the Hawaiian skipjack fishery there were 14 baitboats modeled after the Japanese sampans in 1980 (Otsu, 1980). In French Polynesia there were 132 small skipjack pole-and-line boats actively fishing in 1978 (Marcille, Asine, Marec, and Mariterangi, 1979). In the New Zealand fishery there were 12 purse seiners fishing for skipjack in the 1978-1979 season (Habib, Clement, and Fisher, 1980). In the baitboat fishery based in Papua New Guinea there were 41 boats fishing for skipjack in 1979 (Wankowski, 1980).

During the 1966–1973 period the total number of Japanese baitboats fishing for skipjack averaged 3,826, consisting of 3,274 small coastal vessels under 20 gross metric tons (gmt), and 552 medium-sized offshore vessels and distant-water vessels ranging from 20 gmt to over 200 gmt (Ishida, 1975). Changes in the relative numbers of the larger vessels are shown in Table 2. The number of vessels larger than 200 gmt has increased from 35 in 1965 to 267 in 1976. Ishida (1975) stated that vessels larger than 50 gmt caught more than 80% of the skipjack in the Japanese baitboat fishery. Coastal vessels less than 20 gmt fish only from Japan to as far as 10°N, offshore vessels of 20 to 60 gmt fish from Japan to as far as 8°S, and distant-water vessels greater than 80 gmt are restricted only by international regulations (Kearney, 1979).

In 1977 the Japanese vessels that fished for skipjack in the Pacific consisted of about 3,000 small baitblats, 361 medium-sized baitboats, 250 large distant-water baitboats, and 68 large and medium-sized purse seiners (Ogawa, 1979). By 1978 the Japanese fleet of distant-water tuna purse-seiners had grown to 14 vessels which fished in the Pacific and Indian Oceans (Anonymous, 1979c). Kearney (1979) mentioned that 11 purse seiners, all of which were in the 500 gmt class, fished south of Japan in 1976, 1977, and 1978.

5.2 Fishing areas

The principal fishing areas for skipjack in the western and eastern Pacific are shown in Figures 4 and 8. In the Japanese fishery, the catches are concentrated in three zones: the northern area including the Ryukyu Islands, off southern Japan, and east to 180°; the "southern water" fishing ground south of about 15°N from Papua New Guinea to about 170°W; and a third zone along 20°N from 140°E to 180° in the third quarter of the year (Figure 4). Kearney (1979) gives the estimated catches of skipjack by Japanese baitboats from 1972 to 1976 within 200 miles of the countries and territories in the area of the South Pacific Commission. In 1976 the principal areas fished, in order of decreasing catches, were around the Pacific Islands Trust Territory, the Gilbert Islands, the Solomon Islands, Papua New Guinea, Nauru, and Tuvalu. Wankowski (1980) shows the nominal effort by baitboats based in Japan fishing in the Papua New Guinea Declared Fisheries Zone (within 200 miles of land) to have ceased in 1978, and to have been resumed at a low level in 1979, probably as a response to license and access fees imposed by Papua New Guinea in March 1978 for permission to fish in the area.

In the eastern Pacific most of the skipjack is caught within 600 nautical miles of land, off the coasts of Central America and northern South America (Figure 8). During the 1975–1979 period an average of 73% of the skipjack caught east of 150°W was caught within 200 nautical miles of land (Greenough, 1980).

During the 1960's much of the skipjack was caught off Baja California and off Ecuador and in the Gulf of Guayaquil; while in the 1970's the largest catches were usually made offshore between 5°N and 15°N and in the Panama Bight.

Small fisheries for skipjack exist near the Hawaiian Islands, French Polynesia, northern New Zealand, Fiji, the Solomon Islands, the Pacific Islands Trust Territory, Papua New Guinea, Indonesia, the Philippine Islands, Korea, and Taiwan (Uchida, 1975; Klawe, 1978; Table 6).

Fishing areas have also been discussed in Section 2.22.

5.3 Fishing seasons

In general, there is little seasonal variation in the skipjack fisheries in the equatorial areas. The greater the distance from the equator the more the catches peak in the summer months (Matsumoto and Skillman, in press). Some areas in the equatorial regions, however, do show seasonal patterns in skipjack catches: in the Panama Bight they are low from August to March and peak from April to July (Forsbergh, 1969); close to the coast of Ecuador they are low from January to April, with a major peak from May to July and a minor one in October and November (Forsbergh, 1980); off Papua New Guinea the catch per boat is lowest from December to February and highest from May to September (Wankowski, 1980).

For the entire southern area (south of 15°N) of the eastern Pacific fishery, Joseph and Calkins (1969) found the index of abundance to be lower in September-November and higher in May and June. In the Hawaiian baitboat fishery most of the skipjack catch is made during June, July, and August (Rothschild, 1965). In the pole-and-line fishery of French Polynesia the best catches of skipjack are made from November to June (Marcille, Asine, Marec, and Mariterangi, 1979). Off New Caledonia schools of skipjack are most frequently seen from November to March (Marcille, 1980). Off northern New Zealand they are seen from October to April (Clement, 1976 and 1978).

Fishing seasons have also been discussed in Sections 2.22 and 2.321.

5.4 Fishing operations and results

Various methods of estimating the amount of effort directed toward skipjack have been discussed in Section 4.2. In the eastern Pacific, the logged effort by purse seiners remained fairly constant between 1961 and 1969, ranging from 14,800 to 19,700 days of fishing, standardized to Class-3 vessels (101-200 short tons of carrying capacity). The logged effort began increasing in 1970, reaching 41,400 days in 1976 and 41,200 days in 1978, and then declined to 39,200 days in 1979. The actual effort, which can be estimated by dividing the total catch, determined from landings data, by the catch per unit of effort, is considerably greater than the logged effort. During the past 10 years the actual effort has been from 22 to 61% greater than the logged effort, with the greatest differences occurring during the years with small catches. No trend is apparent in the proportion of the estimated actual effort that is logged.

In the Hawaiian skipjack fishery the relative fishing intensity of baitboats has shown no trend between 1948 and 1970, varying between 1,658 and 2,552 days of fishing, standardized to Class-2 vessels (45-77 gmt), as shown in Figure 14 (Uchida, 1976). In the Papua New Guinea baitboat fishery (Figure 17), the effort increased from 511 days fished in 1970 to 9,941 days fished in 1978 and decreased to 8,184 days in 1979 (Wankowski, 1980). In the New Zealand purse-seine fishery, the vessels fished 458, 401, and 419 days during the 1976-1977, 1977-1978, and 1978-1979 seasons, respectively (Habib, Clement, and Fisher, 1980 and no date).

The number of logged trips by baitboats in the traditional Japanese skipjack fishery north of 15°N has been tabulated by Bour and Galenon (1979) for the 1970-1976 period. The total number of trips for all sizes of boats increased from 7,207 in 1970 to 10,376 in 1976. The number of trips by boats of 50 to 100 gross metric tons (gmt) increased from 1,420 to 8,049 during the same period. Kasahara (1977) shows that the total number of fishing days for all size classes of baitboats in the Japanese "southern water" fishery (south of 15°N) increased from 8,808 in 1970 to 21,529 in 1975; for boats greater than 250 gmt, the effort increased from 2,613 to 19,942 fishing days during the same period.

Longline gear is highly selective for large skipjack because the large hooks are designed to catch the larger tunas, but few skipjack are taken by this gear (Miyake, 1968). In the eastern Pacific, off Baja California, where both baitboats and purse seiners frequently fish in the same areas, the mean weight of skipjack caught from 1959 to 1979 in quarterly periods with sufficient data from both gears was 2.98 kg for baitboats and 3.28 kg for purse seiners, a difference significant at the 5% level, indicating that in this area purse-seine gear may be slightly more selective for larger skipjack than baitboat gear (Forsbergh, 1980).

The nominal catches of skipjack for the 1964-1978 period in the six statistical areas of the Food and Agriculture Organization (FAO) of the United Nations in the Pacific (Figure 19) are shown in Table 3. In recent years the west central area (71) has had the greatest catches, and the northwestern area (61) the next largest catches. For the entire Pacific Ocean the catches increased from 252,400 metric tons (mt) in 1964 to 662,400 mt in 1978, representing 84% of the world catch of 791,800 mt. In 1978, 529,500 mt were caught in the western Pacific and 132,900 mt were caught in the central and eastern Pacific.

The nominal catches of skipjack by Japanese vessels in the FAO statistical areas of the Pacific from 1964 to 1978 are shown in Table 4. Some other species, such as frigate tuna, Auxis thazard, and other scombrids, may be included in these statistics (Klawe, 1978). The catches in the northwestern area show no trend during this period, but those in the west central area have increased greatly. The Japanese catches for the entire Pacific ranged from 133,500 mt in 1965 to 358,200 mt in 1978, representing 54% of the catch from the Pacific Ocean in that year. Ogawa (1979) stated that the average Japanese catch of skipjack during the past few years amounted to 330,000 mt which were "produced as follows: 1) 170,000 mt by distant-water skipjack tuna vessels, 2) 122,000 mt by the coastal skipjack tuna vessels, 3) 10,000 mt by the smaller, nearshore pole-and-line vessels, 4) 22,000 mt by the purse-seine vessels, and 5) about 6,000 mt by various other fishing methods." According to FAO statistics (Table 4) the average Japanese catch of skipjack in the Pacific during 1973-1978 was 309,000 mt, about 96% of the average Japanese catch of 323,000 mt from all oceans for this period.

In the eastern Pacific east of 150°W, the annual catches of skipjack by the eastern Pacific tuna fleet fluctuate greatly. During the 1961-1979 period the catches ranged from 33,300 mt in 1972 to 170,300 mt in 1978 (Table 5). The mean annual catch during the 1976-1979 period increased by 76% over the mean catch for the previous 12 years. The mean catches for 4-year periods are as follows:

1964-1967	77,500 mt
1968-1971	72,700 mt
1972-1975	70,200 mt
1976-1979	129,200 mt

With the exception of 1970, most of the catch had been made south of 15°N (Figure 20). The catch of skipjack in 1979 by vessels of countries fishing in the eastern Pacific is given in Table 5. The vessels of three countries caught 70% of the skipjack: United States, 53.0%; Ecuador, 13.2%; and Panama, 4.2%.

The nominal catches of skipjack in some of the smaller skipjack fisheries of the Pacific are given in Table 6. The fisheries of French Polynesia and the Hawaiian Islands have been established for many years, while the others appear to have developed in the late 1960's and in the 1970's. The Philippine fishery has had the largest catches in recent years, with 55,000 mt in 1977 and 56,300 mt in 1978; Papua New Guinea ranks second, with 45,800 mt in 1978 and 24,000 mt in 1979; Indonesia ranks third, having caught over 16,000 mt annually in the Pacific in 1976 and 1977; the Solomon Islands rank fourth with 11,500 mt in 1977 and 17,400 mt in 1978. The fisheries of the Republic of Korea, Taiwan, the Pacific Islands Trust Territory, Fiji, New Zealand, French Polynesia, and the Hawaiian Islands have each caught less than 10,000 mt annually. In the New Zealand fishery, 9,500 mt of skipjack were caught during the 1977–1978 season, and 9,000 mt were caught during the 1978–1979 season. Uchida (1975) also gives estimates for New Hebrides and Palau up to 1973, but data for recent years are not available.

6 PROTECTION AND MANAGEMENT

At present there are no regulations for skipjack in the Pacific Ocean. In the past the state of California has required a minimum weight of 4 pounds (1.8 kg), equivalent to a length of about 45 cm, but this was repealed in 1975. There is no need yet for the management of skipjack in the eastern Pacific fishery (see Section 4.5).

Concerning the expansion of the Japanese "distant water" fishery for skipjack in the Pacific, Kasahara (1977) proposes that: "It would seem that the future of the fishery lies in the orderly harvesting of skipjack tuna within the limits of the present fishing grounds. In order to continue a stable fishery operation, the fishing effort must be regulated according to the available resources." Kearney (1978 and 1979), however, believes that natural mortalities greatly exceed fishing mortalities at the present levels of effort in the skipjack fisheries of the Pacific, and that management for the purpose of protecting the resource is not justified at this time, nor is it likely to be justified with even higher levels of effort in the future. Furthermore, he suggests that economic constraints on the fishery in the equatorial western Pacific will prevent it from even reaching a maximum sustainable biological yield, and that "development and management strategies will likely be directed towards maximizing yields and optimizing socio-economic returns from the harvest" (Kearney, 1979).

7 CULTURE

There is no information on this subject.

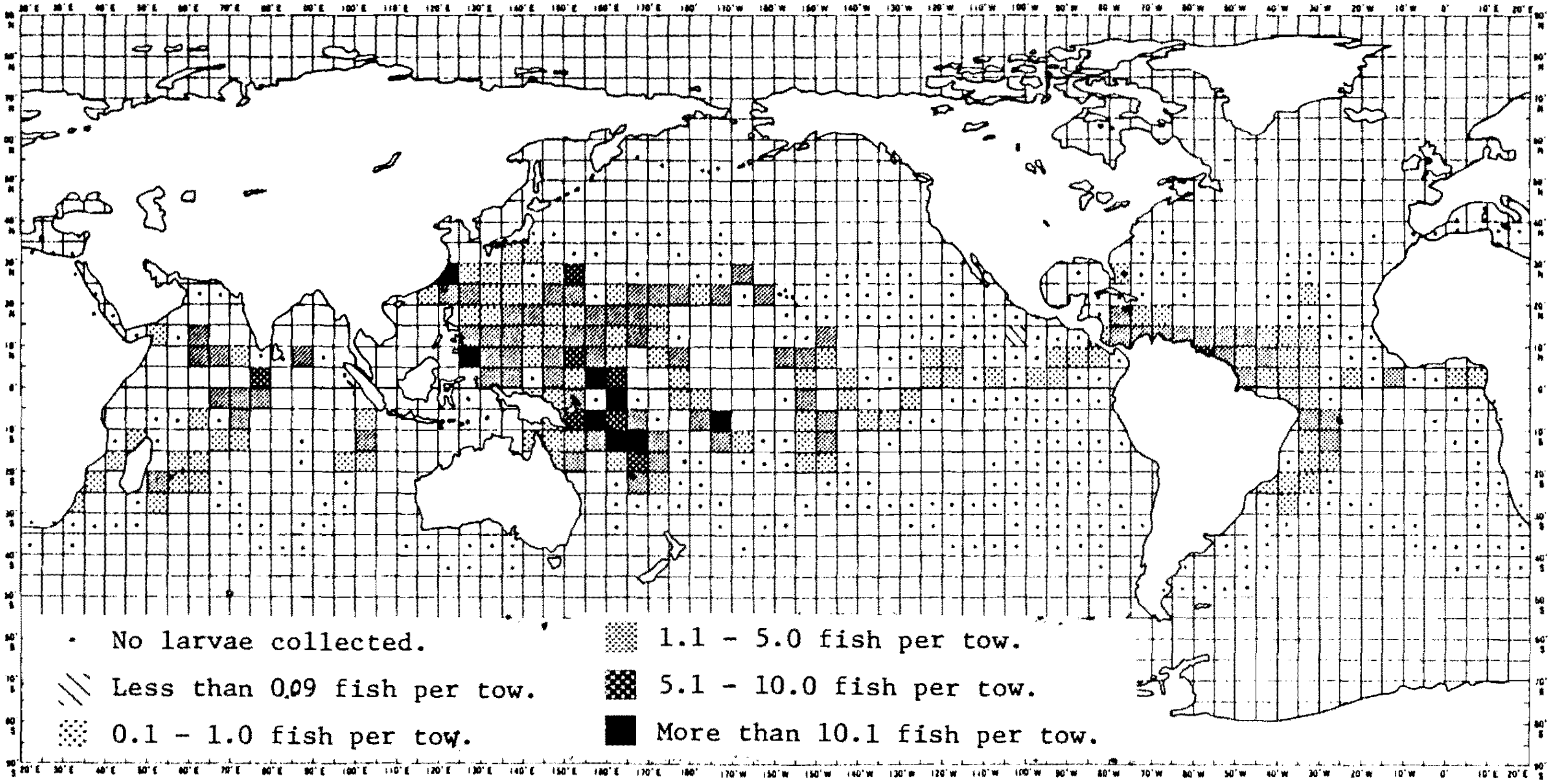

FIGURE 1. Distribution of skipjack larvae captured by Japanese research vessels (from Nishikawa, Kikawa, Honma, and Ueyanagi, 1978).

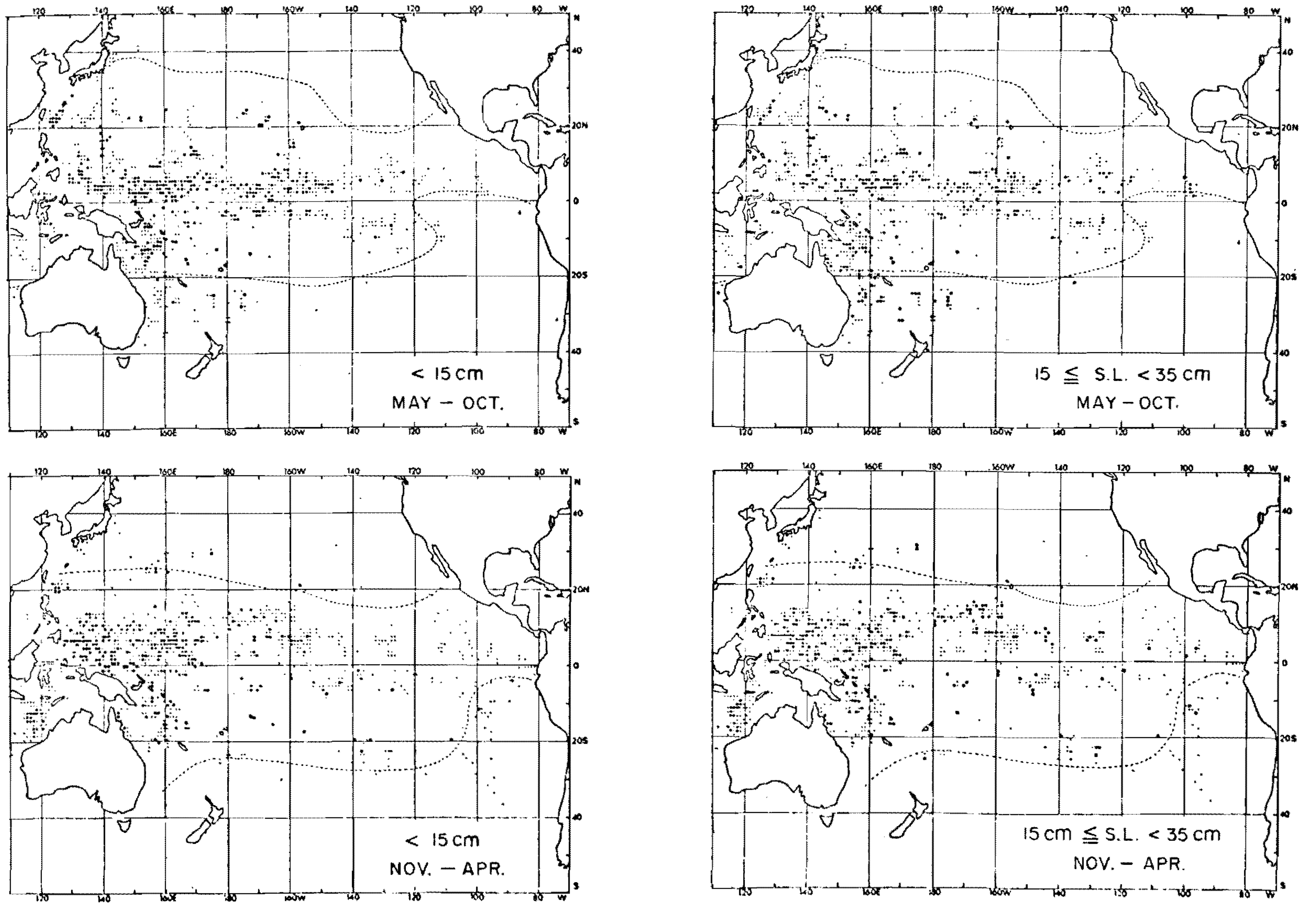

FIGURE 2. Seasonal distributions of juvenile and young skipjack in the Pacific and Indian oceans (from Mori, 1972). The dotted curves indicate the mean positions of the 24°C isotherms.

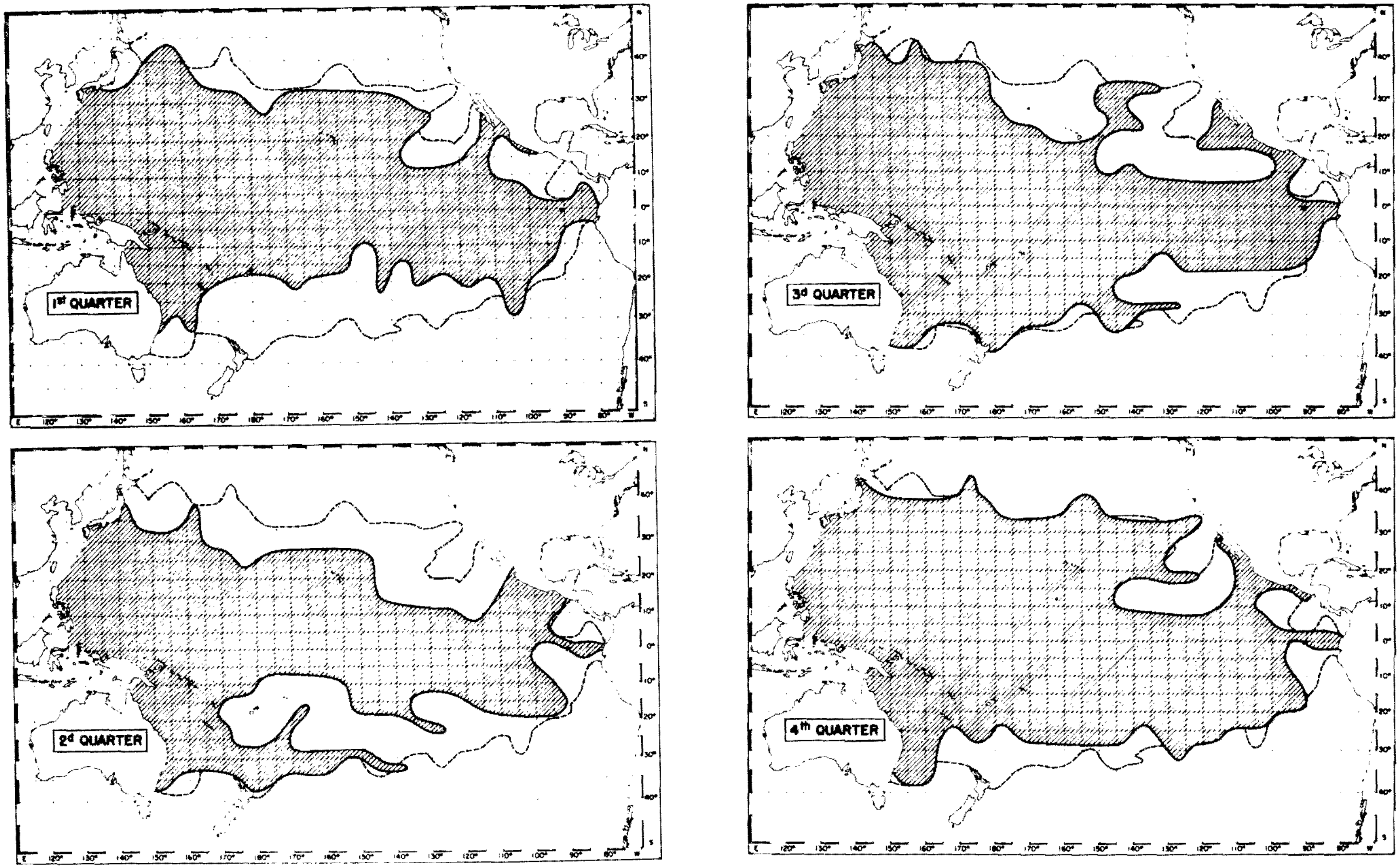

FIGURE 3. Outlines of the northern and southern boundaries of skipjack caught in the Japanese longline fishery, 1964-1967, by quarters (shaded area) (from Matsumoto, 1975). The broken lines denote the maximum ranges in the four quarters.

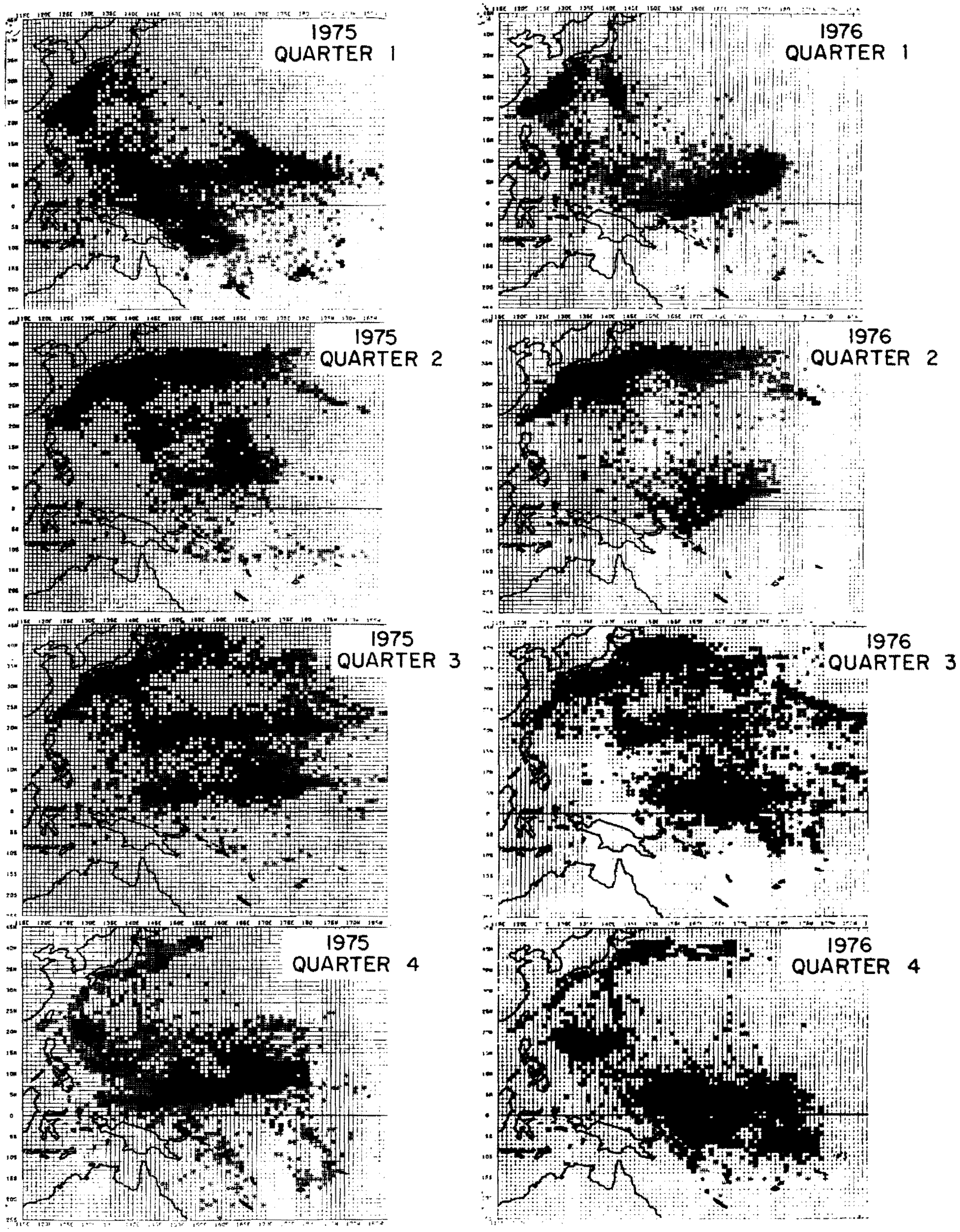

FIGURE 4. Quarterly distributions of skipjack catch by Japanese baitboats, 1975-1976 (from Kasahara, 1978).

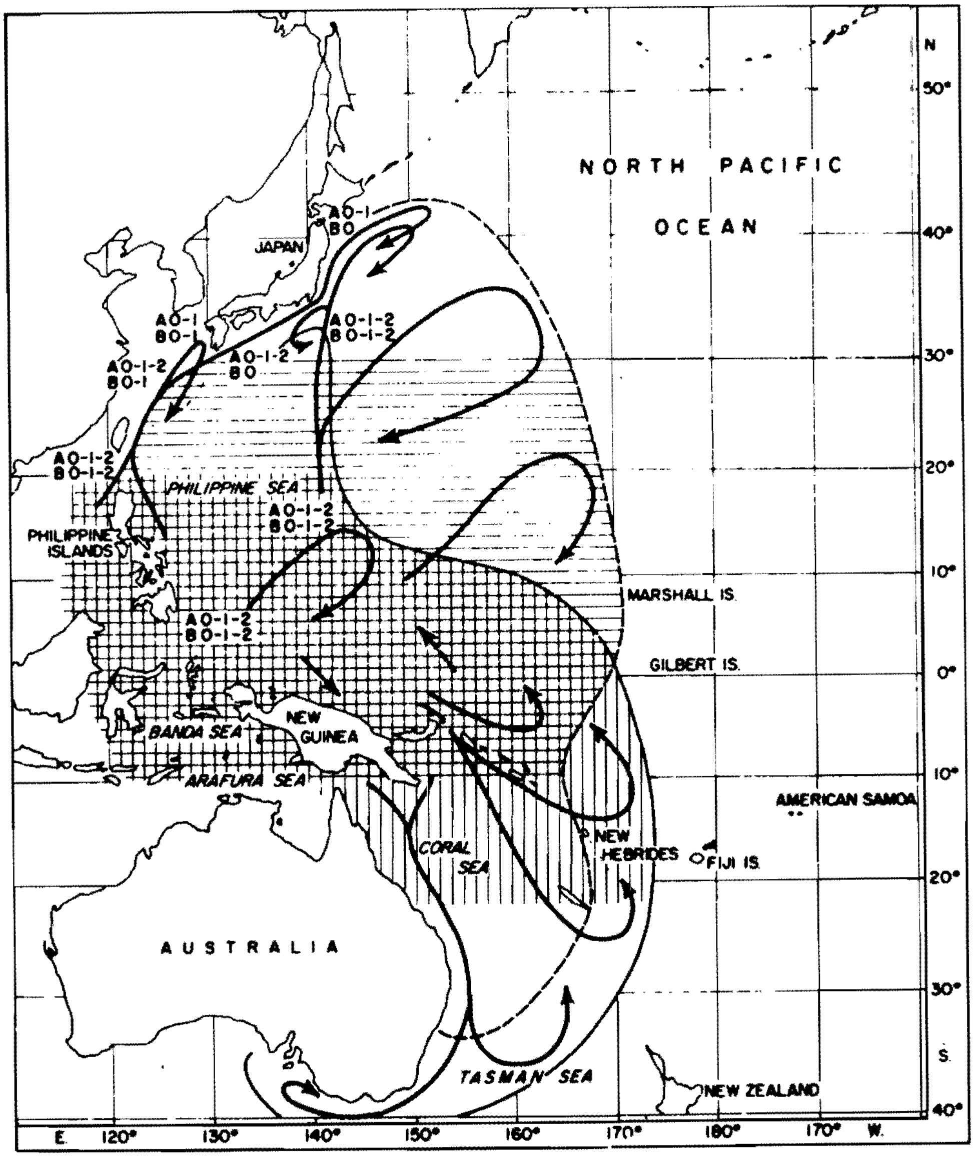

FIGURE 5. "Proposed range and migration routes of skipjack tuna subpopulation in the western Pacific Ocean. Eastern limit of range in the northern winter (southern summer) and northern summer (southern winter) are indicated by a thin solid line and a broken line, respectively. These two lines also represent approximate western limits of ranges of the central and eastern Pacific skipjack tuna subpopulation(s) in the two seasons. Intensive spawning grounds in the northern summer and winter are shown as the areas hatched horizontally and vertically, respectively. Thick solid lines with arrows represent proposed major routes of migration of both group A and B as described in the text. Thick broken lines with arrows show possible infrequent intermingling across the Equator between northern and southern fish. Numerals with a letter A or B mean age classes of fish by group (A or B) in each location, as described in the text...Such numerals are not shown for the southern hemisphere for lack of data" (from Fujino, 1972).

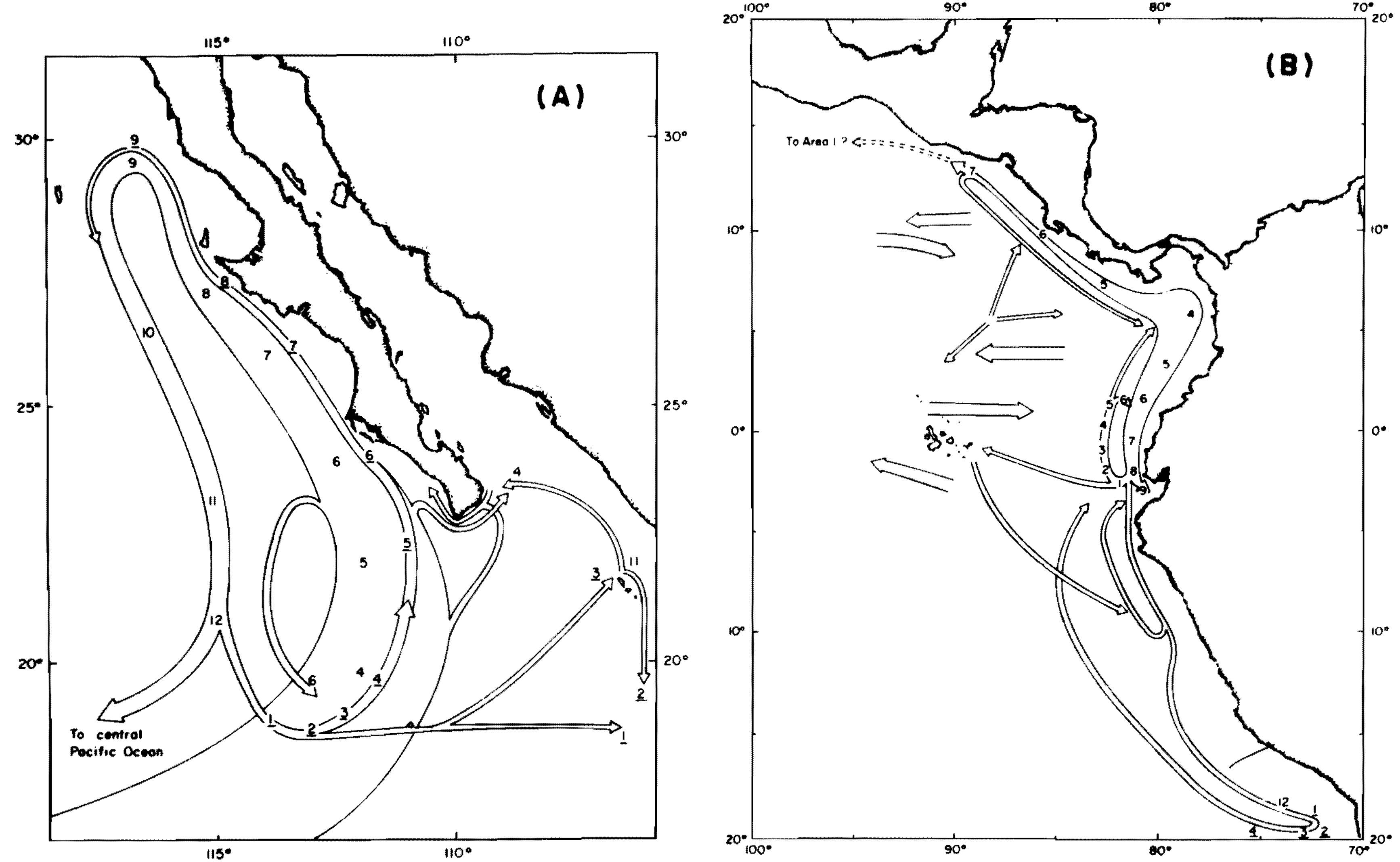

FIGURE 6. Inshore migration of skipjack tuna of the (A) northern fishery group and (B) southern fishery group based on tagging data; the numbers refer to months (from Fink and Bayliff, 1970).

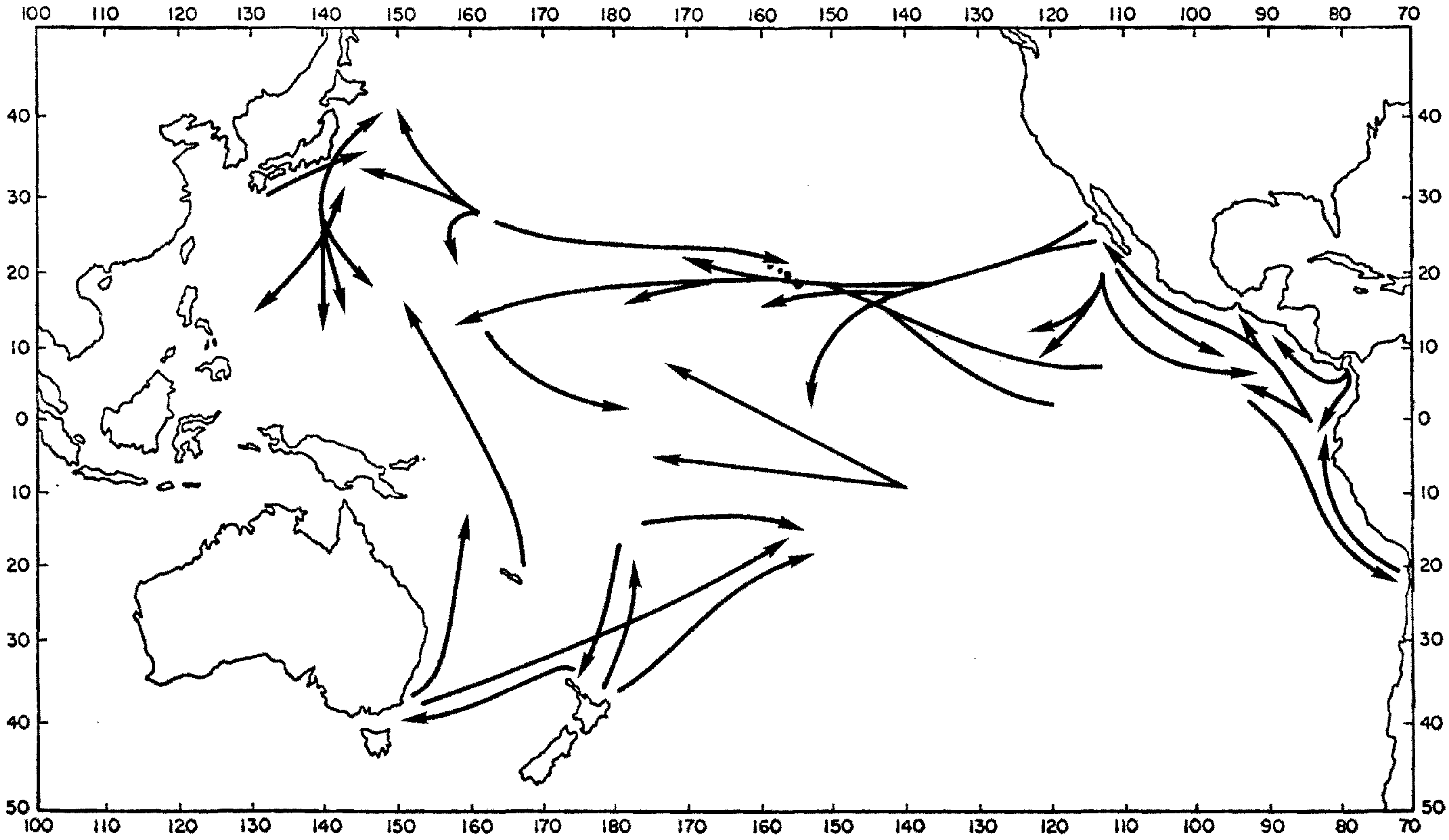

FIGURE 7. Some long-distance migrations which have been recorded for tagged skipjack in the Pacific Ocean (after Joseph, Klawe and Murphy, 1980).

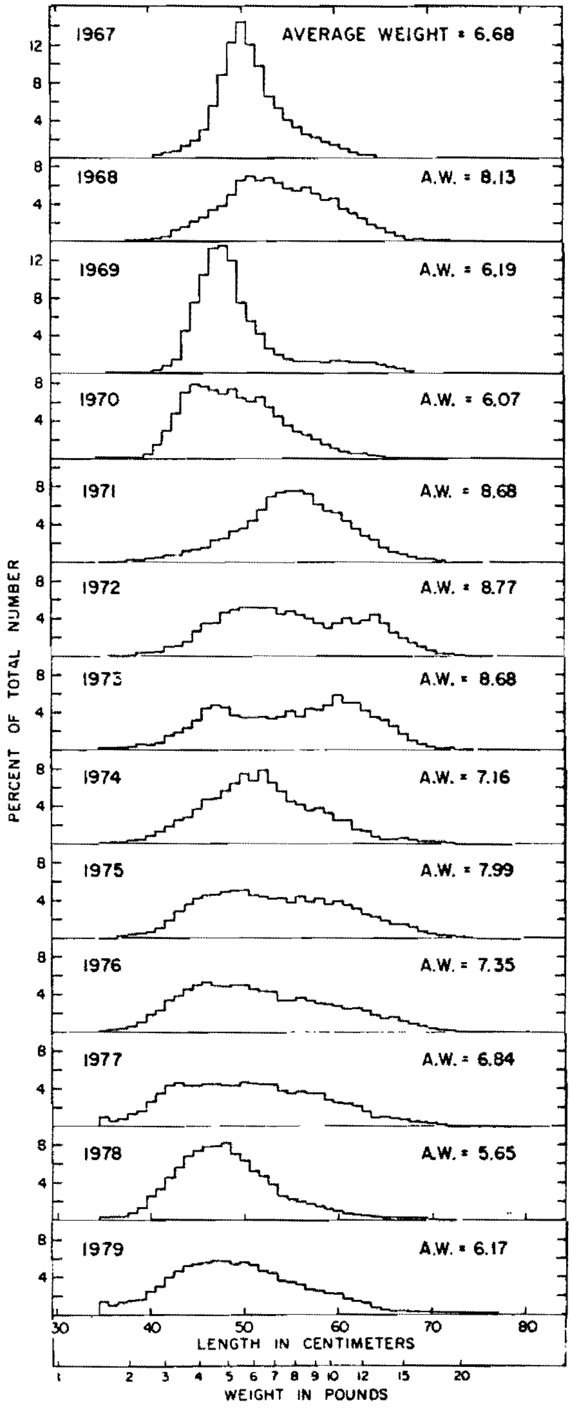

FIGURE 8. Length frequencies of skipjack caught in the CYRA (from Anonymous, 1980a). See Figure 17.

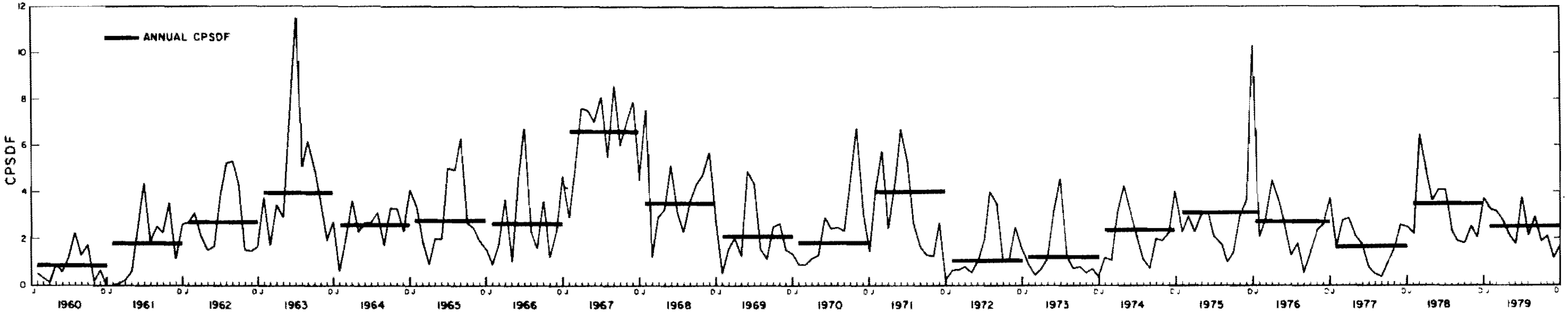

FIGURE 9. Monthly and annual catch per standard day's fishing (CPSDF) for skipjack, in class-3 purse seine units, in the CYRA during 1960-1979 (from Anonymous, 1980a). The values for 1979 are preliminary. See Figure 17.

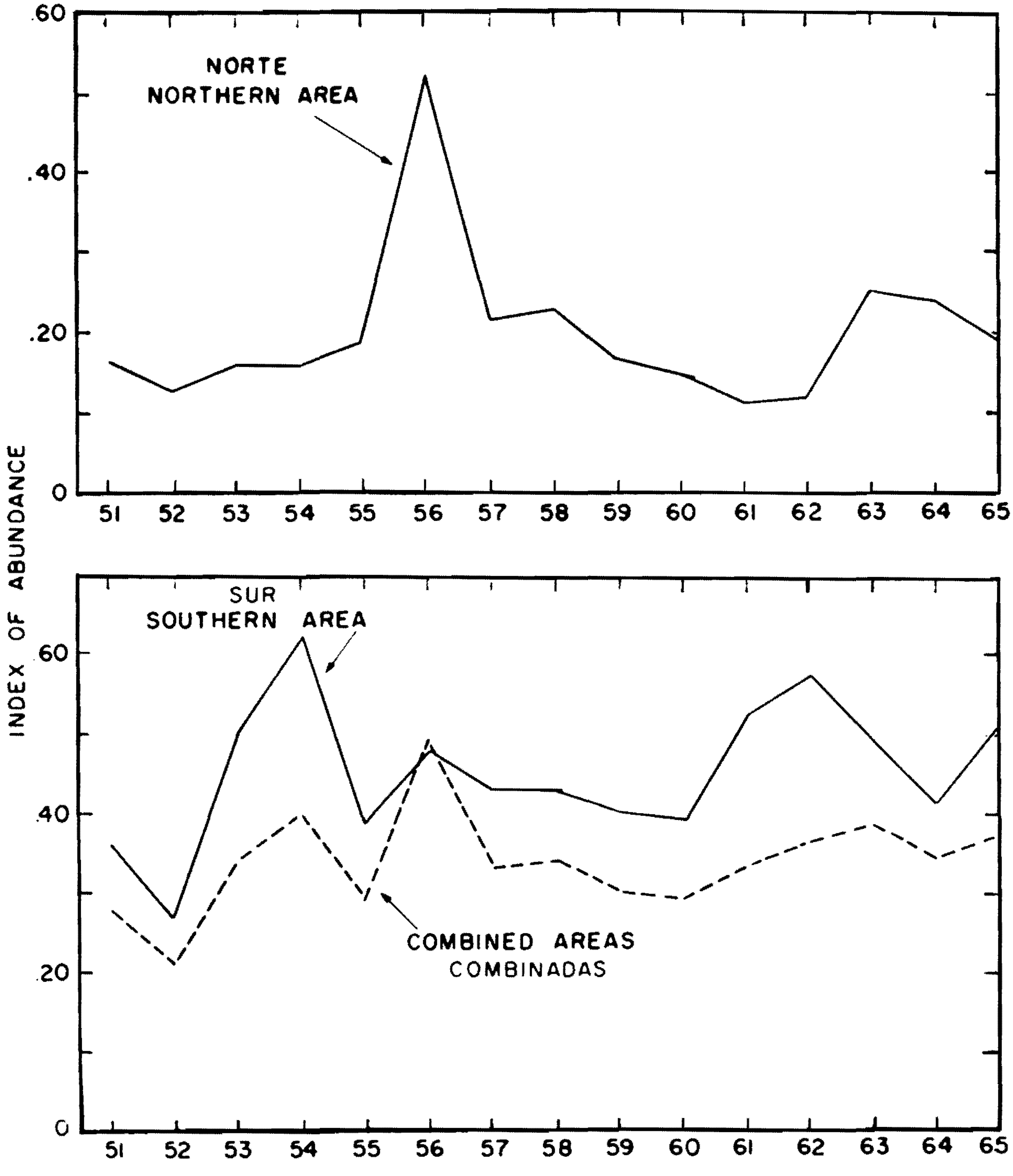

FIGURE 10. Annual estimates of skipjack index of abundance in the eastern Pacific Ocean, 1951-1965 (from Joseph and Calkins, 1969).

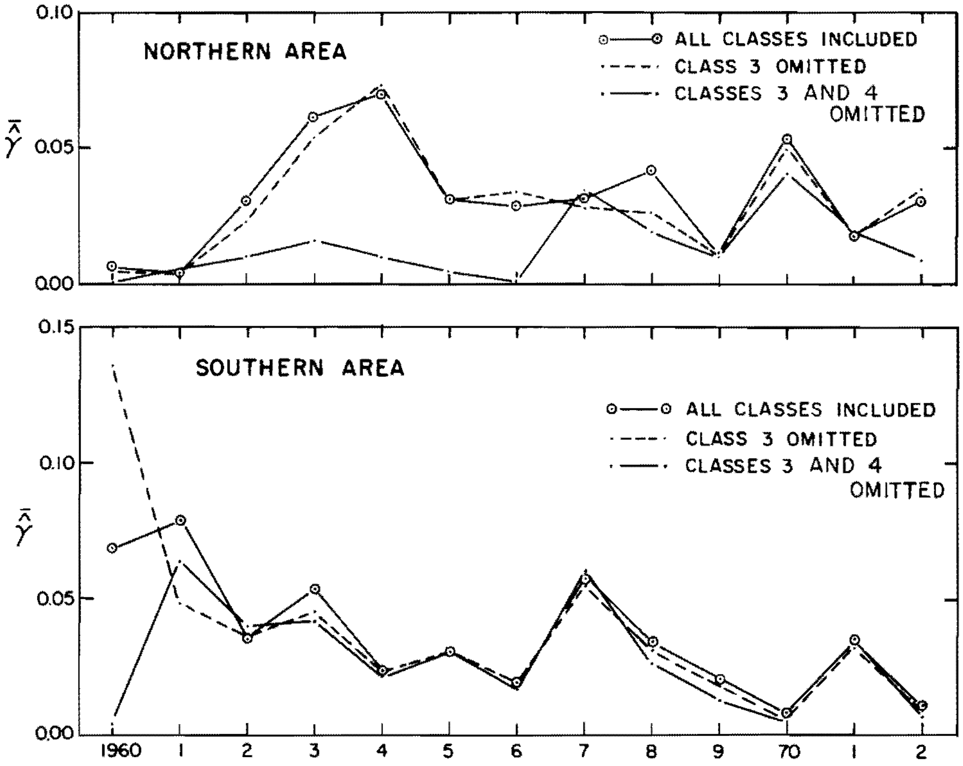

FIGURE 11. Annual biomass indices for skipjack in the historic fishing region of the eastern Pacific, 1960-1972, using information from vessel classes 3, 4, 5, and 6; 4, 5, and 6; and 5 and 6 only (from Pella and Psaropulos, 1975).

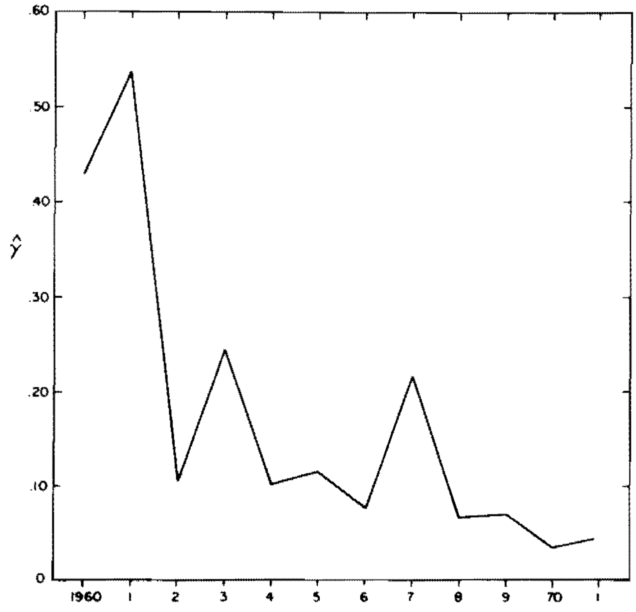

FIGURE 12. Annual biomass indices for skipjack in the area east of 85°W and between the equator and 5°S, 1960-1971, based on information from vessel classes 3, 4, 5, and 6 (from Pella and Psaropulos, 1975).

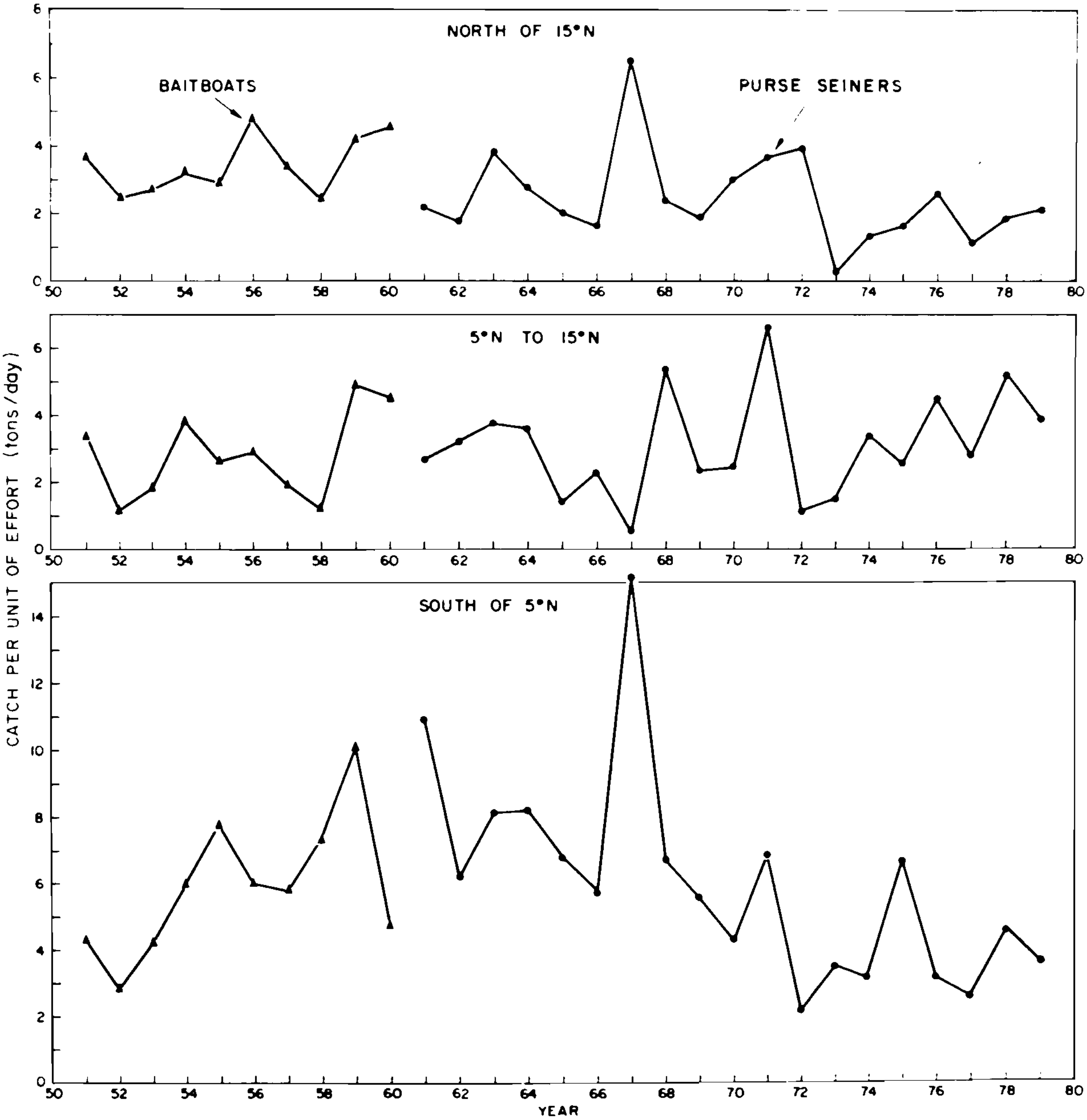

FIGURE 13. Indices of abundance of skipjack (in tons per day's fishing standardized to Class-4 baitboats and Class-3 purse seiners) for three areas of the eastern Pacific Ocean (from Forsbergh, 1980).

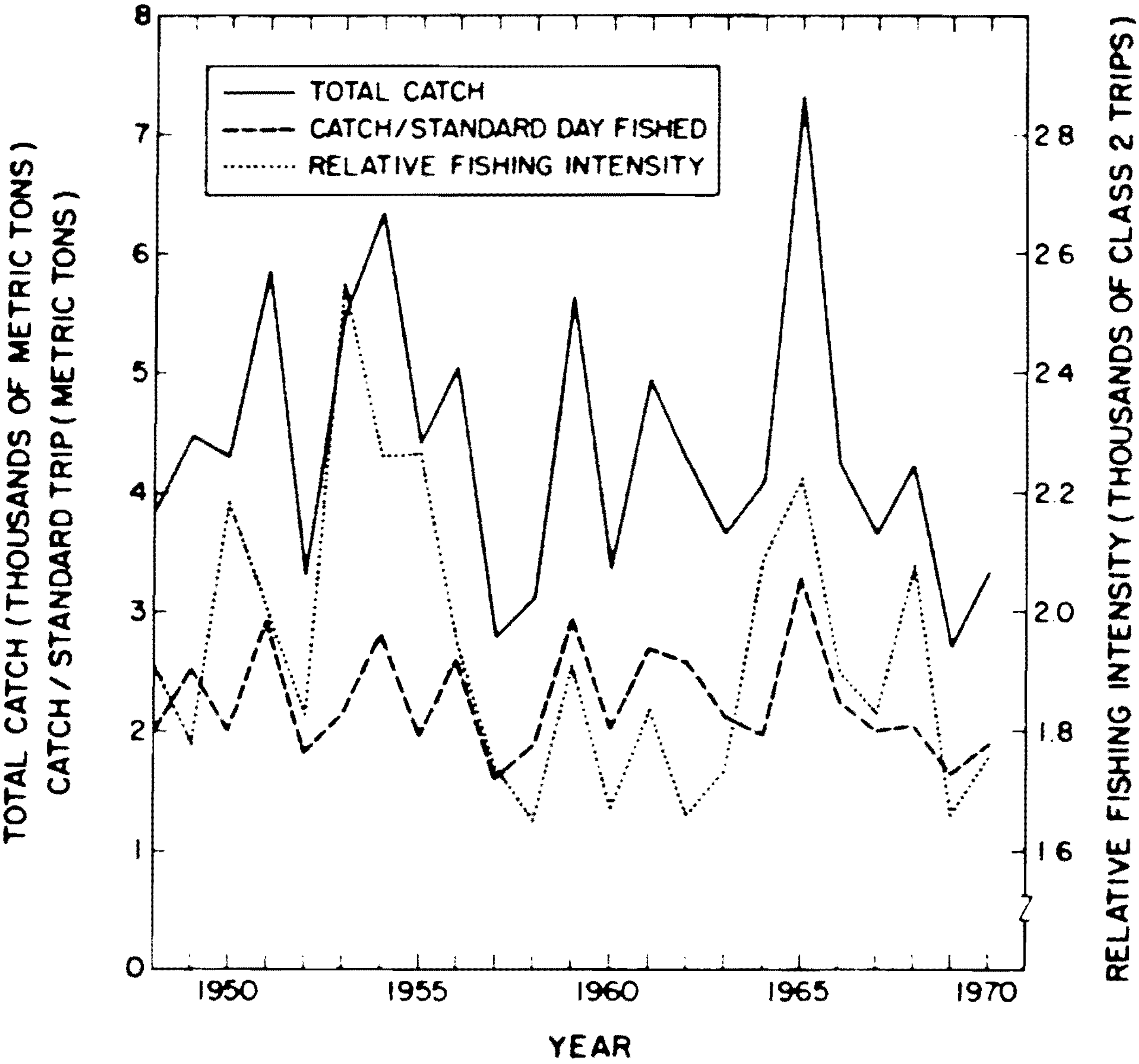

FIGURE 14. Total catch, catch per standard day fished, and relative fishing intensity for skipjack near the Hawaiian Islands, 1948-1970 (from Uchida, 1976).

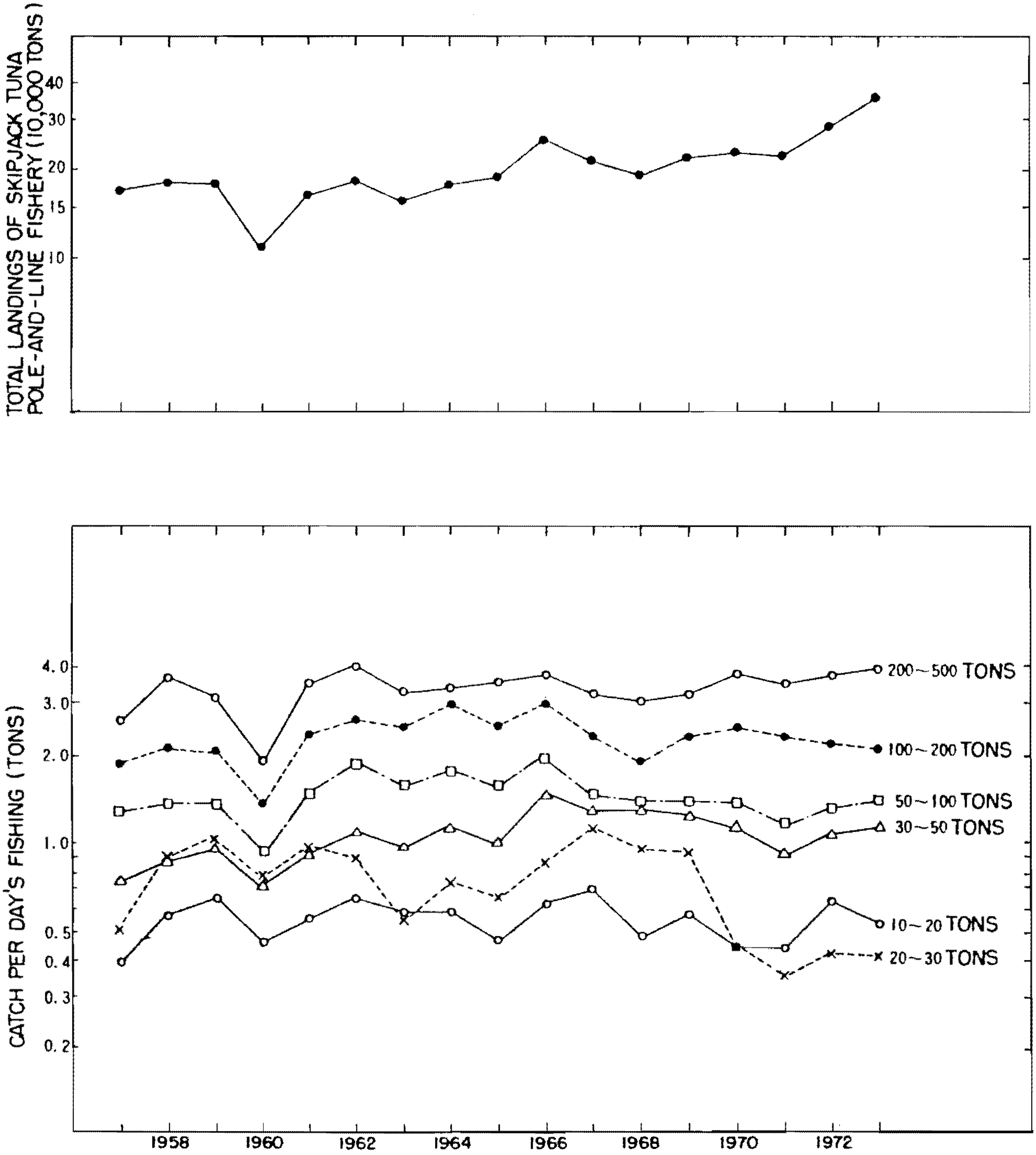

FIGURE 15. Catches of skipjack per day's fishing by Japanese baitboats of various size classes in the western Pacific (from Ishida, 1975).

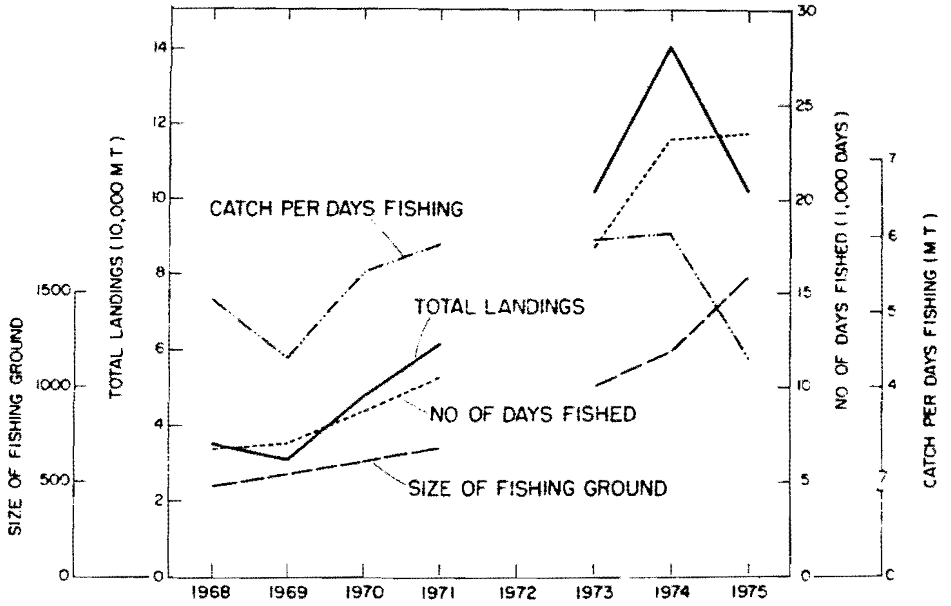

FIGURE 16. Total landings, number of days fished, catch per day's fishing, and size of fishing grounds (in number of 1-degree areas), for Japanese skipjack vessels south of 20°N in the western Pacific, 1968-1975 (from Kasahara, 1977).

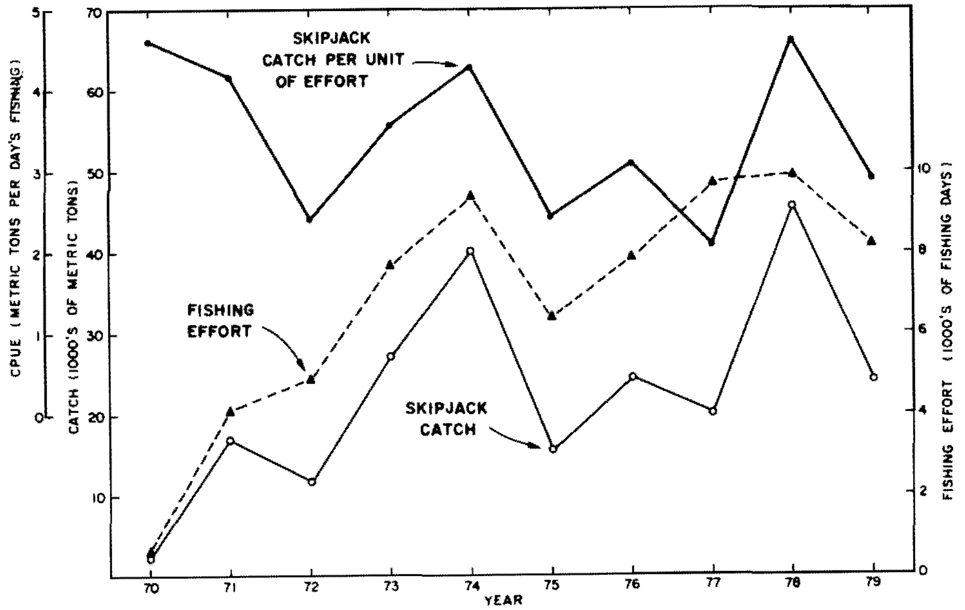

FIGURE 17. Catch of skipjack, fishing effort, and skipjack catch per unit of effort (CPUE) for the 1970-1979 period for baitboats based in Papua New Guinea (after Wankowski, 1980; Tables 32 and 34). The CPUE values were calculated from catch and effort data for Areas 2, 3, 5, 6, 7, and 8 only. The catch and effort data are for all areas.

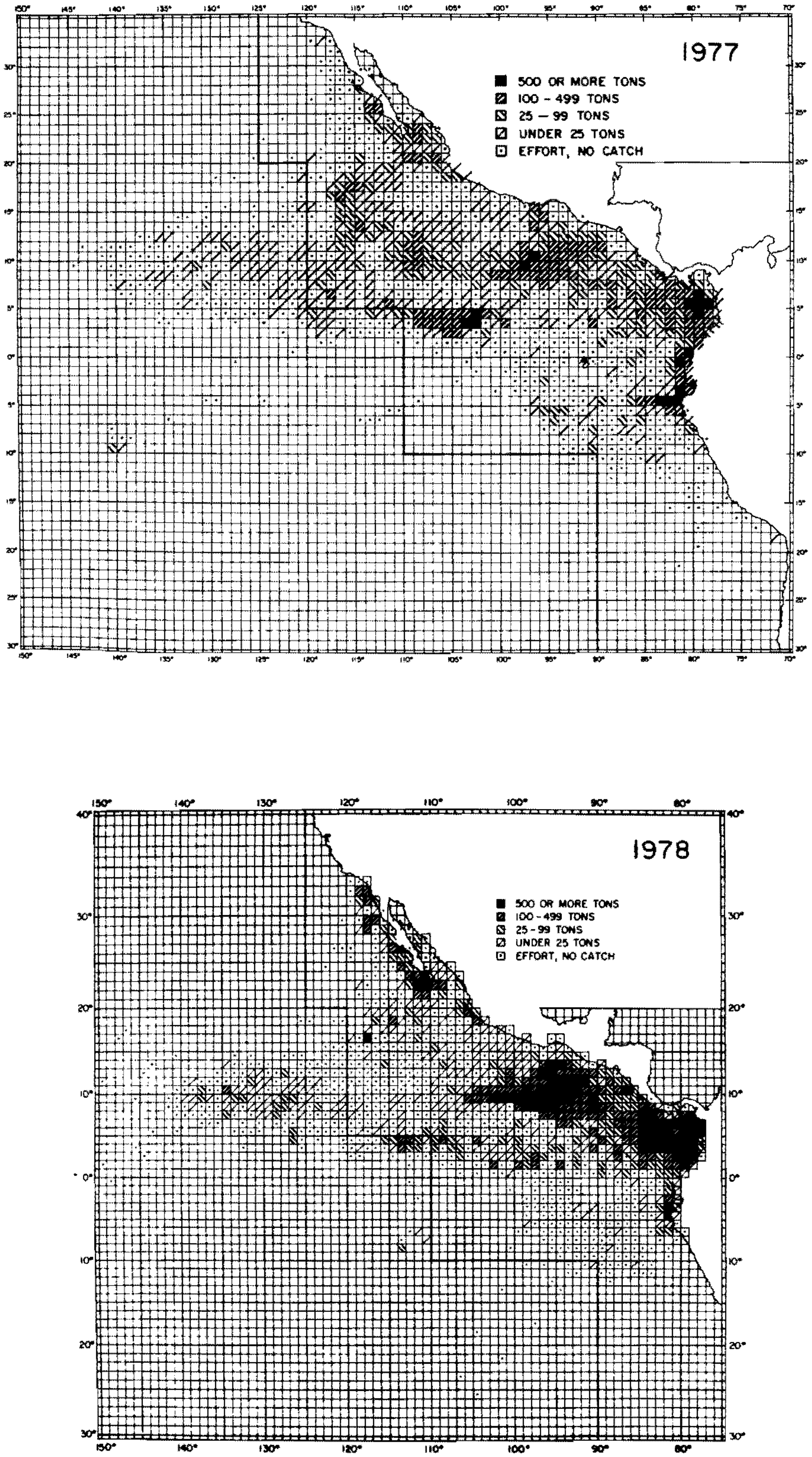

FIGURE 18. Catches of skipjack in the eastern Pacific Ocean in 1977 and 1978, by 1-degree areas, for all trips for which usable logbook data were obtained (from Anonymous, 1978b and 1979a). The heavy line indicates the western limit of the Commission's Yellowfin Regulatory Area (CYRA).

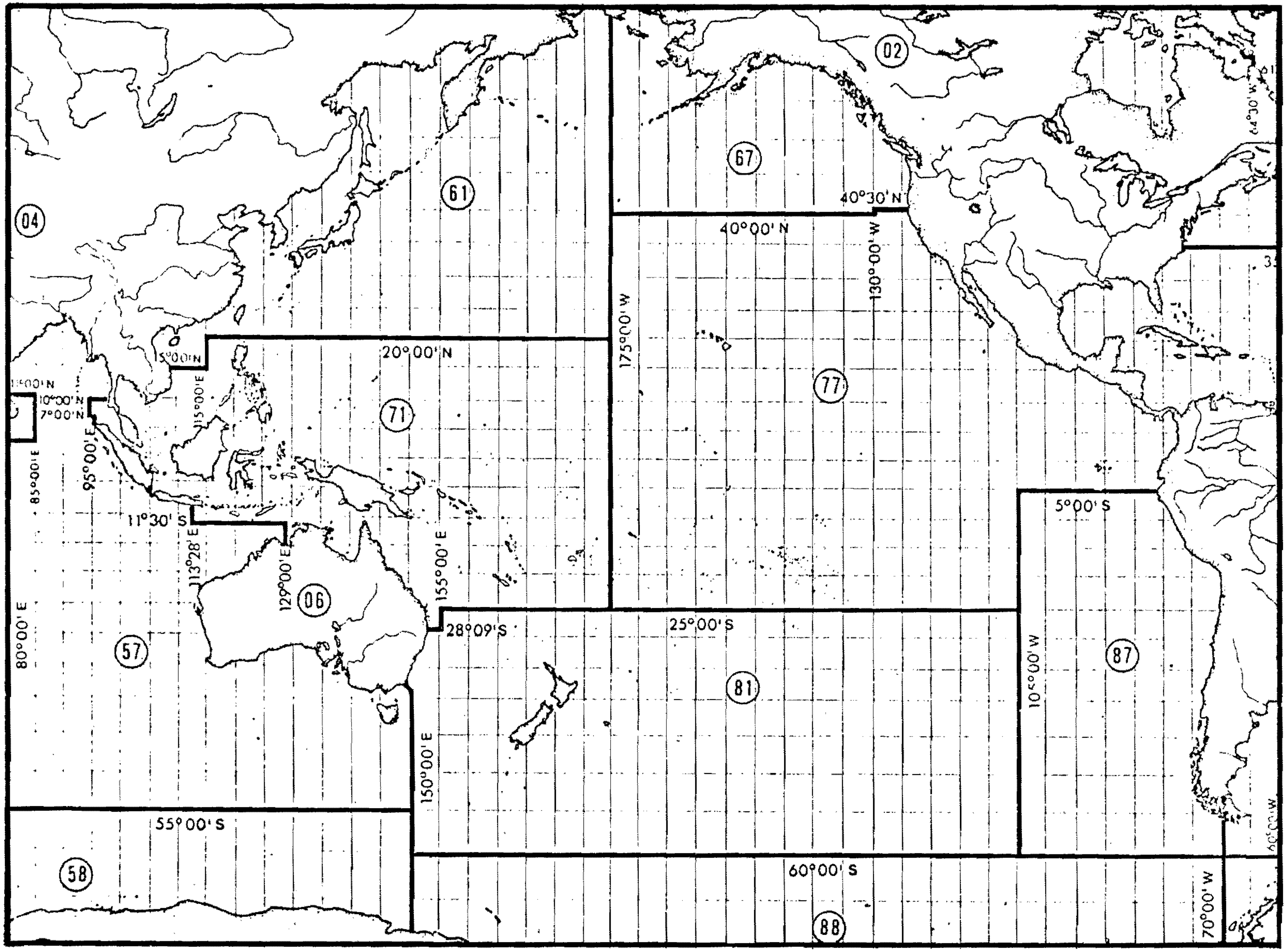

FIGURE 19. FAO statistical areas in the Pacific Ocean (from Anonymous, 1971-1979).

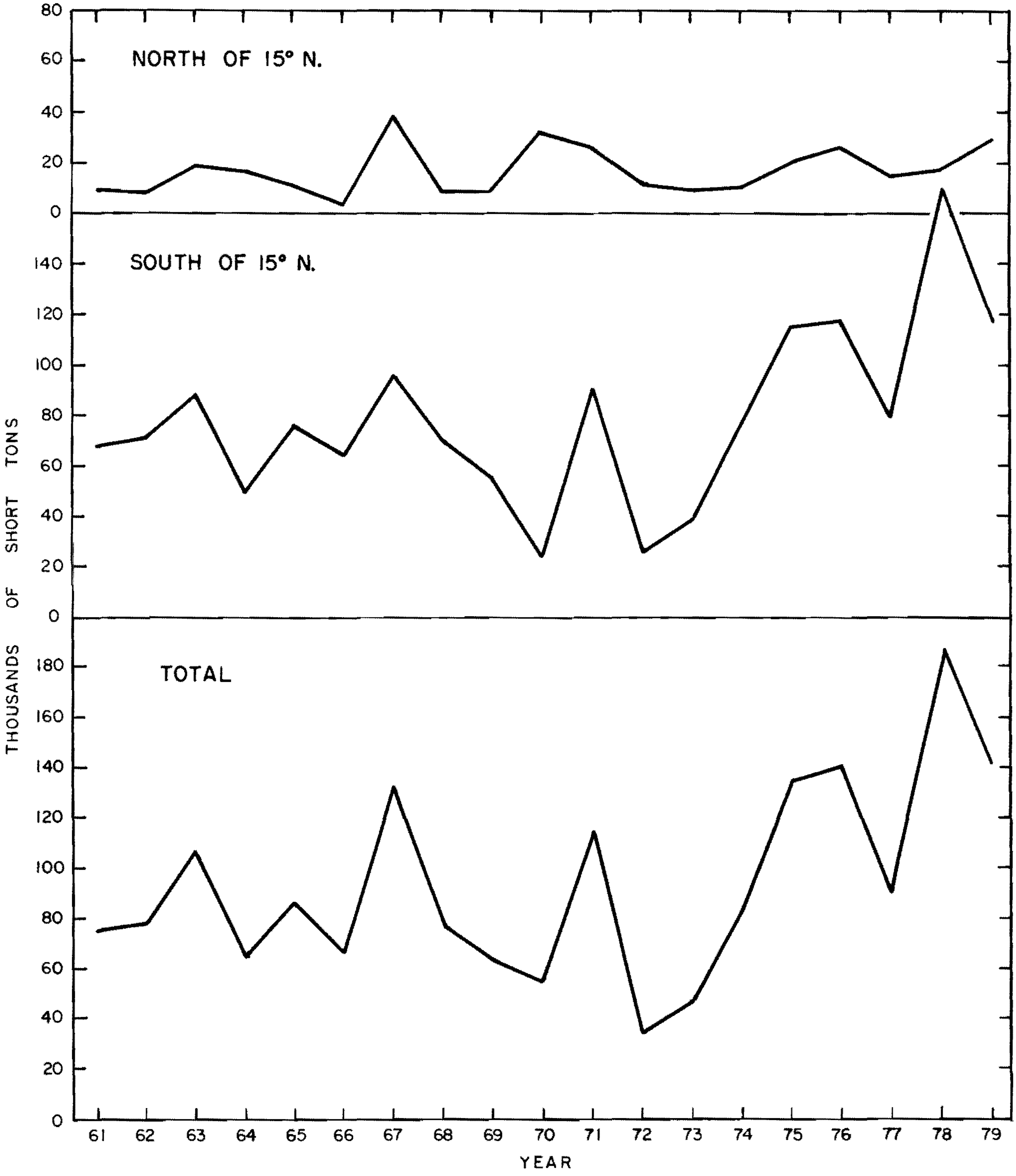

FIGURE 20. Estimated CYRA catches of skipjack north and south of 15°N, 1961-1979 (from Anonymous, 1981). See Figure 17.

TABLE 1. Numbers of vessels by gear fishing for tropical tunas in the eastern Pacific Ocean, and total carrying capacity, for 1961 to 1979. Purse seiners are tabulated according to carrying capacity: Classes 1-5, 401 short tons; Class 6, 401 or more short tons.

Year	Purse seiners Classes 1-5	Purse seiners Class 6	Purse seiners All classes	Baitboats	Bolicheras	Jigboats	Total	Capacity Short tons	Capacity Metric tons
1961	115	9	124	93	15	0	232	40,399	36,649
1962	117	12	129	91	27	0	247	41,385	37,544
1963	125	18	143	113	18	4	278	46,813	42,468
1964	116	20	136	104	18	0	258	46,216	41,926
1965	124	22	146	112	17	7	282	48,712	44,191
1966	105	21	126	115	7	2	250	46,305	42,007
1967	99	24	123	113	8	0	244	46,488	42,173
1968	102	39	141	116	7	1	265	58,756	53,303
1969	100	50	150	105	6	3	264	63,656	57,748
1970	97	65	162	108	6	9	285	73,822	66,970
1971	91	84	175	109	6	67	357	95,324	86,477
1972	87	103	190	108	4	76	378	120,887	109,667
1973	82	119	201	105	22	29	357	138,287	125,452
1974	82	131	213	111	4	7	336 [a]	152,581	138,419
1975	78	146	224	101	4	6	335	169,420	153,695
1976	93	158	251	100	4	36	392 [b]	184,872	167,713
1977	86	160	246	78	3	27	354	183,082	166,089
1978	105	156	261	65	8	33	367	186,791	169,454
1979	102	158	260	45	14	3	322	187,334	169,947

a. includes one longliner

b. includes one vessel of unknown gear

TABLE 2. Numbers of Japanese baitboats 20 gross metric tons (gmt) by size categories (from Ishida (1975) and Wetherall (1979)).

Year	Total number	Size of vessel (gmt)			
		20–50	50–100	100–200	200
1965	572	298	91	148	35
1966	571	299	71	167	34
1967	564	296	54	173	41
1968	561	276	60	170	55
1969	528	248	71	156	53
1970	512	220	91	140	61
1971	510	165	133	129	83
1972	554	131	162	116	145
1973	582	93	210	80	199
1974	716	136	255	98	227
1975	696	95	277	45	279
1976	653	51	318	17	267

TABLE 3. Nominal catches (live-weight equivalent) of skipjack by all countries in the FAO statistical areas of the Pacific, in thousands of metric tons (from Anonymous, 1971-1979). The dashes (-) indicate zero or negligible catches or unavailable data. The data for 1974-1978 have been rounded to nearest 100 tons.

Year	Statistical areas						Total
	61	67	71	77	81	87	
1964	187.2	-	-	53.4	1.5	10.3	252.4
1965	145.8	0.2	-	76.3	-	13.6	235.9
1966	208.4	-	35.7	54.2	-	10.3	308.6
1967	176.0	0.1	35.2	106.9	0.2	17.5	335.9
1968	147.6	-	42.5	74.5	0.1	8.9	273.6
1969	163.1	0.1	41.5	51.5	-	13.4	269.6
1970	166.2	0.2	70.0	58.9	-	8.7	304.0
1971	119.8	0.3	114.8	87.4	0.2	5.7	328.2
1972	157.1	-	141.7	51.0	0.7	2.5	353.0
1973	202.6	0.1	194.9	52.0	1.8	4.8	456.2
1974	127.2	0.5	303.0	75.3	1.7	2.3	510.0
1975	135.5	0.1	205.4	84.5	6.4	4.4	436.3
1976	151.1	6.3	252.9	124.6	6.3	3.1	544.3
1977	130.0	0.4	272.7	91.6	6.4	4.1	505.2
1978	159.6	5.8	363.5	123.9	6.4	3.2	662.4

TABLE 4. Nominal catches (live-weight equivalent) of skipjack by Japanese vessels in the FAO statistical areas of the Pacific, in thousands of metric tons (from Anonymous, 1971-1979). The dashes (-) indicate zero or negligible catches or unavailable data. The data for 1974-1978 have been rounded to nearest 100 tons.

Year	Statistical areas						Total
	61	67	71	77	81	87	
1964	162.6	-	-	0.3	-	-	162.9
1965	132.8	-	-	0.7	-	-	133.5
1966	191.6	-	35.7	0.6	-	0.1	228.0
1967	154.2	-	34.7	0.2	0.2	-	189.3
1968	125.9	-	40.1	1.1	0.1	0.1	167.3
1969	138.8	-	40.9	0.4	-	0.1	180.2
1970	151.3	-	53.4	0.3	-	-	205.0
1971	99.1	-	79.3	3.0	-	-	181.4
1972	156.2	-	79.7	0.3	-	-	236.2
1973	200.9	-	106.9	0.2	-	-	308.0
1974	125.6	-	196.2	4.5	0.1	-	326.4
1975	133.3	-	119.5	1.7	-	-	254.6
1976	149.2	4.7	145.3	16.2	0.6	-	316.0
1977	126.8	0.2	148.8	15.7	0.8	0.3	292.5
1978	156.5	0.1	198.3	2.8	0.5	-	358.2

TABLE 5. Catches of skipjack by flag of vessel in the Inter-American Tropical Tuna Commission's Yellowfin Regulatory Area (CYRA - east of the heavy line in Figure 17), by vessels of all flags west of the CYRA and east of 150° W, and total catches for the eastern Pacific east of 150° W (in thousands of metric tons). The 1979 data are preliminary.

Year	CYRA							West of CYRA and east of 150°W	Total eastern Pacific
	U.S.A.	Ecuador	Panama	Mexico	Peru	Others[a]	Total		
1961	51.3	11.6	0.0	1.0	4.4	0.1	68.4	0.0	68.4
1962	55.7	10.2	1.0	1.0	2.7	0.3	70.9	0.0	70.9
1963	73.8	12.6	2.8	1.3	4.4	0.5	95.4	0.0	95.4
1964	41.8	9.3	0.4	1.4	1.5	0.2	54.6	0.0	54.6
1965	58.1	14.9	0.0	1.6	0.9	1.2	76.7	0.0	76.7
1966	44.1	10.5	0.2	1.4	0.1	2.3	58.6	0.0	58.6
1967	93.6	17.3	0.4	3.9	0.2	4.8	120.2	0.0	120.2
1968	50.8	12.9	1.0	2.5	0.0	3.7	70.9	0.0	70.9
1969	34.2	15.6	3.4	1.6	0.0	3.4	58.2	0.9	59.1
1970	33.4	8.8	2.1	3.4	0.6	1.8	50.1	5.9	56.0
1971	76.4	11.9	4.3	4.1	0.2	7.0	103.9	0.9	104.8
1972	21.0	4.5	0.8	2.4	0.2	3.3	32.2	1.1	33.3
1973	26.0	4.4	2.3	2.3	1.9	5.7	42.6	1.3	43.9
1974	46.0	7.8	3.9	4.5	1.2	12.8	76.2	2.5	78.7
1975	64.3	17.0	12.8	6.6	3.2	18.9	122.8	1.9	124.7
1976	86.7	6.2	4.5	7.1	2.8	19.5	126.8	1.0	127.8
1977	48.6	10.0	5.1	3.8	2.6	14.0	84.1	2.6	86.7
1978	97.7	11.8	8.2	4.7	3.1	42.0	167.5	2.8	170.3
1979	69.7	17.6	5.5	4.7	1.0	30.6	129.2	2.8	132.0

[a] The catches of vessels that belonged to only one fishing company in one or more years have been grouped to preserve the confidentiality of the records. These include the catches of vessels of Bermuda, Canada, Chile, Colombia, Congo, Costa Rica, France, the Republic of Korea, Netherlands, New Zealand, Nicaragua, Senegal, Spain, and Venezuela.

TABLE 6. Nominal catches of skipjack (in thousands of metric tons) in the smaller skipjack fisheries in the Pacific Ocean in recent years. The dashes (-) indicate zero or negligible catches or unavailable data. The 1979 data are preliminary.

	Republic of Korea	Republic of China	Philippines	Indonesia Pacific coast	Papua New Guinea	Pacific Islands Trust Territory	Solomon Islands	Fiji	New Zealand	French Polynesia	Hawaii
Sources	1	2,3	4	4	5	1	6	6	7,8	9	10,11
Year											
1969	-	0.7	-	-	-	-	-	-	-	0.7	2.7
1970	-	0.6	-	-	2.4	1.0	-	-	-	0.6	3.3
1971	0.2	1.3	-	-	16.9	1.0	4.7	-	-	0.4	6.1
1972	0.5	0.9	0.1 a	1.6 a	11.7	0.4	7.9	-	0.2	0.5	5.0
1973	2.6	1.7	1.5 a	14.3	27.3	6.2	6.5	-	0.1	0.5	4.9
1974	2.9	1.6	2.8 a	13.9	40.2	3.2	10.3	-	0.7	0.5	3.4
1975	9.4	2.2	3.2 a	14.2	15.6	7.6	7.1	-	1.2	0.6	2.3
1976	9.2	-	29.2	16.5	24.4	6.1	15.8	0.7	4.7	0.6	3.6
1977	7.7	-	55.0	16.4	20.1	5.9	11.5	1.7	7.5	0.5	3.5
1978	-	-	56.3	8.1 a	45.8	10.8	17.4	2.5	9.5	0.7	3.3
1979	-	-	-	-	24.0	-	-	-	9.0	-	2.7

a. includes data from commercial baitboats only; data from local fisheries are unavailable.

Sources:
1. For 1969-1978, Anonymous (1971-1979).
2. For 1969-1972, Yang (1975).
3. For 1973-1975, Anonymous (1971-1979).
4. Robert E. Kearney, personal communication.
5. Wankowski (1980).
6. Kearney (1979).
7. For 1972-1975, Anonymous (1971-1979).
8. For 1976-1979, Habib, Clement, and Fisher (1980).
9. Data are for fish sold to Papeete market only - Marcille, Asine, Marec, and Mariterangi (1979).
10. For 1969-1973, Uchida (1975).
11. For 1974-1979, Southwest Fisheries Center, U.S. National Marine Fisheries Service.

SYNOPSIS OF BIOLOGICAL DATA ON THE BLACK SKIPJACK TUNA, *EUTHYNNUS LINEATUS* KISHINOUYE, 1920

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Inter-American Tropical Tuna Commission
La Jolla, California
1980

FOREWORD

This synopsis was originally written in Spanish for Revista de la Comision Permanente del Pacifico Sur. Parts of it were compiled by the author and parts of it were translations of Yoshida's (1979a) synopsis on the genus *Euthynnus*. It has now been updated and revised for publication in English. The parts of it which were compiled by the author are enclosed in brackets and the parts of it which were taken from Yoshida's synopsis are not.

CONTENTS

1 IDENTITY

The little tuna [or black skipjack] from the eastern Pacific was originally described as Euthynnus lineatus Kishinouye 1920 and still retains that name.

2 DISTRIBUTION

2.1 Total area

In general the species of Euthynnus are coastal fishes found in tropical and subtropical waters of the world. Of the three species, E. lineatus has the most restricted distribution, occurring only in the eastern tropical Pacific Ocean.

Euthynnus lineatus is found in the tropical coastal waters of the eastern Pacific from about lat. 35°N to 12°S. Calkins and Klawe (1963) constructed [the geographical distribution] from records of E. lineatus reported in the literature, tuna vessel logbooks, scientific logs of oceanographic cruises by ships of the Scripps Institution of Oceanography [SIO] and the National Marine Fisheries Service, and field-book notes of C.L. Hubbs, SIO, and D.P. de Sylva, University of Miami. Records of E. lineatus in the literature include the northernmost record from off San Simeon, Calif. (lat. 35°20'N, long. 120°40'W) (Nowell 1961), specimens from California waters (Roedel 1948; Fitch 1952b), Baja California (Godsil 1954a), the Tres Marias Islands (Fowler 1944), Acapulco, Mexico (Mais and Jow 1960), Costa Rica (Schaefer and Marr 1948), Colombia Bank (lat. 2°N, long. 79°W) [(Clemens, 1957)], Guayaquil Bank (lat. 3°35'S, long. 80°55'W) (Godsil 1954a...), from the Galapagos Islands (Fowler 1938, 1944; Schmitt and Schultz 1940; Seale 1940; Godsil 1954a), [and northern Peru (Hildebrand, 1946).]

Logbooks of commercial tuna vessels indicate that E. lineatus has been encountered nearly everywhere along the coastline from about halfway down the coast of Baja California to northern Peru. They have been frequently encountered in the Gulf of California, the Revillagigedo Islands, all along the coast of Mexico and Central America, and the Galapagos Islands. There have been occasional reports of this species from Clipperton and Cocos Islands and there is a single report of its occurrence from Shimada Bank (lat. 16°52'N, long. 117°30'W) (Calkins and Klawe 1963). More recently, they have been recorded as far as 2,000 mi (3,200 km) off the coast in the eastern Pacific (Klawe 1977b). In addition there are two records of E. lineatus from the Hawaiian Islands (Matsumoto and Kang 1967; Matsumoto 1976).

[Klawe (1977b and 1979) pointed out that the known distribution given by Calkins and Klawe (1963) has changed as a consequence of fishing activities directed toward other species. Accordingly, a composite map (Figure 1), which includes catch locations recorded by the Inter-American Tropical Tuna Commission for 1974, 1976, and 1978 plus the above records has been prepared.]

2.2 Differential distribution

2.21 Spawn, larvae, and juveniles

Larval and postlarval *E. lineatus* are almost as widely distributed as the adults in the eastern tropical Pacific Ocean [Figure 2]. They have been recorded as far north as lat. 29°45'N (Point Antonio, Baja California) and south to lat. 04°00'N, long. 81°35'W (the vicinity of Malpelo Island) (Calkins and Klawe 1963; [Klawe, 1963). Larvae have been collected along the coast of Central America and Mexico, near the Tres Marias Islands, the central region of the Gulf of California and its entrance, and off the west coast of Baja California (Calkins and Klawe, 1963; Klawe, 1963; Klawe *et al*., 1970; Moser *et al*., 1974). The last observed that in June larvae of black skipjack occurred mainly in the southern region of the Gulf of California, are less abundant in the central region, and do not occur in its northern region. However, different results might have been obtained if the sampling had been conducted at other times of the year. Klawe *et al*. (1970) pointed out that temperature is probably the most important factor influencing the distribution of the larvae of this species.] Except for one specimen caught near Malpelo Island, all larval and juvenile *E. lineatus* have been collected within about 150 mi (240 km) of the mainland.

2.22 Adults

[Black skipjack are found throughout the year in all areas of its distributional range. Additional information on this subject appears in Section 5.3.]

2.3 Determinants of distribution changes

[Black skipjack are rarely found in surface waters cooler than 23°C (Calkins and Klawe, 1963). Klawe *et al*. (1970) found a marked increase in the proportion of tows containing larvae of black skipjack occurring at stations where the surface temperatures exceeded 26° or 27°C.] Calkins and Klawe (1963) characterized the general habitats of *E. lineatus* based on published studies (Holmes *et al*. 1957; Brandhorst 1958; Cromwell 1958; Cromwell and Bennett 1959; Sund and Renner 1959). Calkins and Klawe (1963) noted that *E. lineatus* occurs in the equatorial Pacific water mass which extends approximately from lat. 23° or 24°N to northern Peru and the Galapagos Islands. There are transition zones to the north and south of the tropical water mass which are influenced by the cold California Current and the Peru Current in the north and south, respectively. The principal warm currents influencing the tropical water mass are the North Equatorial, the Equatorial Countercurrent, and the South Equatorial Current. Where E. lineatus is most frequently near the coast, these currents are usually weak and variable and the thermocline is relatively shallow (10-50 m) which allows the exchange of nutrients between the deep layer and the surface waters. In a thermal dome located off Central America (lat. 9°N, long. 90°W) the thermocline is frequently less than 10 m and sometimes reaches the surface. In the Gulf of Panama, Gulf of Tehuantepec, the Gulf of California, and the inshore waters of Baja California, upwelling enriches the inshore waters.

[According to Graham and Diener (1978) Euthynnus is a coastal fish inhabiting waters where the thermocline is relatively shallow, whereas Katsuwonus occurs in oceanic waters where the thermocline is often much deeper. Although both genera make forays below the upper mixed layer for feeding, Katsuwonus may have a more efficient heat exchanger system, and thus be able to remain longer in the cooler portions off its habitat.]

2.4 Hybridization

[There is no evidence of hybridization in black skipjack.]

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

All of the species of Euthynnus are heterosexual, males and females do not differ in external appearance, and there is no record in the literature of hermaphroditism in these fishes. However, it would not be surprising if hermaphroditic specimens were to occur since cases have been discovered in closely related species, e.g., Katsuwonus pelamis (Uchida, 1961).

3.12 Maturity

The size at first spawning for E. lineatus is not known. There are only fragmentary observations on the gonadal development of this species in the eastern tropical Pacific where it occurs. [Schaefer and Marr (1948) reported four adults of E. lineatus from Costa Rica in advanced stages of maturity, a male and a female from the Gulf of Nicoya, a female from Quepos Point, and a male from Cape Blanco.] Mead (1951) reported two females 54.4 and 55.0 cm long, which had swollen and turgid ovaries, from the waters off Central America.

3.13 Mating

Although the reproductive behavior of *Euthynnus* has not been positively observed in the natural environment or in experimental tanks and ponds, Hunter and Mitchell (1967) observed a high frequency of wobbling and chasing by three ripe male *E. lineatus* in a manner similar to that described by Magnuson and Prescott (1966) as reproductive behavior of Pacific bonito, *Sarda chiliensis*. These observations were made by Hunter and Mitchell (1967) near drifting objects under which *E. lineatus* had collected off the coast of Costa Rica. Whether these observations actually represented reproductive behavior by *E. lineatus* remains to be demonstrated.

3.14 Fertilization

[Fertilization in black skipjack is external (Calkins and Klawe, 1963).]

3.15 Gonads

The fecundity of *E. lineatus* has yet to be investigated. [However, it can be assumed that the relationship between the number of eggs produced and the size of the fish is of the same order of magnitude as those of related species (Calkins and Klawe, 1963).]

3.16 Spawning

[Schaefer and Marr (1948), based on their collections of mature black skipjack in the spring of 1947, suggested that this species spawns in Central American waters during the early spring. Mead (1951) also observed mature individuals in Central American waters in May 1949.]

Records of larval and juvenile *E. lineatus* from the eastern Pacific and from near Costa Rica are shown in Tables 1 and 2. The records indicate probable spawning periods and localities in the eastern tropical Pacific Ocean. [Klawe (1963) found that black skipjack spawning off western Baja California is limited to the summer months, and Klawe *et al*. (1970) observed that the peak of spawning of this species in the entrance of the Gulf of California occurs in October-December. Calkins and Klawe (1963) and Klawe (1963) recorded the abundance of black skipjack larvae throughout the year near Cape Blanco, Costa Rica (Table 3). The peak of spawning in this area appears to be March and April.

As black skipjack adults occur in the vicinity of the major islands of the eastern Pacific, as well as along the coast, it is probable that the spawning of this species takes place also in the vicinity of these islands (Klawe, 1963).]

3.17 Spawn

[The egg of E. lineatus is spherical and contains a single oil globule. In appearance and structure it is similar to those of other tunas (Calkins and Klawe, 1963). They found the diameter of mature eggs from a running-ripe female to be between 0.90 and 0.95 mm and the diameter of the oil globule to range from 0.23 to 0.26 mm.

Matsumoto (1959) and] Calkins and Klawe (1963) stated that the fertilized eggs of E. lineatus are pelagic but they had never been specifically identified in plankton collections.

3.2 Pre-adult phase

3.21 Embryonic phase

[There is no information available on this subject for black skipjack.]

3.22 and 3.23 Larval and adolescent phases

[Descriptions of the larvae and juveniles of black skipjack are given by Schaefer and Marr (1948), Mead (1951), Matsumoto (1958 and 1959), Calkins and Klawe (1963), and Yoshida (1979a). Clemens (1956) induced juveniles of black skipjack to feed on live zooplankton (larval blennies), pelagic planktonic fish eggs, and ground fish flesh.]

3.3 Adult phase

3.31 Longevity

[There is no information on the longevity of black skipjack. The world record for a sport-caught E. lineatus is 14 pounds, 8 ounces, or 6.57 kg (Anonymous, 1980c), equivalent to a length of 27 3/4 inches or 70.5 cm.]

3.32 Hardiness

Calkins and Klawe (1963) stated that the hardiness of E. lineatus is similar to that of other tunalike fishes and that "They are hardy enough to be successful in their natural environment, but they can only stand a minimum of handling."

3.33 Competitors

In the eastern tropical Pacific, E. lineatus is found in close association with yellowfin tuna, skipjack tuna, and dolphin fish (Coryphaena) that undoubtedly compete with it for food (Calkins and Klawe 1963). [Graham (1975) states that black skipjack and bonito, Sarda velox, eat similar prey where they occur together in the Gulf of Panama.]

3.34 Predators

Euthynnus lineatus have been found in the stomachs of yellowfin tuna (Alverson, 1963; [Anonymous, 1979a), striped marlin (*Tetrapturus audax*), blue marlin (*Makaira nigricans*), and sailfish (*Istiophorus platypterus*)(Eldridge and Wares, 1975).]

3.35 Parasites, diseases, injuries, and abnormalities

[Shino (1959a and 1959b) observed the external parasitic copepods *Caligus coryphaene* and *C. macarovi* on *E. lineatus*.] Calkins and Klawe (1963) also found that *E. lineatus* was parasitized by the trematode *Hirudinella marina*. [Silas (1967) and Silas and Ummerkutty (1967) added the monogenic trematode *Hexostoma euthynni* and doubtful records for the digenic trematodes *Lecithochirum magnoporum* and *L. microstomum* to the list of parasites of this species. More recently, Cressey and Cressey (1980) found the parasitic copepods *Unicolox colleteralis*, *U. micterobius*, *Caligus bonito*, and *Ceratocolox euthynni* on black skipjack.]

3.36 Physiology

Klawe *et al*. (1963) determined the hemoglobin content of the blood of *E. lineatus*. They noted that the hemoglobin content of the blood of fishes is generally related to the level of activity of the species. The hemoglobin concentration of *E. lineatus* blood ranged from 16.9 to 19.9 g/100 ml for five fish measuring 427 to 657 mm. This level of hemoglobin concentration was higher than for *Scomber japonicus* and *Sarda chiliensis*. They speculated that the higher hemoglobin content of the blood of *E. lineatus* was somehow related to its complex cutaneous vascular system which *S. japonicus* and *S. chiliensis* lack.

Graham (1973) determined the thermal profile of *E. lineatus*, which uses a centrally located vascular heat-exchange mechanism similar to that of *E. alletteratus* to maintain core body temperatures warmer than ambient temperature of seawater. He also described the structure of the central heat-exchange mechanism and the effect of temperature changes in blood-gas relationships in *E. lineatus*. Graham found that a warm central core in *E. lineatus* was related to the distribution of red muscle [Figures 3 and 4]. The warmest body temperatures occurred along the vertebral column between the first and second dorsal fins. The heat-exchange mechanism in *E. lineatus* was composed of the dorsal aorta, the posterior cardinal vein, and a large vertical rete. The dorsal aorta was embedded in the posterior cardinal vein and was thus completely bathed in venous blood. Graham found that similar to the situation in bluefin tuna, *Thunnus thynnus*, the oxygen-carrying capacity of hemoglobin was unaffected by changing blood temperature. Graham (1975) discussed the adaptive significance of elevated body temperatures in scombrid fishes. He reiterated the observation made by Carey *et al*. (1971) that the principal advantage of a high and fairly constant body temperature is facilitation of continuous swimming by increasing the frequency of muscular contractions, thus increasing available swimming power. Graham (1975) also observed that warm-bodied fishes probably achieve a marked independence from environmental temperature that permits them to make rapid horizontal and vertical migrations without the necessity of thermal acclimation. [Graham (1975), based on the results obtained by Magnuson (1973) in his comparative study of adaptations for swimming and hydrostatic equilibrium of scombroid and xiphoid fishes, stated that "*Thunnus albacares*, *Katsuwonus pelamis* and *Euthynnus affinis* have burst speeds nearly double those of *Sarda chiliensis* suggesting that elevated body temperatures, coupled with morphological adaptations, greatly increase the maximum swimming speed. The principal contribution of high body temperature to burst swimming is probably the maintenance of a thermal profile that warms large portions of white muscle."

The comparative morphology of the central heat exchangers of *Katsuwonus* and *Euthynnus* has been studied by Graham and Diener (1978). They and Collette (1978) also studied the phylogenetical adaptations of this species.]

3.4 Nutrition and growth

3.41 Feeding

[There have been no observations specifically made on the feeding of *E. lineatus*, but Hiatt and Brock (1948), Bullis and Juhl (1967), and Wicklund (1968) have investigated the feeding of *E. alletteratus*, and Kishinouye (1923), Walters (1966), and Magnuson and Heitz (1971) have studied the feeding of *E. affinis*. Calkins and Klawe (1963) stated that the feeding of *E. lineatus*, like that of related species, is probably by sight and therefore confined to the daylight hours and to the surface layer.]

3.42 Food

[The food consumed by juvenile *E. lineatus* in confinement is discussed in Sections 3.22 and 3.23.]

Small fish; squid; *Auxis thazard* [ranging from 7.6 to 12.7 cm]; a pelagic

4.13 Size composition

The length-frequency distribution of *E. lineatus* taken between June 1972 and August 1975 in the Gulf of California and from Baja California to Ecuador is shown in Figure 5. [Annual length-frequency distributions, based on data collected by the IATTC during 1972 to 1979, are shown in Figure 6. Only two individuals less than 35 cm in length have been sampled. Information on the largest known specimen of black skipjack is given in Section 3.31.

Klawe and Calkins (1965) derived the length-weight relationship of 109 specimens of black skipjack ranging from 0.91 to 6.2 kg and 365 to 667 mm. The predictive equations are as follows:

$$Y = 3.0817X - 7.6155 \ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{or } W = (2.4237 \times 10^{-8})L^{3.0817} \ldots\ldots\ldots(2)$$

$$\text{or } W = 0.01327L^{3.0817} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In (1), Y and X represent the common logarithms of the weight in pounds and the length in millimeters, respectively (Figure 7). In (2), W and L represent the weight in pounds and the length in millimeters respectively. In (3), (from Yoshida, 1979a) W and L represent the weight in grams and the length in centimeters respectively.]

4.2 Abundance and density

[Only small amounts of black skipjack have been caught, but it appears to be sufficiently abundant between 25°N to 5°S to support commercial operations (Joseph and Klawe, 1974; Anonymous, 1975b). Black skipjack larvae are relatively abundant in plankton hauls (Section 2.21), and fishermen have reported seeing large schools of black skipjack and occasionally catches of 1 to 100 tons have been recorded (Calkins and Klawe, 1963). Based on the above information, Peterson and Klawe (1974) speculated that the potential production of black skipjack in the eastern Pacific is about 30,000 to 40,000 metric tons. To date, however, the catches have fluctuated between 500 to 4,000 metric tons (Table 6).]

4.3 Natality and recruitment

[The number of black skipjack recruited annually has not been estimated. Recruitment to the purse-seine fishery appears to take place when the fish are between 40 to 50 cm in length, although smaller individuals sometimes appear in samples (Figures 5 and 6).]

4.4 Mortality and morbidity

[There is no information available on this subject.]

4.5 Dynamics of population

[There is no information available on this subject.]

4.6 The population in the community and the ecosystem

[Except for some information on communities around floating objects (Section 3.52), there is no specific information available on this subject.]

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gears

[Black skipjack are] taken incidentally by gear used to catch other species of fish. They have been taken by tuna purse seines, by live-bait pole-and-line fishing, and commercial and sport trolling. [In various locations in Latin America black skipjack are taken by trolled hand lines (Calkins and Klawe, 1963).]

5.12 Boats

[There are no boats specifically designed for fishing for black skipjack, but they are occasionally] taken by commercial tuna vessels of all sizes, from small albacore trollers to large purse seiners and by baitboats. [In Ecuador and Peru, black skipjack are taken by canoe and raft fishermen, as well as by the types of boats mentioned above (Calkins and Klawe 1963).]

5.2 Fishing areas

5.21 and 5.22 General geographic distribution and ranges

[The catches of black skipjack in the eastern Pacific Ocean in 1974, 1976, and 1978 by 1-degree areas for all trips for which usable logbook data were obtained by the IATTC are shown in Figure 8. These catches are concentrated in two major zones; one extending from southern Mexico to Ecuador and the other around the tip of the Baja California peninsula. However, black skipjack are caught from 35°N to 12°S latitude and as far west as 140°W longitude.]

5.23 Depth ranges

[Black skipjack are taken in the surface layer (Calkins and Klawe, 1963).]

5.24 Conditions of the grounds

[There is no specific information in this subject.]

5.3 Fishing seasons

[There is no fishing season as such for black skipjack. They are caught all year throughout most of their range. Off Ecuador black skipjack are said to be more abundant from May to September in the open coastal areas and from January to March in the Gulf of Guayaquil (Calkins and Klawe, 1963).]

5.4 Fishing operations and results

5.41 and 5.42 Fishing effort and selectivity

[There is no information recorded on fishing effort for black skipjack in the eastern Pacific. Calkins and Klawe (1963) state that they are taken by non-selective gear.]

5.43 Catches

[Data on the catches of black skipjack by tuna vessels are listed in Table 6. These data include only the fish that are landed; additional amounts are known to be caught but not landed, and these are not included in the statistics. Furthermore, black skipjack are caught by small boats in Latin America for which statistical data are not obtained.]

6 PROTECTION AND MANAGEMENT

[As black skipjack appear to be underexploited, there are no regulations to protect this species.]

7 CULTURE

[Clemens (1956) was able to hold young black skipjack in shipboard aquaria for as long as 10 days (Sections 3.22, 3.23 and 3.43).]

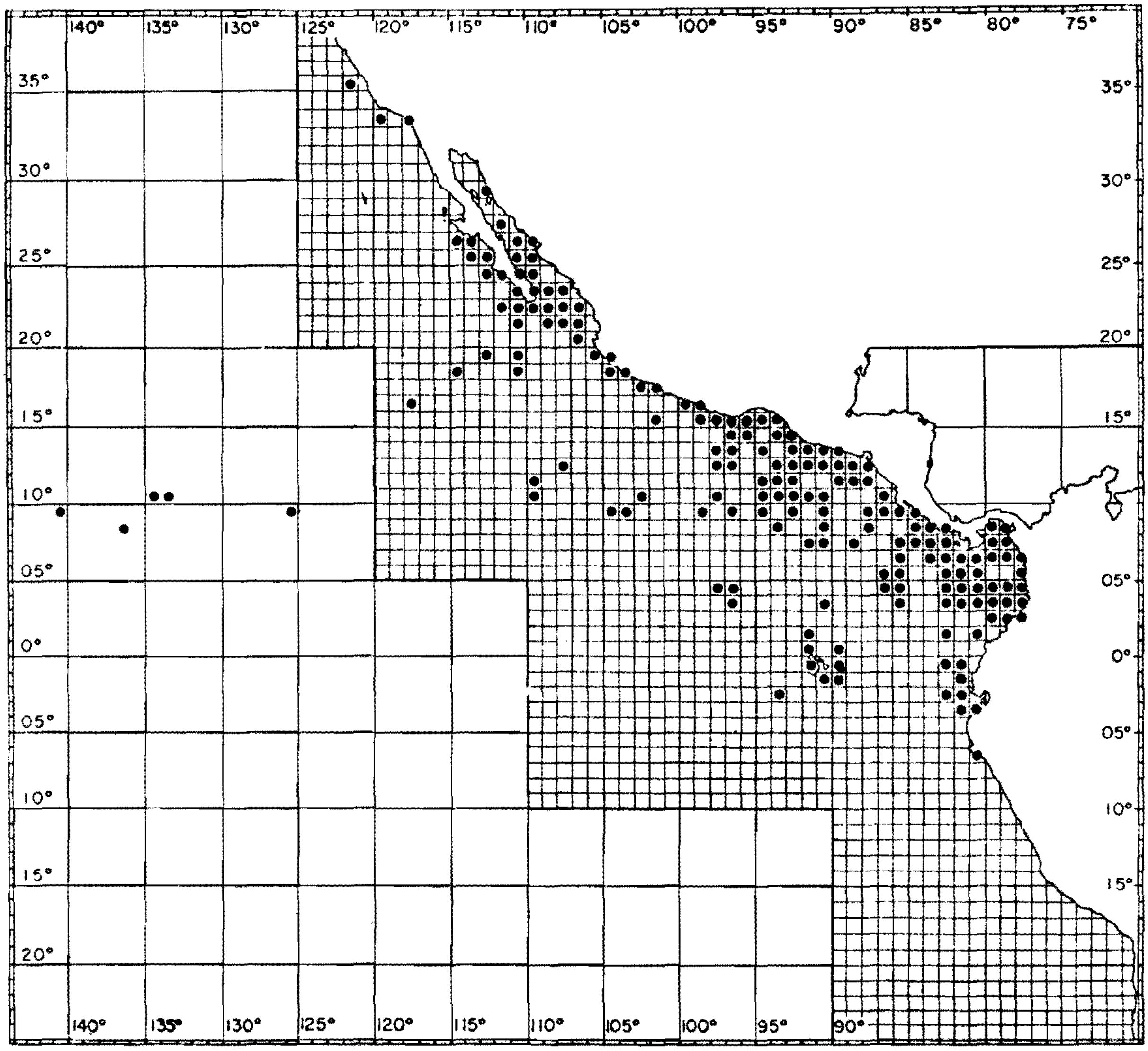

FIGURE 1. Distribution of black skipjack in the eastern Pacific Ocean, including all records to date.

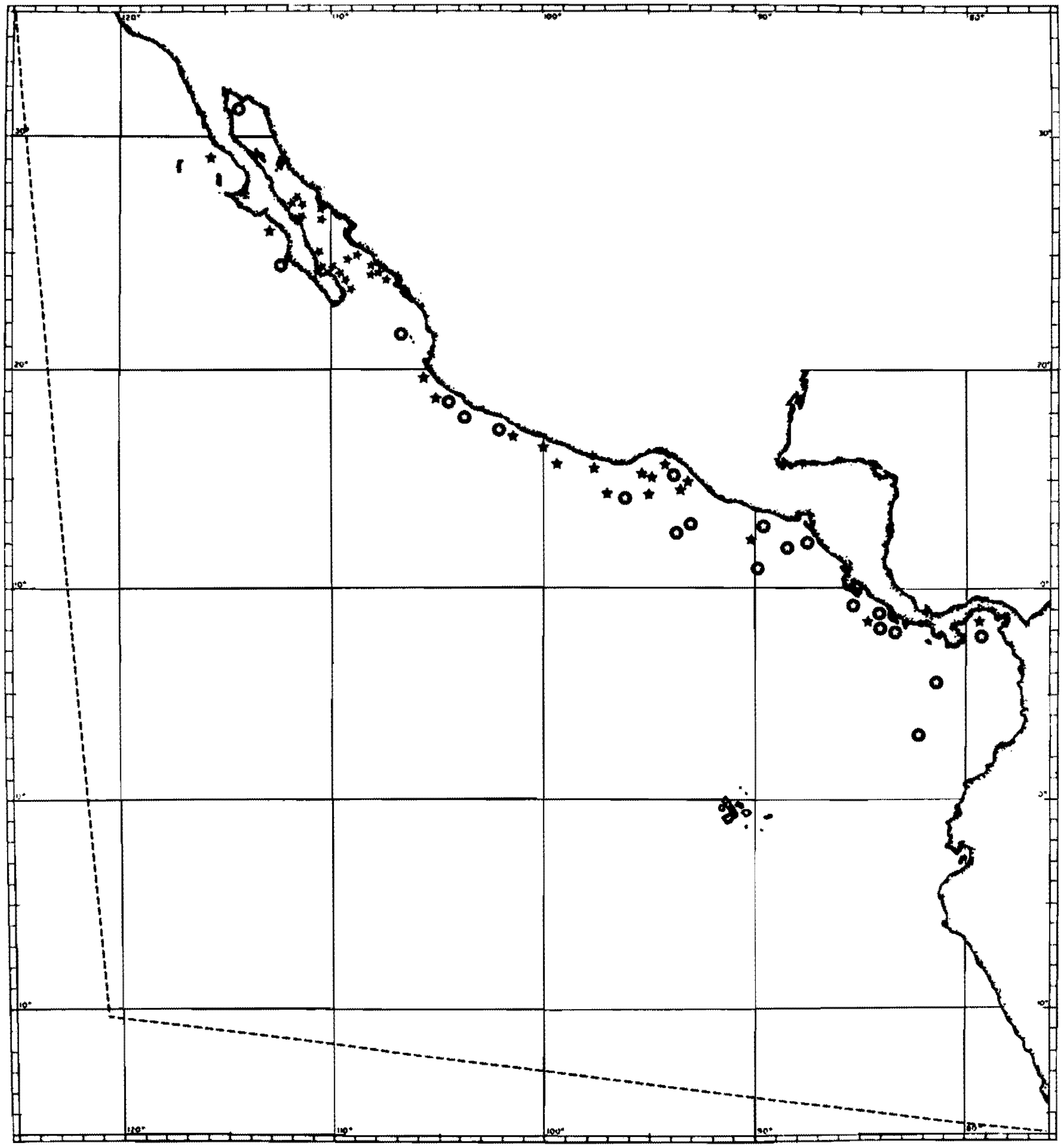

FIGURE 2. Locations of capture of larvae and juveniles of black skipjack, including all records to date (after Klawe, 1963, and Moser *et al.*, 1974). The localities of capture are designated by the following symbols: solid star, larvae from plankton tows; circle with star, juveniles from night collections.

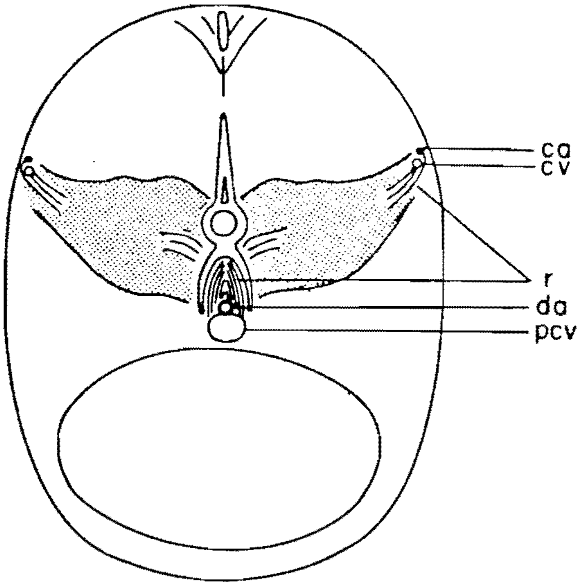

FIGURE 3. "Transverse section" of black skipjack "showing the position of central and lateral retia miribilia (r) that function as the vascular heat exchangers. The major blood vessels supplying retia are: dorsal aorta (da), posterior cardinal vein (pcv), cutaneous arteries (ca), and veins (cv). Veins are shown with larger diameters and thinner walls. Red muscle distribution (shaded areas) is also depicted. Noted that the position of the cutaneous arteries and veins in black skipjack is reversed compared to that in other species and that only an epaxial pair is present" (from Graham, 1975).

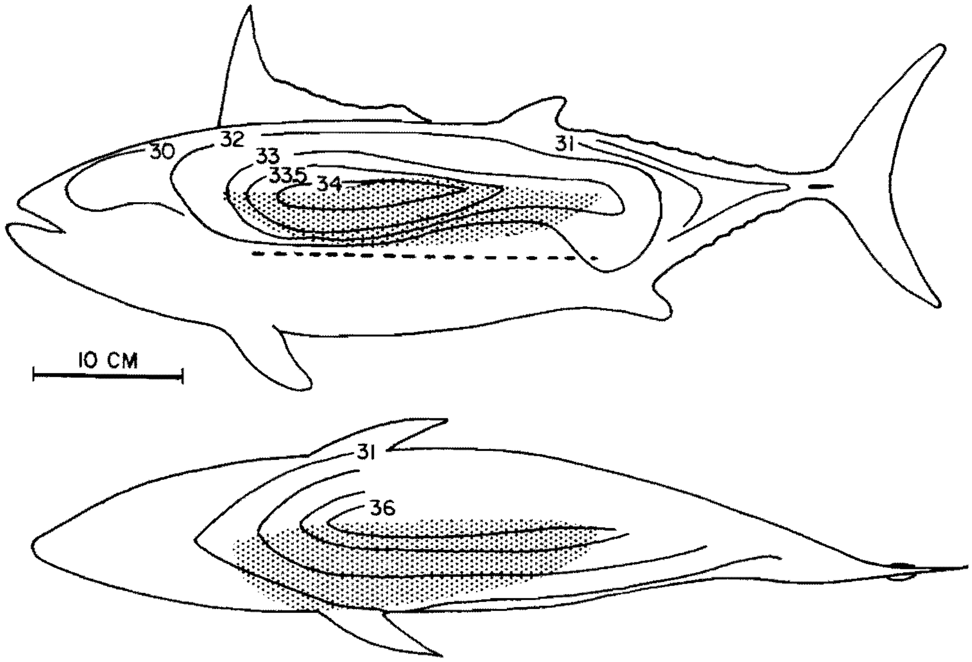

FIGURE 4. "Thermal profiles, red muscle distribution (stippled), and lineal distribution of the central heat exchanger (dashed line) in E. lineatus. Profiles are based on body-temperature measurements of 22 fishes. In the dorsal view, red muscle is shown on one side only. Water temperature, 29^{o}" (from Graham, 1973).

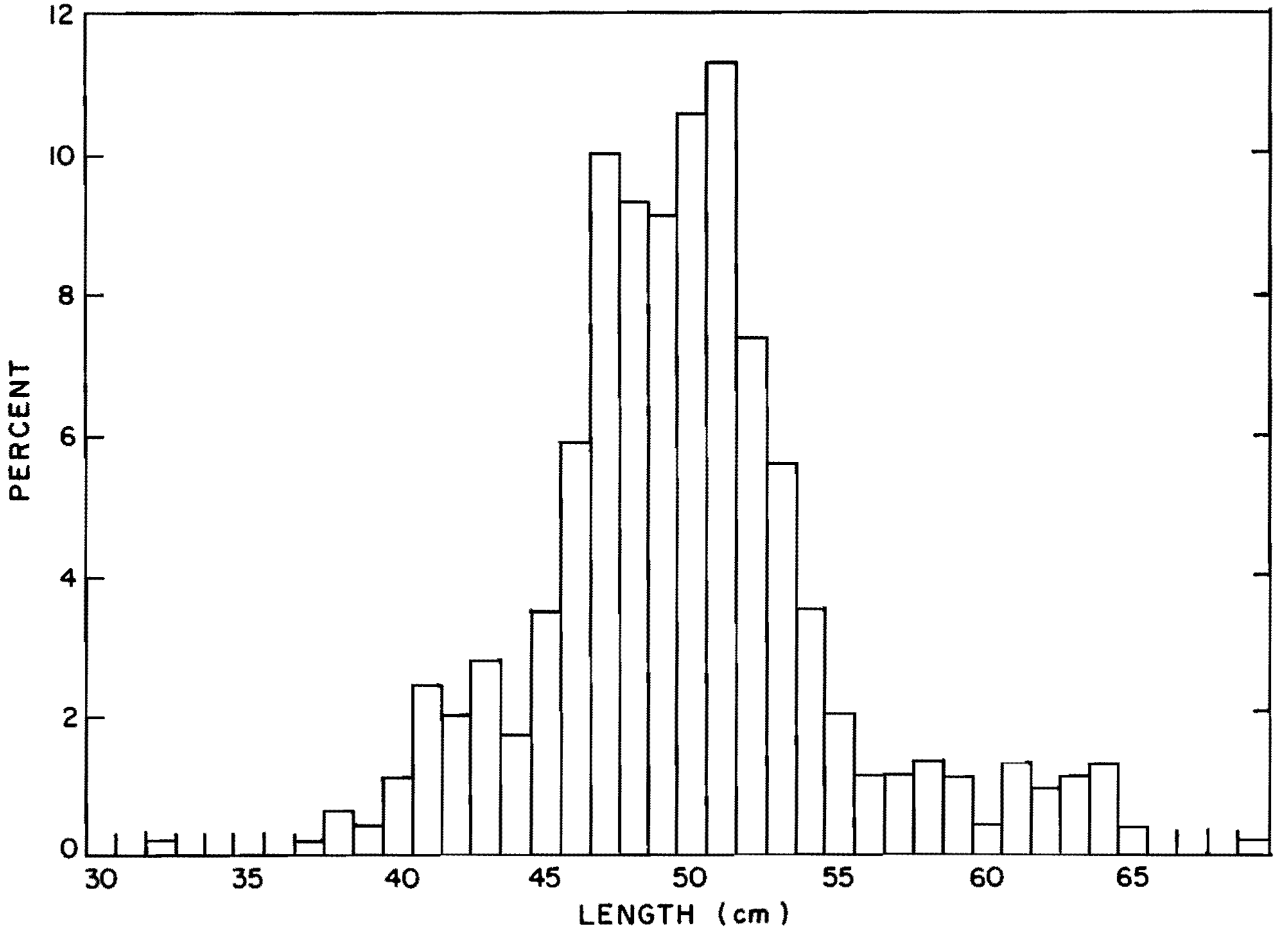

FIGURE 5. Length-frequency distribution of black skipjack from samples of fish caught from 1972 to 1975 (from Yoshida, 1979a).

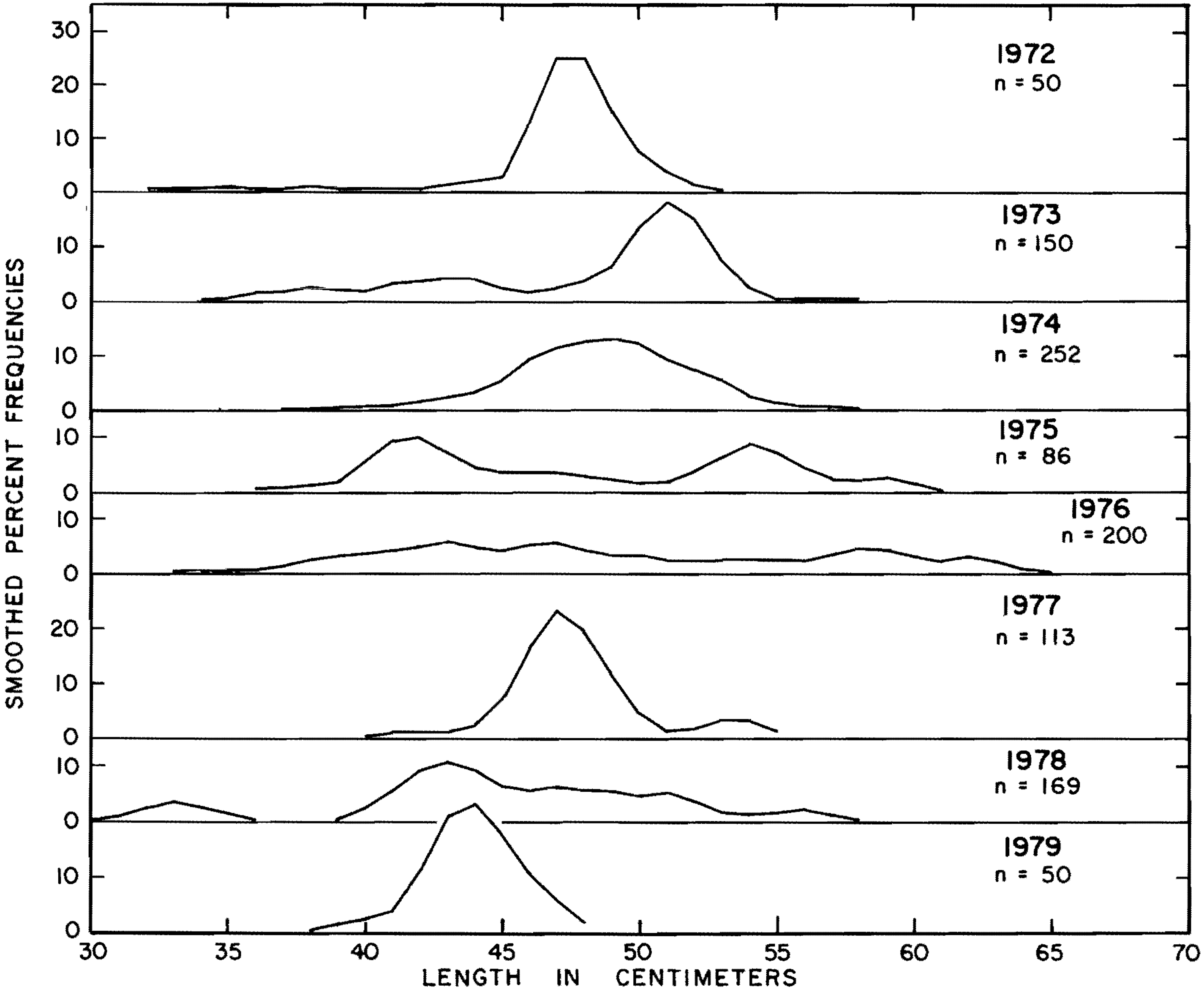

FIGURE 6. Annual length-frequency distributions of black skipjack from samples of fish caught from 1972 to 1979.

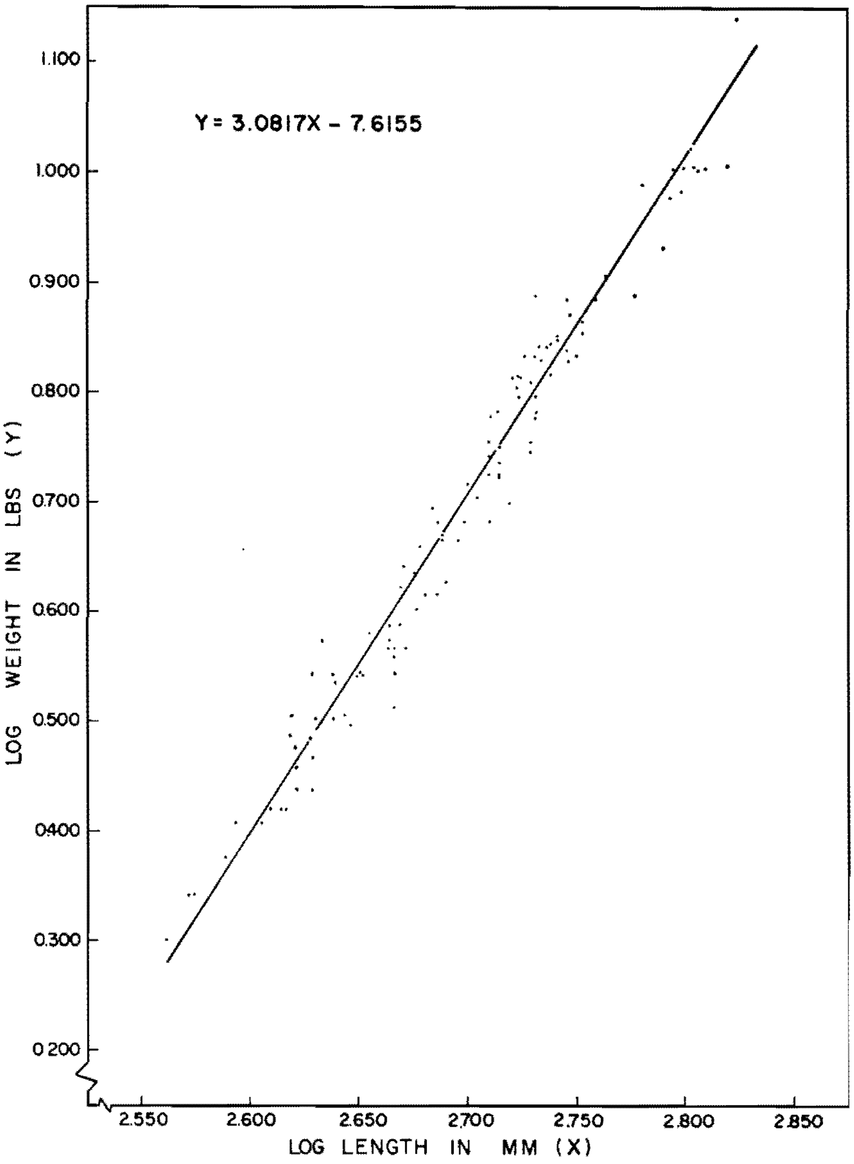

FIGURE 7. Linear regression of the logarithm of the weight on the logarithm of the length of black skipjack (from Klawe and Calkins, 1965).

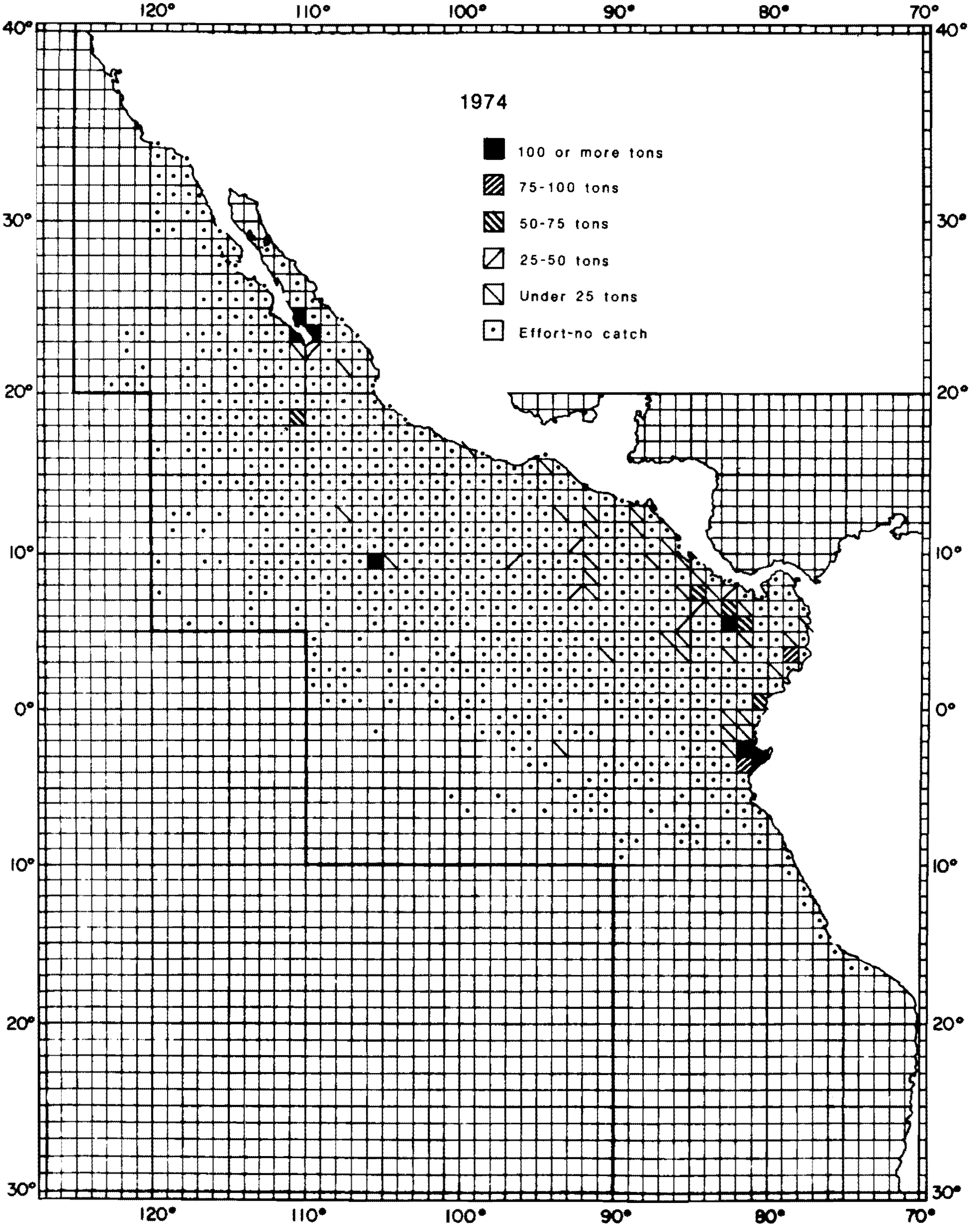

FIGURE 8. Catches of black skipjack in the CYRA (the area between the heavy line and the coast of the Americas) in 1974, 1976, and 1978 by 1-degree areas, for all trips for which usable logbook data were obtained by the IATTC.

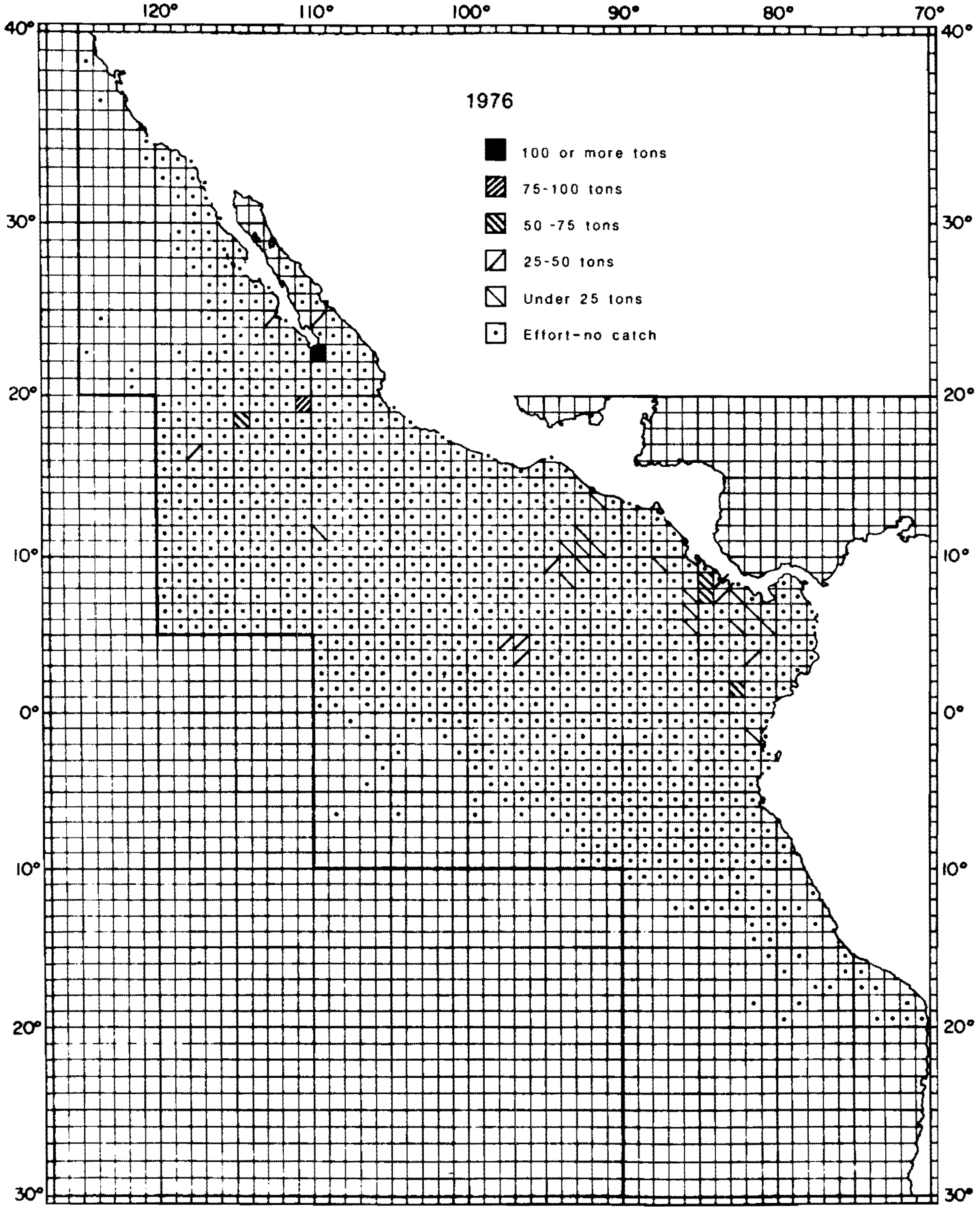

FIGURE 8. (continued)

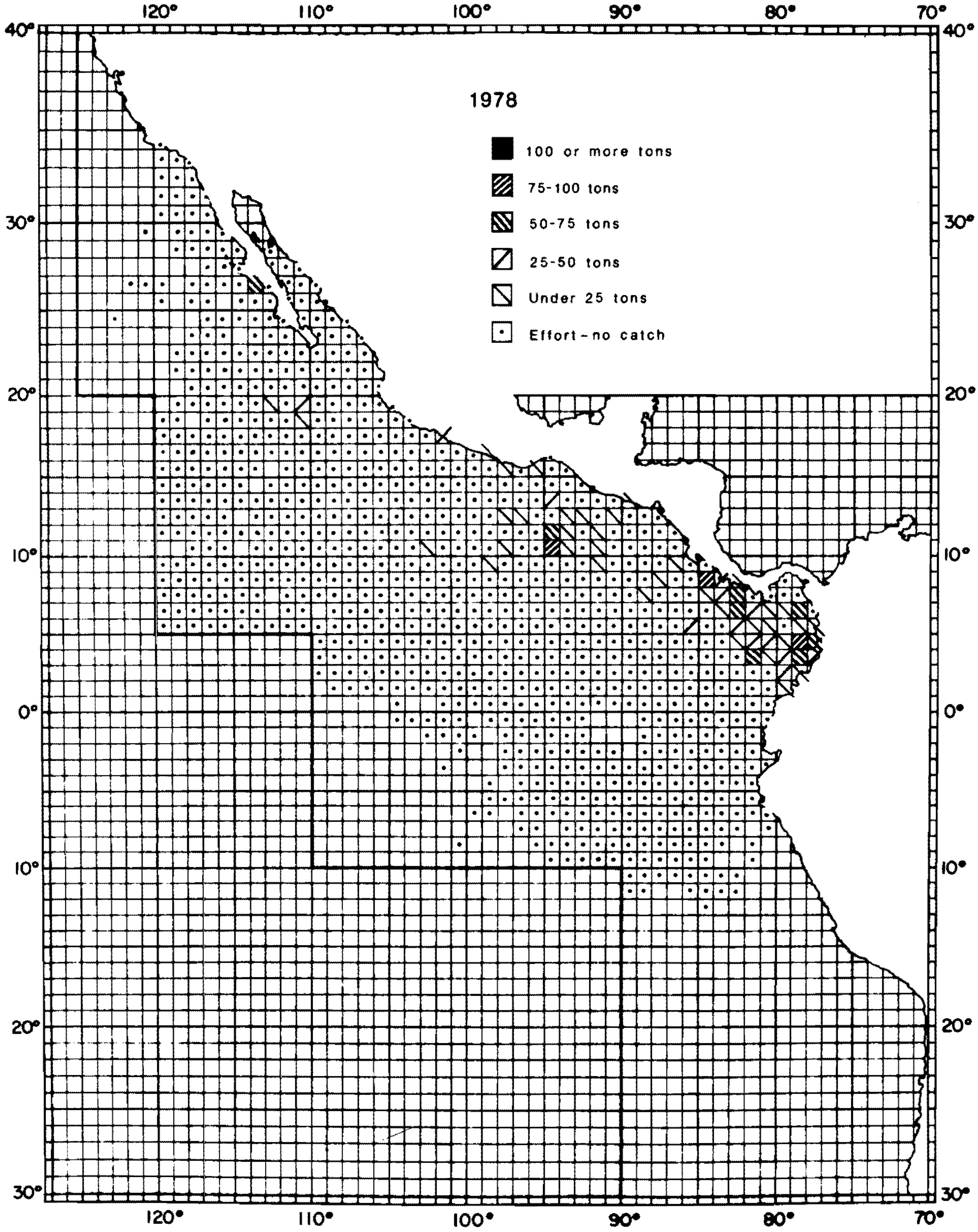

FIGURE 8. (continued)

TABLE 1. Records of larval and juvenile black skipjack in the eastern Pacific Ocean (after Yoshida, 1979a, with additional records added by the author). The lengths of the specimens were given as the total or fork length in the various references listed in the table; however, both were taken in the same manner, i.e., from the tip of the snout to the shortest median ray in the caudal fin.

Date	Locality		Number		Total or fork length (mm)	Collector or reference
			Larvae	Juveniles		
Jan. 1922	06°49'N	80°25'W	19	1	-	Matsumoto (1950)
	06°40'N	80°47'W	68	-	-	Do.
	06°48'N	80°33'W	7	-	-	Do.
	08°24'N	79°23'W	13	-	-	Do.
	08°40'N	79°23'W	25	-	-	Do.
Sep. 1928	07°06'N	79°55'W	2	-	-	Do.
	07°16'N	78°30'W	1	-	-	Do.
	07°55'N	79°02'W	1	-	-	Do.
Mar. 1947	08°20'N	84°10'W	-	8	48-86	Schaefer and Marr (1948)
	09°20'N	85°20'W	-	10	29-56	Do.
	09°10'N	85°20'W	-	1	61	Do.
May 1949	10°58'N	89°56'W	-	2	7.5,10.5	Mead (1951)
	11°20'N	87°20'W	-	23	14-18	Do.
	12°50'N	89°40'W	-	2	18,24	Do.
Oct. 1951	24°35'N	112°05'W	-	1	9.7	Sefton, Jr.[1]
Jan. 1955	12°34'N	89°50'W	-	8	25 (mean)	Clemens (1956)
	08°43'N	84°11'W	-	34	17-28	Do.
Nov. 1955	07°42'N	79°20'W	-	1	30	Eastropic Expedition[1]
	03°01'N	82°15'W	-	6	27-38	Do.
Dec. 1955	11°48'N	88°25'W	-	1	46	Do.
Nov. 1955	08°31.3'N	79°32'W	2	-	-	Klawe (1963)
Aug. 1956	26°04.5'N	112°48'W	1	-	7.0	La Jolla Lab., NMFS[1]
Sep. 1956	15°05'N	93°54'W	-	3	15-27	Klawe (1963)
Oct. 1956	12°51'N	93°05'W	-	1	51	Do.
Nov. 1956	14°00'N	96°11'W	-	1	30	Schaefer and Shimada[1]
Feb. 1957	17°24'N	102°04'W	-	1	21	Renner and Hark[1]
June 1957	24°25'N	108°03'W	10-90	-	-	Moser *et al.*, 1974[2]
	23°55'N	109°43'W	10-90	-	-	Do.
	24°10'N	109°55'W	10-90	-	-	Do.
	23°38'N	109°31'W	1-9	-	-	Do.
	22°27'N	110°59'W	1-9	-	-	Do.
	24°37'N	110°33'W	1-9	-	-	Do.
	24°51'N	110°30'W	1-9	-	-	Do.
	25°24'N	110°32'W	1-9	-	-	Do.
	25°16'N	110°48'W	1-9	-	-	Do.
	26°46'N	111°34'W	1-9	-	-	Do.
	27°21'N	111°59'W	1-9	-	-	Do.
	27°18'N	111°22'W	1-9	-	-	Do.
	26°41'N	110°22'W	1-9	-	-	Do.
	26°59'N	110°25'W	1-9	-	-	Do.
	25°01'N	109°00'W	1-9	-	-	Do.

TABLE 1. (continued)

Date	Locality	Number		Total or fork length (m m)	Collector or reference
		Larvae	Juveniles		
	24°54'N 109°15'W	1-9	-	-	Do.
	24°18'N 108°18'W	1-9	-	-	Do.
	24°15'N 107°47'W	1-9	-	-	Do.
	23°59'N 107°29'W	1-9	-	-	Do.
Aug. 1957	29°12'N 115°39'W	-	1	-	La Jolla Lab., NMFS[1]
	31°11'N 114°15'W	-	2	29.5,35.3	Do.
May 1958	05°34'N 81°29'W	-	1	60	Klawe (1963)
	08°28'N 84°21'W	1	-	-	Do.
	15°15'N 95°23'W	11	-	-	Do.
June 1958	18°44'N 104°21'W	-	5	20-27	Do.
	17°49'N 103°38.5'W	-	99	7.5-45	Do.
	21°36'N 106°44'W	-	3	18-48	Do.
	16°39'N 100°05'W	1	-	-	Do.
	17°24'N 101°25'W	6	-	-	Do.
	18°44'N 104°21'W	1	-	-	Do.
Nov. 1958	14°56.5'N 93°06.5'W	11	-	-	Do.
	15°39'N 93°59.5'W	1	-	-	Do.
	14°18'N 95°02.8'W	1	-	-	Do.
	15°02'N 95°07.5'W	1	-	-	Do.
	14°21'N 97°01'W	27	-	-	Do.
	15°31'N 97°44'W	5	-	-	Do.
Dec. 1958	Do. Do.	15	-	-	Do.
	15°36'N 99°23.5'W	1	-	-	Do.
Jan. 1959	15°29.5'N 98°32.5'W	8	-	-	Do.
Feb. 1959	19°46'N 105°44'W	5	-	-	Do.
Apr. 1959	08°12'N 83°15.5'W	-	6	12-18	Broadhead and Chatwin[1]
	08°12'N 83°17'W	-	1	7.5	Do.
	08°15'N 83°23'W	-	6	13-28	Do.
Sep. 1959	15°39'N 97°00'W	2	-	-	Klawe (1963)
	14°20'N 95°59'W	12	-	-	Do.
	14°54.8'N 95°07.1'W	36	-	-	Do.
	14°21.5'N 94°01'W	5	-	-	Do.
	16°28'N 99°32.5'W	2	-	-	Do.
Feb. 1961	12°35'N 93°40'W	-	3	7.5-9.5	Vann[1]
Oct. 1966	Entrance, Gulf of California	2	-	-	Klawe *et al.* (1970)
Nov. 1966	Do.	3	-	-	Do.
	Off Tres Marias Is.	1	-	-	Do.
Dec. 1966	Entrance, Gulf of California		1	-	- Do.

1. As reported by Klawe (1963)

2. Added by the author

TABLE 2. Larval and juvenile black skipjack captured off Cape Blanco, Costa Rica (after Klawe, 1963).

Date	Location from Cape Blanco	Number		Total length (mm)
		Larvae	Juveniles	
Nov. 1958	20 mi S	1	-	6.5
	20 mi S	1	-	9.0
	20 mi SSW	1	-	6.0
	20 mi SSW	2	-	5.0
Jan. 1959	20 mi S	-	8	21-39
	20 mi S	-	43	14-25
Feb. 1959	20 mi S	-	8	25-50
	20 mi S	1	-	5.0
Mar. 1959	20 mi S	3	-	5.1-6.7
	20 mi S	1	-	6.7
	5 mi SE	2	-	6.2,8.2
	5 mi SE	6	-	5.2-9.2
	5 mi SE	1	-	5.3
Apr. 1959	20 mi S	-	4	13-29
	5 mi SE	-	77	16-25
	20 mi S	2	-	6.5-7.7
	20 mi S	7	-	5.0-8.2
	20 mi SE	12	-	4.1-7.1
	5 mi SE	23	-	4.5-7.5
	5 mi SE	25	-	4.4-7.5
	5 mi SE	12	-	4.4-7.2
	5 mi SE	88	-	4.4-14.2
May 1959	10 mi SE	-	11	16-25
	10 mi SE	5	-	5.5-8.0
	10 mi SE	1	-	8.5
	10 mi SE	2	-	6.0-13.0
June 1959	10 mi W	-	2	17 ca.
Aug. 1959	12 mi SE	3	-	4.6-8.8
	6 mi SE	-	3	15-17
Sept. 1959	20 mi S	4	-	4.8-5.7
	10 mi S	5	-	6.1-7.4
	10 mi S	4	-	5.0-7.3
	10 mi S	5	-	4.4-7.5
Nov. 1959	20 mi S	-	4	11.5-53
	20 mi S	1	-	4.4
Jan. 1960	10 mi S	9	-	4.1-5.5
	10 mi S	2	-	4.6-4.8
Feb. 1960	20 mi SSW	-	1	18
Mar. 1960	10 mi S	-	12	15-28
	20 mi S	6	-	3.3-6.3
	20 mi S	19	-	4.3-8.6
	10 mi S	6	-	3.7-6.7
	10 mi S	4	-	6.6-8.3

TABLE 2. (continued)

Date	Location from Cape Blanco	Number		Total length (mm)
		Larvae	Juveniles	
May 1960	20 mi S	-	14	13-21
	10 mi S	-	6	9.5-24
	10 mi S	1	-	6.5
July 1960	10 mi S	-	4	13-17
	10 mi S	-	62	10-24
	10 mi S	1	-	7.0
Aug. 1960	10 mi S	1	-	6.0
	20 mi S	-	1	19
	10 mi S	-	3	12-18
Sept. 1960	10 mi S	-	51	12.5-24
Oct. 1960	10 mi S	1	-	7.5

TABLE 3. Average numbers of black skipjack larvae caught per hour of surface plankton tow off Cape Blanco, Costa Rica (from Klawe, 1963).

Month	Number of larvae	Month	Number of larvae
January	1.5	July	0.1
February	0.1	August	0.2
March	3.2	September	1.4
April	14.9	October	0.0
May	0.6	November	0.2
June	0.0	December	0.7

TABLE 4. Growth of postlarval black skipjack (from Clemens, 1956). The hours of growth were computed from the time the fish started feeding, 42 hours after capture.

Number of fish	Hours		Standard length (mm)		Fork length (mm)		Weight (g)	
	Range	Average	Range	Average	Range	Average	Range	Average
23	0	0	17.0-37.5	26.8	18.5-40.0	28.3	0.10-0.57	0.29
3	171-175	173	48.0-52.0	49.3	51.0-55.0	52.0	1.51-1.91	1.70
3	194-200	197	54.0-55.0	54.3	58.0	58.0	1.94-2.37	2.14
4	244-248	246	59.0-71.5	63.6	63.0-75.0	67.5	2.61-4.72	3.46

TABLE 5. Release and recapture data for tagged black skipjack.

Release			Recapture			Days	Miles	Direction
Date	Locality	Length (mm)	Date	Locality	Length (mm)			
Nov. 1, 1975	19°00'N-112°08'W	500	Nov. 24, 1975	19°00'N-112°08'W	?	24	0	-
Apr. 2, 1979	12°58'N-92°19'W	486	Aug. 18, 1979	4°15'N-78°32'W	?	139	970	123°
Apr. 2, 1979	12°58'N-19°19'W	438	Sept. 4, 1979	9°55'N-92°12'W	488	156	183	178°
Apr. 2, 1979	12°58'N-92°19'W	407	Sept. 12, 1979	9°35'N-91°30'W	499	164	209	167°
Apr. 14, 1979	6°26'N-86°55'W	313	June 17, 1979	5°16'N-78°31'W	339	65	506	98°
Apr. 15, 1979	6°24'N-86°48'W	315	May 25, 1979	6°15'N-78°00'W	329	41	525	91°
Apr. 17, 1979	5°40'N-87°02'W	?	June 18, 1979	4°20'N-79°54'W	321	63	434	101°

TABLE 6. Catches of black skipjack in metric tons in the eastern Pacific during 1972 to 1979 (from Anonymous, 1980a).

Year	Catch
1972	601
1973	1,674
1974	3,742
1975	531
1976	1,518
1977	1,381
1978	2,153
1979	1,383

SYNOPSIS OF BIOLOGICAL DATA ON THE CHUB MACKEREL, *SCOMBER JAPONICUS* HOUTTUYN, 1782, IN THE PACIFIC OCEAN

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Inter-American Tropical Tuna Commission
La Jolla, California
1980

CONTENTS

1 IDENTITY

The scientific name for the chub mackerel, also known as the "Pacific mackerel," is Scomber japonicus.

2 DISTRIBUTION

The adult chub mackerel in the northeastern Pacific Ocean is distributed from southeastern Alaska (Rounsefell and Dahlgren, 1934) to Banderas Bay, Mexico (Kramer, 1969), and into the Gulf of California as far north as Puerto Penasco (Kramer, 1960). In the southeastern Pacific its range extends from Panama to Chile (Matsui, 1967), including the Galapagos Islands (Hildebrand, 1946). The chub mackerel does not occur in the central Pacific Ocean (Matsui, 1979). The distribution of chub mackerel in the western Pacific Ocean extends from near the Kurile Islands in the north to the East China Sea and Taiwan and as far south as the Philippines. The chub mackerel is found on the west side of the warm Kuroshio Current (Usami, 1976). Watanabe (1970) reports it to be most abundant off the Pacific coast of Honshu Island, Japan.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

The chub mackerel in the northeastern Pacific is heterosexual, and sexual dimorphism has not been reported (Kramer, 1969).

3.12 Maturity

Fry (1936b) reports for chub mackerel in the northeastern Pacific, "In terms of age--the yearling fish do not spawn whereas most of the two-year-olds do." Fitch (1951) reported that spawning does not occur until the third or fourth year. Knaggs and Parrish (1973), using data for fish caught during April through August of 1958-1970 to determine the age at maturity, found that no females spawn during their first season (age-group 0), and that the percentages which were mature were 22.5, 65.7, 84.7, 84.2, and 87 for fish of ages 1, 2, 3, 4, 5, and 6+, respectively. Male fish mature sooner in life than do females, yet none of the age-0 males examined were mature.

Parrish and MacCall (1978) analyzed the original samples used by Knaggs and Parrish (1973) to determine if the percent maturity of age-1 fish is density dependent. They found that 50% of the age-1 fish were mature or maturing during 1969-1971, when the spawning biomass was low.

Chub mackerel off Peru are reported to reach sexual maturity for the first time at 27 cm in length (Anonymous, 1971). Jordan Sotelo *et al.* (1978)

report a high incidence of chub mackerel in spawning condition at 31 cm.

Usami (1976) states that chub mackerel off Japan reach maturity 2 or 3 years after birth at 30 cm or more in length.

3.13 Mating

The mating of chub mackerel is presumably promiscuous (Kramer, 1969).

3.14 Fertilization

The fertilization of chub mackerel eggs takes place externally (Kramer, 1969).

3.15 Gonads

The fecundity of chub mackerel has not been studied in detail. MacGregor (1966) reported that it produces 304 eggs per gram of fish, based on counts for 6 specimens. MacGregor (1976) stated that 18 chub mackerel produced an average of 264 eggs per gram of body weight. In Japan a mature female produces from 100 to 400 thousand eggs at each spawning (Usami, 1976).

3.16 Spawning

Parrish and MacCall (1978) indicate that the spawning stock of chub mackerel extends from British Columbia to Point Abreojos, Mexico. Kramer (1960) states that the chief spawning areas in the northeastern Pacific are in Sebastian Vizcaino Bay, and south of Point Eugenia to Cape San Lucas, Baja California. Ahlstrom (1959) suggests that spawning occurs closer to the surface and to the shoreline for this species than for the other major pelagic species in the California Current region.

Fry (1936b) reported that in 1936 spawning in southern California began in late April or early May and extended until August, with the peak from mid-May to early July. Kramer (1960) reported that spawning in that area during 1952-1956 occurred in about the same months. He stated that the spawning of chub mackerel is sporadic, and that there is no definite seasonal peak. However, he stated that during those years spawning took place off southern California and northern Baja California principally during April and May, and off central Baja California mainly from March through August. Ahlstrom (1959) reported that the peak of spawning off central Baja California in 1957 occurred from June through October and, based on the numbers of larvae captured off northern Baja California, it possibly peaked in the area in April and May.

Knaggs and Parrish (1973) state that the great length and apparent variability of the spawning season is the result of the fact that the eggs mature in successive batches in individual fish. After examining the ovaries of chub mackerel from the commercial catch they concluded that spawning can occur from March through October, but that the majority of spawning occurs from April through August. They also report that the spawning of older mackerel peaks in May, while for age-2 and age-1 fish it peaks in June and July, respectively. Parrish and MacCall (1978) report the peak of spawning coincides with the peak of upwelling off central Baja California, occurring in May according to Bakun (1973).

According to Jordan Sotelo (1979), chub mackerel spawn off Peru from January to May and in September.

In the northwestern Pacific, according to Kishinouye (1923), spawning of chub mackerel occurs in May off Japan. Eggs of this species were found in collections made during June and July of 1954 and 1955 off the west coast of Hokkaido and northern Honshu, with the highest concentrations occurring in Ishikari Bay (Sano et al., 1956). Odate (1961) reports that eggs and larvae were also found in the northeastern sea along the Pacific coast of Japan between April and August, with the highest concentrations in May. The central area of their distribution was the southern part of this region (Joban offshore), which is approximately 200 miles from the coast. Mackerel spawn in this region in early summer. Watanabe (1970) reports the spawning season in Japan as generally March to June, with the peak between April and May. The major spawning grounds are generally near offshore islands or around submarine banks. He states that spawning occurs around the Kii Peninsula in February, around the Boso Peninsula and Izu-Shoto Islands in March, in the Sea of Kashimanada in April, and off the Sanriku coast in May and June (Figure 1). Watanabe (1970) also reports that the spawning takes place between 2000 and 2400 hours, based on field sampling of eggs immediately after ovulation. Uda (1970) reports that since 1965 the main spawning grounds have been around the Izu Islands area, especially near Zenizu Reef, that spawning occurs when the water temperature is at least 10°C and most often when it is 15-20°C, and that the main fishing season coincides with the spawning season. Usami (1976) states that several hundred trillion eggs are laid on the main spawning grounds near the Izu Islands.

3.17 Spawn

The chub mackerel egg is described by Fry (1936a) and Orton (1953) from live material for the northeastern Pacific Ocean. Kramer (1960) described the egg in greater detail from preserved material from the same area. Descriptions of eggs from the northwestern Pacific are provided by Uchida et al. (1958), Dekhnik (1959), and Watanabe (1970).

3.2 Pre-adult phase

3.21 Embryonic phase

References to investigations of the embryonic phase of chub mackerel are given in Section 3.17.

3.22 Larval phase

The development of the larvae of chub mackerel is described for the northeastern Pacific Ocean by Fry (1936a), Orton (1953), and Kramer (1960), and for the northwestern Pacific by Uchida et al. (1958), Dekhnik (1959), and Watanabe (1970).

The distribution of chub mackerel larvae off southern California and Baja California was reported for 1936 through 1941 by Fry (1936b) and Roedel (1949a). Data on the distribution of these larvae for 1951 through 1956 have been given by Ahlstrom (1953, 1954, and 1958) and Ahlstrom and Kramer (1955, 1956, and 1957). Larval chub mackerel in the northeastern Pacific have been collected from Point Conception, California, to Banderas Bay, Mexico, and throughout the Gulf of California (Kramer, 1960). The occurrences of larvae in 1951-1960 on the survey pattern of the California Cooperative Oceanic Fisheries Investigations (CALCOFI) are shown in Figure 2. Kramer (1960) reports that the offshore extent of the larvae is about 150 miles off southern California, 250 miles off northern Baja California, and 200 miles off central Baja California. Ninety-four percent of the samples collected 10 m beneath the surface which contained larvae were taken at temperatures between 14.0° and 21.9°C. Parrish and MacCall (1978) point out that most larvae that have been taken off the Pacific coast of Baja California were captured in the region near Punta Eugenia, as seen in Figure 2. Ahlstrom (1956) reported that in February 1956 the population of larvae in the Gulf of California exceeded by far the total population of larvae in 1956 in the whole CALCOFI survey area for the entire year of surveys on the outer coast. These data also showed heavy concentrations of larvae off the mainland of Mexico in February 1956 (Figure 3). In 1956 and 1957 the chub mackerel larvae averaged 3 larvae per station on the outer coast and 39 larvae per station in the Gulf (Moser et al., 1974). Chub mackerel larvae are abundant in the Gulf of California in the area between Bahia Kino and Mazatlan. The largest concentrations of larvae are found in the southwestern portion of the Gulf of California near Isla San Carmen, Baja California. The major concentrations of larvae appear to occur between the 20.5° and 21.5°C surface isotherms, and virtually no larvae were collected at temperatures in excess of 22°C (Olvera Limas, 1975).

Information on the occurrences and distribution of chub mackerel larvae in the southeastern Pacific is limited. These larvae were not abundant in the collections made on EASTROPAC survey cruises in the eastern tropical Pacific. There were two occurrences totaling seven larvae of Scomber sp. collected from near the Galapagos Islands in February and March 1967, and during August and September 1967 in the same general area there were two occurrences totaling four larvae (Ahlstrom, 1971 and 1972). Chub mackerel eggs and larvae were collected in surface tows of a 1-m net off the coast of Chile during September 1967. A relatively large sample of eggs and one larva were collected at 18°32'S and 71°42'W, and a smaller group of eggs and five larvae were collected at 20°10.8'S and 71°33.2'W (Ahlstrom, 1979).

Chub mackerel larvae distribution in the northwestern Pacific around Japan has been described by Watanabe (1970), who states: "Larvae have been collected from the major spawning site, i.e., Izu-Shoto Islands to Boso Peninsula, as well as Joban area, the Sea of Kashimanada, Sagami Bay, Suruga Bay, the Sea of Enshunada and off the northeastern Honshu (Tohoku Region). The positive areas have usually been changing year by year depending upon sea conditions of the area."

3.23 Adolescent phase

Fry (1936b) reports mackerel a few months old being collected close to shore from Monterey, California, to Cape San Lucas, Baja California. Kramer (1969), who gives a description of juvenile mackerel behavior in aquaria, stated that nothing is known about them in the sea. Watanabe (1970) describes the developmental changes from the postlarva to the adult.

3.3 Adult phase

3.31 Longevity

Fitch (1951), who used otoliths to estimate the ages of chub mackerel in the southern California catch for the 1939-1940 through 1950-1951 seasons, found the oldest fish to be age 11.

3.32 Hardiness

Gregory (1977) conducted experiments holding both tagged and untagged chub mackerel in a ship's bait tanks for 15 days, to investigate the causes of tagging mortalities. Leong (1977), who reported on the techniques for maturation and induced spawning of chub mackerel, was able to hold them in tanks for over two years.

3.33 Competitors

Kramer (1969) states that chub mackerel may compete for food with jack mackerel, *Trachurus symmetricus*. MacCall *et al*. (1976) suggest that Pacific bonito, *Sarda chiliensis*, is a likely competitor.

3.34 Predators

Iverson (1971) and Pinkas (1971) found chub mackerel in small numbers in the stomachs of albacore, *Thunnus alalunga*, and bluefin tuna, *T. thynnus*, from off southern California and northern Baja California, respectively. Evans and Wares (1972) and Eldridge and Wares (1974) report the occurrence of chub mackerel in the stomachs of striped marlin, *Tetrapturus audax*, and sailfish, *Istiophorus platypterus*, from off Buena Vista, Baja California. Chub mackerel are preyed upon off California by sea lions, *Zalophus californianus*, white seabass, *Cynoscion nobilis*, yellowtail, *Seriola dorsalis*, giant sea bass, *Stereolepis gigas*, and sharks (Frey, 1971). Gress *et al*. (1980) report on the feeding activity of the California brown pelican, *Pelecanus occidentalis californicus*, which includes chub mackerel in its diet, based on regurgitated stomach contents of young pelicans at Anacapa Island, California.

Morita (1960) reports *Scomber* sp. to be one of the most important food items of black marlin (*Makaira indica*) in the East China Sea.

3.35 Parasites, diseases, injuries, and abnormalities

Lists of parasites found on the chub mackerel are given by Silas (1967), Silas and Ummerkutty (1967), Love and Moser (1977), and Cressey and Cressey (1980). This fish develops hyperplasia (cancer-like growths) on the skin in the head region when raised in captivity (Kramer, 1969). Leong (1977) reported chub mackerel held in tanks of seawater at 19°C developed malformed jaws after a period of 4 months, at which time they became unable to feed and began to die.

3.36 Physiology and biochemistry

Klawe *et al*. (1963) determined the hemoglobin content of the blood of chub mackerel. They noted that the hemoglobin content of the blood of fishes is generally associated with the level of activity of the species. The hemoglobin concentration in the blood of chub mackerel ranged from 8.0 to 14.8 g/100 ml for 10 fish measuring 244 to 287 mm. The level of hemoglobin concentration in chub mackerel was the lowest of the six species of scombroid fishes examined.

The percent composition of protein, fat, moisture, and ash of the edible portion of a chub mackerel is reported by Sidwell et al. (1974).

Magnuson (1973) reports a basal swimming speed of 1.5 l/s (lengths per second) for the chub mackerel. This low swimming speed is sufficient to maintain hydrostatic equilibrium in the chub mackerel due to its low density and the presence of a gas bladder.

Roberts and Graham (1979) report a mean heart rate of 106 beats per minute in chub mackerel cruising at 1-1.5 l/s in the laboratory. When the fish accelerated to 4-5 l/s the mean heart rate was 130 beats per minute, but returned to the resting rate within a few minutes after deceleration. They also found that the chub mackerel does not develop large temperature excesses in its tissues swimming at basal speeds (1.3-1.9 l/s) or sustainable speeds (3-5 l/s). The temperature excesses measured in the heart and in the red and white muscles of this species never exceeded 1°C. They report further that both the red and white muscles function in low-speed swimming and that both probably remain active throughout a wide range of sustainable speeds, as well as at burst velocities, in fast-swimming scombrids.

3.4 Nutrition and growth

3.41 and 3.42 Feeding and food

Hunter and Kimbrell (1980) report on the feeding behavior of laboratory-reared chub mackerel larvae and upon the food of sea-caught larvae, in which 59% of the identifiable organisms were copepods. Cannibalism was common in the rearing containers when the fish were about 8 mm long, but ended as they approached metamorphosis (15 mm) and began schooling. Chub mackerel larvae of mean length 16.4 mm were observed to capture and ingest anchovy larvae of 11.7-13.5 mm.

Fry (1936b) reports that copepods, schizopods, and other crustaceans form a large portion of the adult chub mackerel's food in the northeastern Pacific, but fish and squid are also included in the diet. Fitch (1956) reported that the stomach contents of mackerel taken between Point Conception, California, and Santa Maria Bay, Baja California, consisted mostly of larval and juvenile fish (by volume), the remainder being crustaceans, such as mysids, copepods, and euphausids. Frey (1971) reports that larval and juvenile fish are the most important food of the chub mackerel, but that they sometimes rely heavily on euphausids, and also feed to some extent on squid. Based on a laboratory study on feeding, O'Connell and Zweifel (1972) suggest that chub mackerel utilize only the larger planktonic crustaceans, such as euphausids, in the sea. Magnuson and Heitz (1971) provide a description of the gill raker apparatus of chub mackerel and its application to feeding.

Analysis of stomach contents of chub mackerel from off Peru reveals the primary food to be anchoveta, *Engraulis ringens*, followed by copepods and euphausids. Small chub mackerel have been found in the stomachs, demonstrating the existence of cannibalism (Anonymous, 1971). Jordan Sotelo (1979) provides a list of the following food items of the chub mackerel from Peru: anchoveta (*Engraulis ringens*), smelt (Atherinidae), sardine (Clupeidae), machete (Elopidae), red crabs (*Pleuroncodes* sp.), isopods, copepods, fish eggs, and fish larvae.

Kishinouye (1923) found that fry and immature chub mackerel feed on the fry of other fishes. Yokota *et al*. (1961) and Shirota (1970) report on the feeding habits of larval chub mackerel. Shirota (1970) notes that the mouth size is large at the commencement of feeding and that the chub mackerel has a fast growth rate. Kasahara and Ito (1953), summarizing some 30 reports on adult chub mackerel from the Sea of Japan, report that the food consists primarily of euphausids, copepods, and amphipods, followed by small fishes such as sardines, anchovies, sand lance, and small squids. Hatañaka *et al*. (1957) report that young chub mackerel in Japan eat mainly pelagic crustaceans, especially *Euphausia*, during the period from April to mid-July, and thereafter to mid-October feed on fish, mostly anchovy, but also sardine, horse mackerel, and squid. Hatanaka and Takahashi (1960), who review the studies of food and feeding habits in Japanese waters in detail, report that the most important food items from midsummer to autumn is the anchovy, along with traces of sardines, sauries, small squids, and *Euphausia*. During the rest of the year chub mackerel feed primarily on *Euphausia* and other larger pelagic crustaceans such as amphipods. Chub mackerel consume food of smaller sizes than would be assumed by the gill raker gap (Hiyana and Yasuda, 1957). Hatanaka and Takahashi (1956) report a daily ration of 24% of body weight per day in a feeding experiment with chub mackerel being fed *Engraulis japonicus*. Chub mackerel captured food with great rapidity, becoming 60% satiated in from 1 to 4 s. The interest in food declined and the time involved in further feeding increased greatly after 70% satiation (Kariya and Takahashi, 1969b). Chub mackerel satiated with anchovy exhibited a fast rate of digestion at the temperature level of 18-23°C, with only 20% of the initial weight of stomach contents being retained after 5 hours (Kariya and Takahashi, 1969a).

3.43 and 3.44 Growth rate and metabolism

Hunter and Kimbrell (1980) report information on the growth and metabolism of chub mackerel larvae reared in captivity. They found that the larvae have a relatively high metabolic rate and grow rapidly, completing metamorphosis at 15 mm in 2 to 3 weeks for the temperature range of 16.8-22.1°C.

Fry (1936b) gives some data from the early California fishery on the lengths and weights of chub mackerel. Fitch (1951) reports information on age and growth rate of chub mackerel, as estimated by examination of the otoliths. Age data superimposed on a weight-length curve for the chub mackerel sampled during the 1939-1940 through 1950-1951 seasons are given in his report. Kramer (1969) gives condition factors for ocean specimens from data of Fitch (1951) and for laboratory-reared specimens (Table 1). Knaggs and Parrish (1973) estimated the parameters for the von Bertalanffy growth equation, $l_t = L_\infty[1-\exp(-kt+kt_o)]$, and calculated the length-weight relationships for data from the 1958-1959 to 1969-1970 seasons (Table 2). Data on expected weights of fish of various lengths, based on data given by Knaggs and Parrish (1973) are given in Table 3. Length-weight relationships for chub mackerel in Peru are given by Sanchez and Lam (1970). Jordan Sotelo (1979) gives the weight-length relationship, $W = 0.00126L^{3.65}$, for Peruvian chub mackerel. Hatanaka *et al*. (1957) report that chub mackerel in the coastal waters of Japan that are a little over 1 year old and average 149 g in weight require 8% of their body weight per day in crustaceans to sustain the growth rate observed in nature, which was estimated as 0.42% of the body weight per day. The investigations on growth in Japanese waters are reviewed by Hatanaka and Takahashi (1960).

3.5 Behavior

3.51 Migrations and local movements

Fry and Roedel (1949) and Roedel (1949b) report on a tagging program carried out from July 1935 to March 1943, during which 76,038 chub mackerel were tagged from Magdalena Bay, Baja California, to Tillamook Head, Oregon. The fish were found to migrate throughout most of the region of the tagging program, individuals from as far north as Oregon and as far south as central Baja California migrating to the southern California area (Figure 4). No fish tagged south of San Roque Bay, Baja California, were recaptured, indicating that these do not migrate to the waters off southern California or contribute to that fishery.

In the vicinity of Japan the migrations and local movements of chub mackerel are reported by Kawakami (1962), Kojima (1962), Watanabe (1970), Usami and Matsushita (1974), and Usami (1976). Recapture data for fish tagged near the Oki Islands during May and June indicated that fish in the western Japan Sea migrate as far north as Point Saruyama on the Noto Peninsula (Kojima, 1962). Usami (1976) reports that in recent years the chub mackerel in the Sea of Japan migrate to the west coast of Hokkaido, Soya Strait and the Sea of Okhotsk. Kawakami (1962) reports that mackerel in Ishikari Bay in summer aggregate into subschools which tend to enter the fishing grounds at intervals of about 7 days, which correspond to the period between waxing and waning of the moon. Watanabe (1970) reports that adult chub mackerel during winter and spring aggregate off the Boso Peninsula to around the Izu-Shoto Islands. In the summer there is a northward migration to off northeastern Honshu and the southern coast of Hokkaido, and in the fall this migration is reversed. This north-south migration takes place every year (Figure 5), the migration to the north being a feeding migration, and that to the south a wintering and spawning migration. There is shoreward migration of juvenile and young fish from the offshore waters with a shoreward shift of a warm water mass toward the Sanriku coast in summer. Also, the immature fish migrate toward the Joban-Kashimanada region because of lowering of water temperature in the fall and winter seasons. Information from tagging experiments conducted between 1950 and 1968 on the Japanese Pacific subpopulation of chub mackerel, reported by Usami and Matsushita (1974), substantiated the Pacific coast migrations described by Watanabe (1970). However, in recent years on the Pacific coast of Japan, the fish appear between April and July off the central and southern Kurile Islands around 49° north latitude and 172° east longitude (Usami, 1976).

3.52 Schooling

Croker (1933) reports chub mackerel to be gregarious, running in schools, with catches of 50 short tons or more in a single purse-seine set. Kramer (1969) reports that the chub mackerel school by size, which agrees with the findings of Sette (1943) for Atlantic mackerel, *Scomber scombrus*. Kramer (1969) also states that they are found in pure schools and in mixed schools with jack mackerel, Trachurus symmetricus, and Pacific sardine, Sardinops sagax caeruleus. Watanabe (1970) reports that chub mackerel larvae begin schooling at approximately 30 mm. Van Olst and Hunter (1970) investigated the schooling organization of the larval through adult stages of chub mackerel. The schools of adult chub mackerel were the most compact and organized. School organization was unaffected by food deprivation for 9 days in the laboratory. The swimming behavior, including cruising speeds, was investigated by Hunter and Kimbrell (1980) for laboratory-reared larvae and juveniles, and Hunter and Zweifel (1971) report on the swimming speed of adult chub mackerel.

3.53 Responses to stimuli

Chub mackerel are known to be attracted to lights, as they have been sampled at night off Baja California, using a blanket net (Radovich and Gibbs, 1954). Sizeable quantities of chub mackerel are captured through fishing with light by Japanese fishermen. The approach of chub mackerel to artificial lights is probably more due to feeding instinct than to phototaxis. Small schools move in and out of the illuminated area and sometimes show negative phototaxis. The importance of feeding in the vicinity of artificial light has been proven by the effective Japanese fishing method using both light and chum simultaneously (Ben-Yami, 1976).

4 POPULATION

4.1 Structure

4.11 Sex ratio

Kramer (1969) reports a 1:1 ratio of male to female chub mackerel in the northeastern Pacific, and in Peru the sex ratio is also 1:1 (Anonymous, 1971). Watanabe (1970) states that during the wintering and spawning periods the sex ratio varies among schools, but is assumed to be 1:1 for the population as a whole.

4.12 Age composition

Information on the age composition of chub mackerel in the California commercial landings since 1939 has been published by Fitch (1951, 1953a, 1953b, 1955, 1956, and 1958), Hyatt (1960), Parrish and Knaggs (1971 and 1972), Knaggs (1972a), and Parrish and MacCall (1978). Parrish and MacCall (1978) estimated the catch by age groups for the seasons of 1929-1930 to 1969-1970 (Table 4). Kramer (1969) however, noted the presence of older fish (see Section 4.13).

The catches off Peru consist of 10+ age groups (Anonymous, 1979d).

In Japan, off the Pacific coast of Honshu, most of the adult chub mackerel caught by the fishery are 3 and 4 years of age. In 1956-1958 the proportions of 2- and 3-year-olds were larger than usual. The catches for 1962-1965 consisted mainly of 3- and 4-year-olds, and during 1966-1970 the proportions of older fish were greater than in previous years (Figure 6) (Watanabe, 1970). Usami (1976) reports on the age and size composition of the fish from the various fishing grounds around Japan (Table 5).

4.13 Size composition

Fitch (1956) reports the largest chub mackerel on record was nearly 25 inches (63.5 cm) in length and weighed 6.33 pounds (2.8 kg). Kramer (1969) reports the data for the length composition of the California catch for each age group for the 1939-1940 through 1963-1964 seasons as follows:

Age groups with range of length (mm)

0	1	2	3	4	5	6	7	8	9
168-332	218-385	235-392	278-405	282-400	315-410	332-422	330-430	362-425	385-415

Length-frequency distributions of chub mackerel in the commercial fishery of the northeastern Pacific have not been published, except for the 1929-1930 and 1930-1931 seasons (Parrish and MacCall, 1978), and the 1968-1969 season (Blunt and Parrish, 1969).

The chub mackerel landed in Peru range from 17 to 44 cm in length, with an average length of 30 cm and an average weight of 325 g (Jordan Sotelo, 1979).

Watanabe (1970) gives length-frequency data for adult chub mackerel in Japanese waters for 1958 through 1964 (Figure 7). Usami (1976) reports that chub mackerel 50 cm or more in length and 2 kg in weight have been captured off the Pacific coast of Japan.

4.2 Abundance and density

Data on the annual fluctuations in abundance of the chub mackerel in the early California fishery are reported by Croker (1933 and 1938), Fitch (1952a), and Roedel (1952a). The catches for 1924-1974 and estimates of the total biomass for 1939-1974 of chub mackerel in the California fishery are shown in Figure 8. Reports on the status of the northeastern Pacific chub mackerel stock have been published by Frey and Knaggs (1973), MacCall (1973), Knaggs (1974), Knaggs and Sunada (1975), and Klingbeil (1976 and 1977). Squire (1972) reports the calculated indices of annual apparent abundance for chub mackerel from September 1962 through December 1969, based on observations of aerial fish spotters, from Monterey Bay to southwest of San Diego, and occasionally offshore to San Clemente Island, Cortez Bank, and San Nicholas Island. The indices showed an 89% decline in annual apparent abundance from 1963 to 1968. The catches have declined since the 1935-1936 season, when 66,540 metric tons were caught, and a moratorium on commercial fishing was set in 1970. The moratorium was to remain in effect until the spawning population reached 10,000 short tons (9,000 metric tons). A total biomass of 9,762 to 20,918 short tons (8,883 to 19,035 metric tons) for 1975 was estimated by Klingbeil (1976). The spawning during the 1976 season was the most successful in over a decade, and the spawning population is now greater than 10,000 short tons, (Klingbeil, 1977). He suggests that the total biomass, as a result of the strong 1976 year class, has increased by a factor of five or six. The total biomass estimated for the chub mackerel population north of Point Eugenia, Baja California, is 145,000 short tons (132,000 metric tons) for 1979 (Klingbeil, 1979). Parrish and MacCall (1978) give biomass estimates for the individual age groups, the total population, and the spawners for 1928 to 1969 (Table 6). Parrish and MacCall (1978) evaluate the environmental factors possibly causing the variation in size of the northeastern stock of chub mackerel. Catch data (Table 7) also provide information on the annual fluctuations in abundance and/or density in the northeastern Pacific.

Jordan Sotelo _et al_. (1978) report a population estimate of 1.9 million metric tons of chub mackerel off the coast of Peru for 1978. They report this as a 138% increase in biomass over the previous year, with a substantial number of younger fish entering the fishery. Seventy percent of the population is distributed from Callao to the north. The greatest density of this species is found within 30 miles of the coast. A probable increase in the abundance off Peru is evident from the annual landings data in Table 7. It should be noted that the increase in landings began in 1973, following the El Niño of 1972, reported by Miller and Laurs (1975). There was also a drastic decline in the landings of anchoveta, _Engraulis ringens_, from Peru in 1972 (Anonymous, 1971-1979).

Chub mackerel has been declining in the Sea of Japan since 1962. However, the Pacific population has rapidly increased since 1958 and apparently replaced the Pacific saury, Cololabis saira, as the dominant species (Uda, 1970). Watanabe (1970) reports that in 1960 there was a remarkable increase in the landings from off the Pacific coast of Honshu, Japan, and that the catches since then have remained at a high level. There is no population estimate available for the northwestern Pacific. The fluctuations in annual abundance based on the landings are listed in Table 7.

4.3 Natality and recruitment

During most years fish have been recruited into the California fishery as 1-year-olds, but since 1965 the proportions of age-0 fish in the catch have increased, and in 1967 age-0 fish comprised more than 65% of the landings (Parrish, 1974). "Spawning success is aperiodic and varies in series of about 2 to 10 or more years" (Parrish, 1974). The "recruitment biomass", i.e. the weight of age-1 fish, for 1928-1969 estimated by Parrish and MacCall (1978) is shown in Table 6. Parrish and MacCall (1978) provide an index of reproductive success l_N (recruits/spawners) (Figure 9) and a graph of the spawner-recruit relationship (Figure 10). Several types of spawner-recruit functions were fitted by Parrish and MacCall (1978) to their estimates of recruit biomass and spawning biomass. The three principal density-dependent functions they used were those of Ricker (1975), Beverton and Holt (1957), and Cushing (1971).

Watanabe (1970) states that recruitment within a stock of a constant level may be governed by egg abundance fluctuations due to age and physiological condition of the parent fish and to mortality rates in the early stages of life. The relationships of egg abundance to recruitment into the fishery are discussed by Watanabe (1970). In Figure 11 is shown the relationship of egg abundance in any year (E) and the catch of 3- to 5-year-old fish of the same brood (R) (Watanabe, 1970).

4.4 Mortality and morbidity

Parrish (1974) reports a trend of increasing fishing mortality rates in the northeastern Pacific fishery, especially for fish of age groups 0 and 1. The instantaneous annual fishing mortality rate (F) for age-group 1 in 1964 exceeded 0.5 and before 1965 fish of age-group 0 were almost entirely unexploited.

Parrish and MacCall (1978) suggest that the instantaneous annual rate of natural mortality (M) is probably between 0.4 and 0.6. An abundance index based on surveys in the fall of 1950 through 1961 (Mais, 1974) is used by Parrish and MacCall (1978) to derive an effort index (f). Estimates of f and Z (instantaneous annual total mortality rate) calculated from a cohort analysis by Parrish and MacCall (1978), using M = 0.5, are found in Table 8. Estimates of fishing mortality rates by seasons and age calculated by Parrish and MacCall (1978) are found in Table 9.

Gregory (1977) reports on the mortality of chub mackerel tagged and held in tanks.

4.5 Dynamics of the population

Parrish and MacCall (1978) used two computer simulation models in their investigations of the population dynamics of the chub mackerel in the northeastern Pacific. The first is a yield-per-recruit model (ISOE) based on the yield equations described by Beverton and Holt (1957) and revised by Ricker (1975). Parrish and MacCall (1978) state: "ISOE calculates the relative yield from a cohort at various combinations of exploitation rate and age at recruitment to the fishery." The second, QUOTAE, is also a yield-per-recruit model, but it includes a spawner-recruit function. This model, which integrates the ideas of Walters (1969) and Allen (1973), was designed to simulate the chub mackerel population under a quota system similar to the present California regulations. Parrish and MacCall (1978) state: "QUOTAE calculates the mean yield over a period of years with various combinations of quota proportion and age at recruitment. The quota proportion is defined as a fraction of the stock above some minimum level." The spawner-recruit functions used in the simulations included density-dependent functions and environmental-dependent functions. The QUOTAE model was also run with a recruitment function that includes both environmental- and density-dependent factors. Parrish and MacCall (1978), using a value of 0.5 for M, found that the maximum yield per unit weight of recruits occurred at an age of 1 or less with the highest instantaneous fishing mortality rate of F = 1.0 (Figure 12A). This does not mean that there should be a heavy fishery on 1-year-olds, however, as such a fishery would produce a minimal spawning biomass per recruit as shown in Figure 12B (Parrish and MacCall, 1978).

The QUOTAE model was run with several of the density-dependent recruitment functions. When applying nonlinear regression fits to the Ricker and Cushing spawner-recruit functions, Parrish and MacCall (1978) showed high exploitation rates cause little reduction in yield at ages of recruitment of 3 to 4. However, the age at recruitment during most of the past observed fishery has been at age 1. "It should be noted that the Ricker functions predict that extinction will occur if the age at recruitment is 1 or lower and the exploitation rate exceeds 0.6" Parrish and MacCall (1978). Parrish (1974) reported that during the collapse of the chub mackerel population of the late 1960's the exploitation rate exceeded 0.6 and the age at recruitment was less than age 1.

The QUOTAE program was also run with environmental-dependent recruitment functions (Table 10) described by Parrish and MacCall (1978). Simulations under four management options were run for comparison of the yields (Figures 13 and 14).

Parrish and MacCall (1978) report that the recruitment models that include both density-dependent and environmental-dependent components are superior to the density-dependent recruitment functions for predicting recruitment in a given year. The Ricker transport model (Table 10) has some predictive capability of recruitment in a given season, accounting for over 75% of the variation in recruitment for the period of 1946-1968 (Parrish and MacCall, 1978).

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gears

The gear used historically in the chub mackerel fishery in the northeastern Pacific is reviewed by Fry (1931), Croker (1933 and 1938), Scofield (1951), Roedel and Joseph (1954), Messersmith and Hyatt (1965), and Knaggs (1972). Lampara nets and scoop nets in previous years contributed significantly to the catch, but the present fishery uses primarily purse seines. Sportfish gear captured a larger number of chub mackerel in 1971-1974 than did commercial gear in California.

Purse seines are used almost exclusively off Ecuador, Peru, and Chile for capturing chub mackerel, although gill nets have also been used off Peru (Anonymous, 1971). The fishing gears utilized in Peru, in order of importance, are purse seines, gill nets, and midwater trawls. In recent years more than 80% of the chub mackerel has been captured by purse seines (Jordan Sotelo, 1979).

In Japan purse seining is the principal method for the capture of chub mackerel, but lampara nets, set nets, trap nets, gill nets, large lift nets, spoon nets, trolling, balance fishing, stake lines, long lines, and skip fishing are responsible for part of the catch. Tomiyama and Hibayo (1976) give descriptions and photographs of some of the above gear and techniques used in the chub mackerel fisheries in Japan.

5.12 Boats

In California, the purse seiners range in capacity from under 20 tons to approximately 80 tons (18 to 73 metric tons) and in length from 50 to 100 feet (15 to 30 m). Smaller boats from 32 to 48 feet (10 to 15 m) with maximum capacities of 30 short tons (27 metric tons), utilizing gear other than purse seines, were still operating in 1976.

The purse seiners fishing for chub mackerel off Ecuador, Peru, and Chile range in capacity from 15 to over 300 short tons (14 to 270 metric tons). The majority of the fish captured off Peru are taken by 100- to 300-ton vessels.

In Japan, there is a wide range in the size and type of boats used for catching chub mackerel, from 5-meter skiffs to a fleet of purse seiners with capacities of 100 metric tons, which land most of the fish.

5.2 Fishing areas

The fishery in the northeastern Pacific is conducted primarily off southern California and Baja California. The fishing areas off California from 1928 to 1951 are described by Croker (1933 and 1938) and Roedel (1952a). Less than 20 short tons of chub mackerel were captured off central California from 1964 to 1968 (Parrish and Knaggs, 1972). The majority of the fishing from 1968 to 1970 was conducted in southern California around Santa Catalina and San Clemente Islands, and nearshore from San Pedro to San Diego (Knaggs, 1972a). The Mexican fleet has captured chub mackerel mostly in the area of Sebastian Vizcaino Bay, Baja California (MacCall, 1973), but extensive catches have been made in the Gulf of California (MacCall, 1979).

Information on specific fishing areas off the coasts of Ecuador, Peru, and Chile is not available.

The principal fishing grounds around Japan are shown in Figure 15 and listed in Table 4.

5.3 Fishing seasons

Roedel (1952a) reviews the seasonal catches of chub mackerel off California during 1928-1951. During this period fish were most abundant off southern California in the fall, progressively scarcer during the winter, and virtually unavailable by March. During 1930-1940 the May through August landings comprised 24% to 47% of each season's catch. Parrish and MacCall (1978) state that in the later years of the fishery the catches became sporadic, and there was no seasonal pattern.

Off Peru the best catches of chub mackerel are made on the northern fising grounds from July to November and on the southern fishing grounds from January to April (Doucet, 1965). Jordan Sotelo (1979) more recently reports the fishing season to be from September to December. Off Ecuador, chub mackerel appear around December, with the peak catches being made during January and February and lesser catches in March. Chub mackerel do not become abundant again off Ecuador until the following December (Cole, 1979).

In the northwestern Pacific, the fishing seasons are summarized by specific fishing grounds in Table 5. The purse-seine fishery, which is the most important, produces its greatest catches in the summer and autumn (Usami, 1976).

5.4 Fishing operations and results

The total landings of chub mackerel in the Pacific Ocean are estimated to be 2.26 million tons, for 1978. This value approaches the 2.5 million metric tons of tunas, bonitos, and billfishes landed in 1978 from the oceans of the world (Anonymous, 1971-1979).

Chub mackerel catch statistics for the northeastern Pacific are presented in Table 7. The data were obtained from Anonymous (1971-1979), MacCall _et_ _al_. (1976), Pinkas (1977), Sunada (1977), Parrish and MacCall (1978), Klingbeil (1979), and MacCall (1979). The catch statistics for California and Mexico for the seasons, May through the following April, of 1926-1927 to 1969-1970 are reported, and thereafter the annual landings are reported. The California commercial landings for 1976-1978 are preliminary estimates of the California Department of Fish and Game, along with the data for 1976-1978 sport catch. Following the procedure of Parrish and MacCall (1978), the total sport catch for 1970, 1971, and 1974-1978 was estimated at twice the reported partyboat catch, to account for additional catches from private boats, piers, and jetties. For estimating the annual weights in metric tons, the fish were assumed to each weigh 1 pound (0.454 kg).

The catches of chub mackerel for Japan, Korea, Peru, Chile, and the Soviet Union are presented in Table 7. The data were obtained from Anonymous (1971-1979).

The statistics for the landings in Ecuador are not available; however, based on the statistics for Peru and Chile, the annual landings of chub mackerel in Ecuador were probably about 50-100 thousand metric tons for 1977, so the total catch for the three countries in 1977 was probably about 300 thousand metric tons.

6 PROTECTION AND MANAGEMENT

In 1970, a moratorium on the commercial catch of chub mackerel was enacted in California. However, up to 18% (by weight) of any landing could consist of chub mackerel caught incidentally while fishing for other species. A limit of 10 fish per day was placed on sport fishermen.

In 1972, a management scheme became effective that set a quota on the chub mackerel landings, depending on the spawning biomass as estimated annually by the California Department of Fish and Game. The quota was determined to be 20% of the excess over 10,000 short tons (9,000 metric tons) of spawning biomass, and 30% of the excess over 20,000 short tons (18,000 metric tons) of spawning biomass (MacCall, 1973). Effective on July 5, 1978, the regulations were changed, to remain in effect until January 1, 1981. The allowable catch per season is equal to 20% of the total biomass of chub mackerel in excess of 20,000 short tons. The incidental catch of chub mackerel with other species may not exceed 50% (by number) of the fish in any landing. When the quota is open the allowable catch can be taken mixed or unmixed with other species (Anonymous, 1979g). The quota for the season beginning October 1, 1979, was approximately 25,000 short tons (22,500 metric tons). This quota was met and the season was closed on May 15, 1980. The quota for 1980 with a new season opening date of July 1 is set at 15,000 tons (13,650 metric tons) with a 10-inch (25.4 cm) fork length minimum size limit from January 1 to June 30 (Klingbeil, 1980).

There are no regulations for the chub mackerel fishery in Mexico (MacCall, 1979), and the same is probably the case for Ecuador, Peru, and Chile. Jordan Sotelo _et al_. (1978), considering the total biomass of chub mackerel off Peru to be 1.9 million metric tons, recommended that the maximum catch for 1978 not exceed 350 thousand metric tons.

There is no information available on the protection and management of chub mackerel in the northwestern Pacific. Japanese domestic fishery regulations are very local in nature. Taken as a whole, they are very complicated and do not constitute a uniform policy (MacCall, 1979).

7 CULTURE

A considerable amount of research has been conducted by the U.S. National Marine Fisheries Service at the Southwest Fisheries Center, La Jolla, California, with the spawning and rearing of chub mackerel. Chub mackerel eggs were hatched and reared to the age of 6 months, at which time the prorated yield of the experiment was 31,130 kg/ha (Bardach _et al_., 1972). Leong (1977) describes the procedure used to induce spawning of male and female chub mackerel under laboratory conditions. Inoue _et al_. (1969) conducted experiments on the storage of sperm of chub mackerel by quick freezing for use in artificial fertilization. The early life history of chub mackerel from laboratory rearing studies is described by Hunter and Kimbrell (1980).

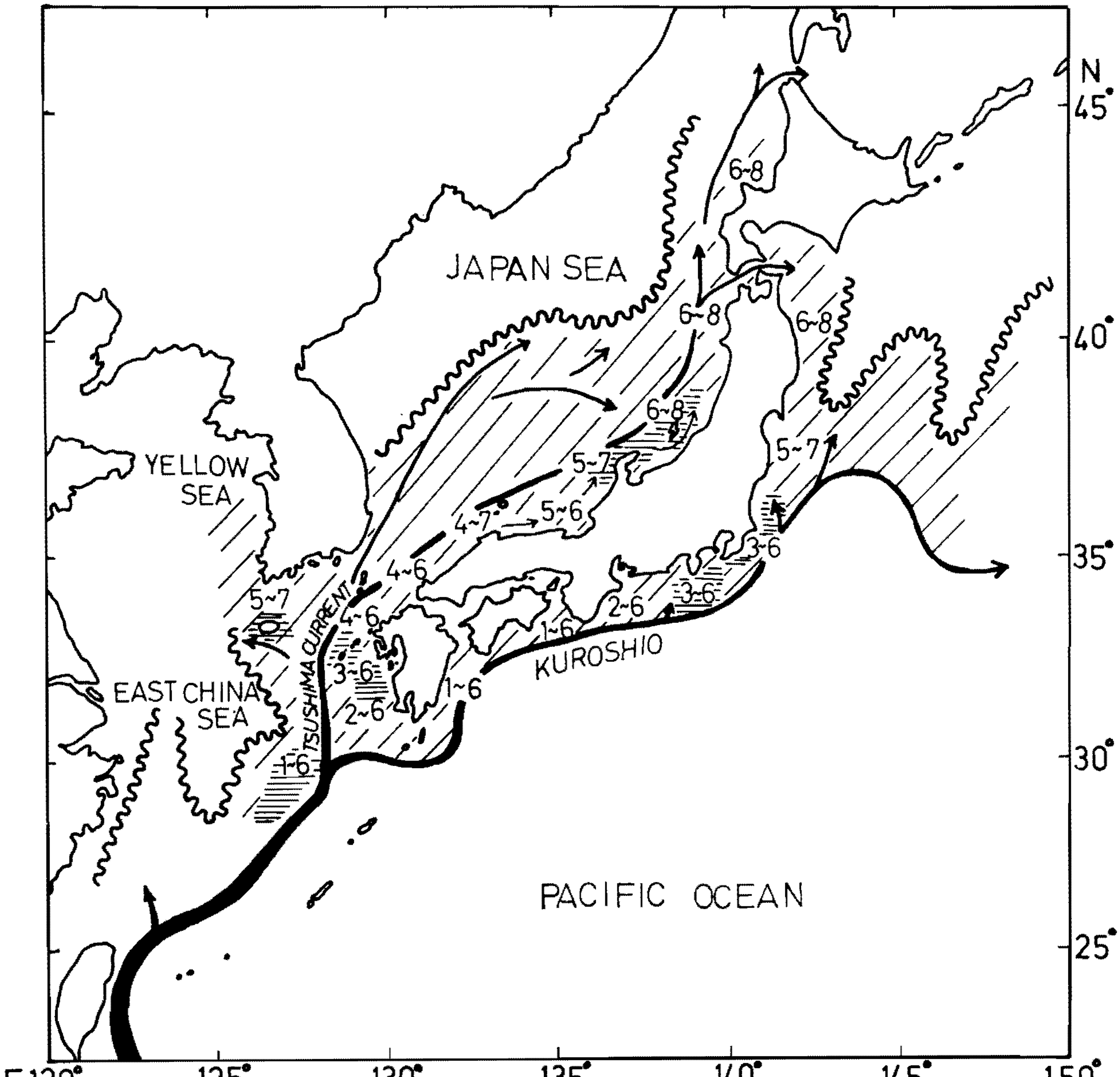

FIGURE 1. Spawning areas of chub mackerel in the northwestern Pacific Ocean, and inferred drift of the eggs and larvae (from Watanabe, 1970).

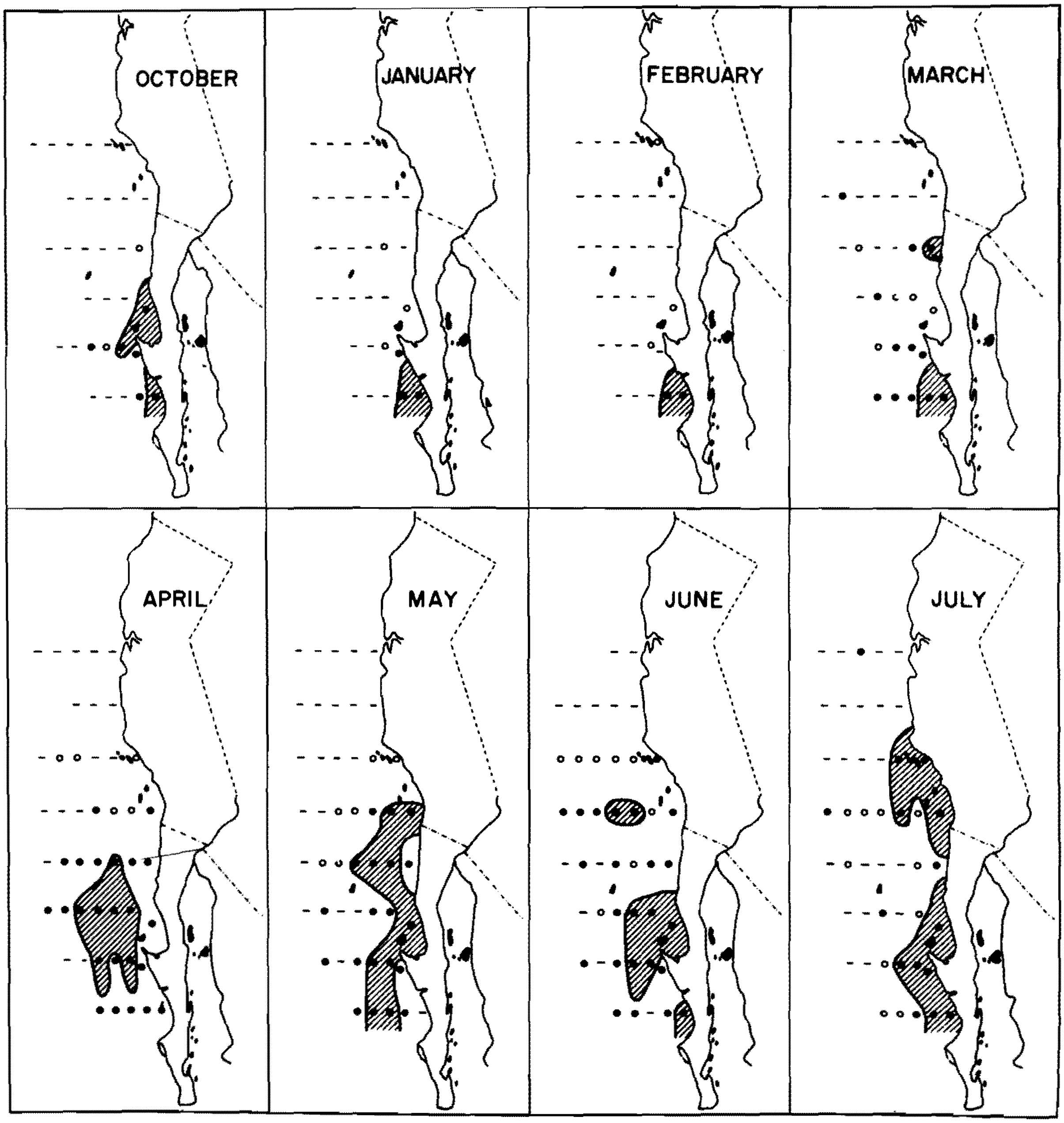

FIGURE 2. Percent occurrences of chub mackerel in 1951-1960 on the CALCOFI survey pattern (from Kramer and Smith, 1970). Each line, circle, or dot represents a pooled statistical area (see Kramer and Smith, 1970a). (o) — less than 5% occurrence; shaded area — equal to or greater than 10% occurrence; (-) — area occupied with no occurrence.

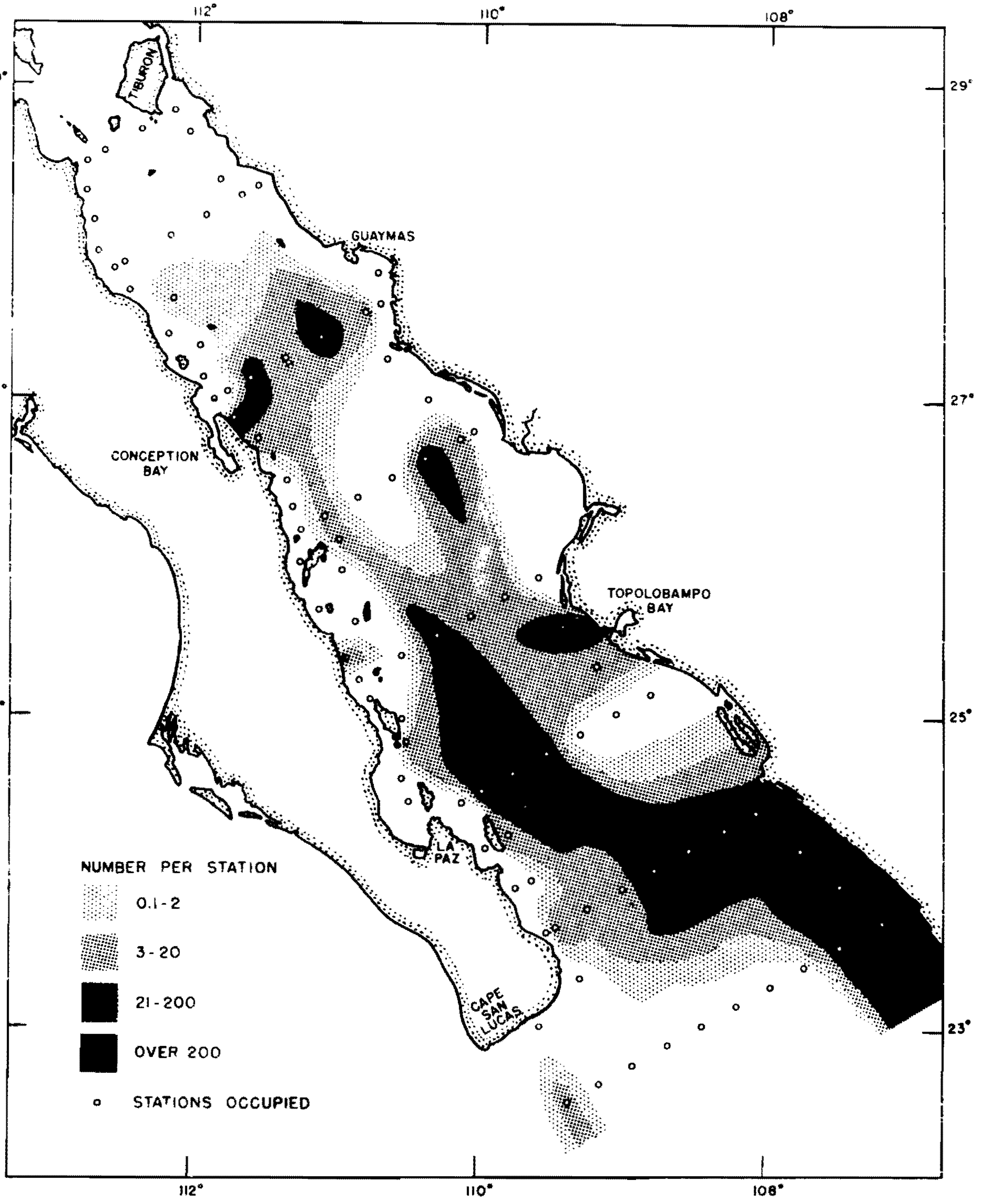

FIGURE 3. Distribution of chub mackerel larvae in the Gulf of California in February 1956 (from Ahlstrom, 1956).

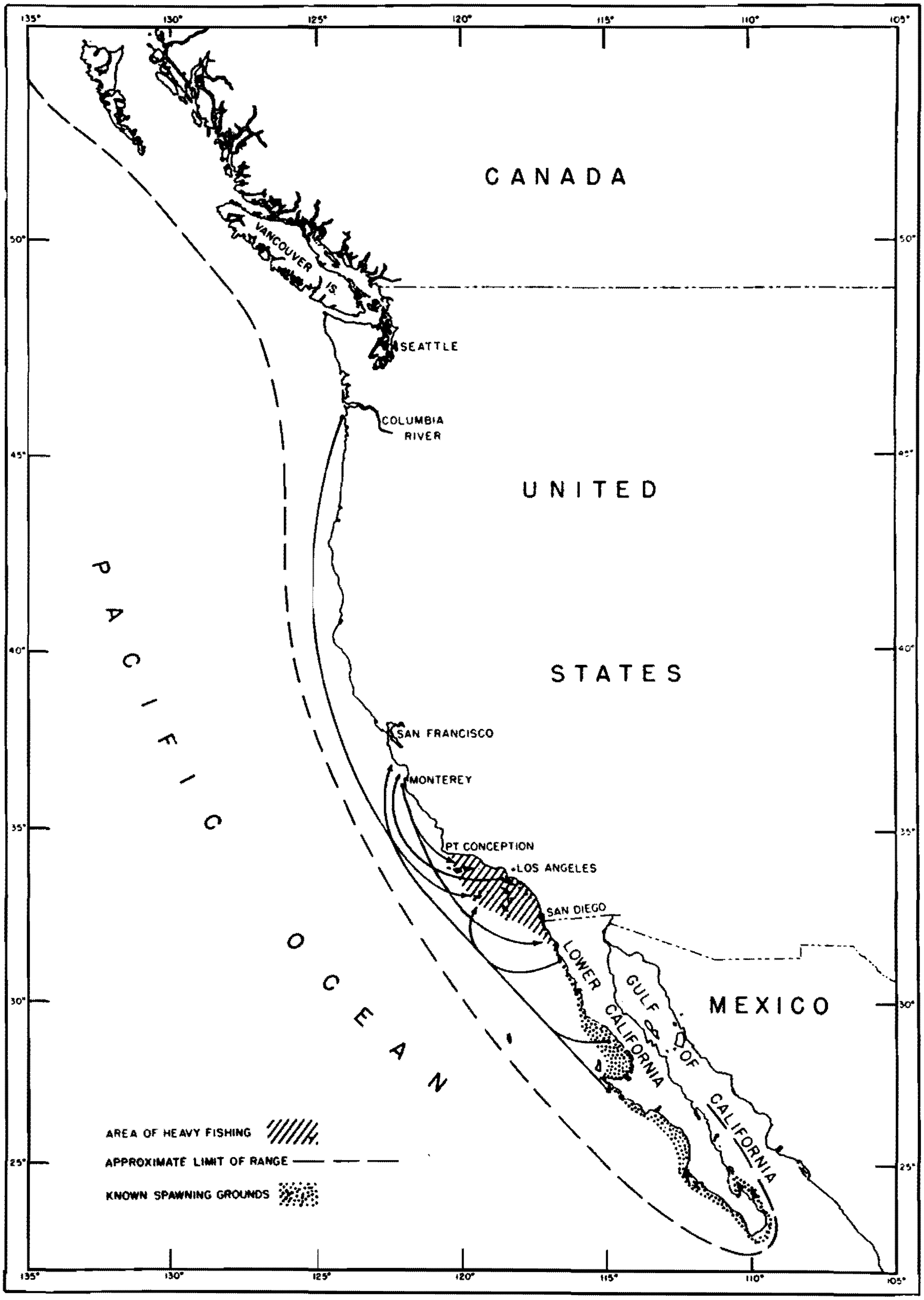

FIGURE 4. Major movements of tagged chub mackerel in the northeastern Pacific Ocean (from Roedel, 1949b).

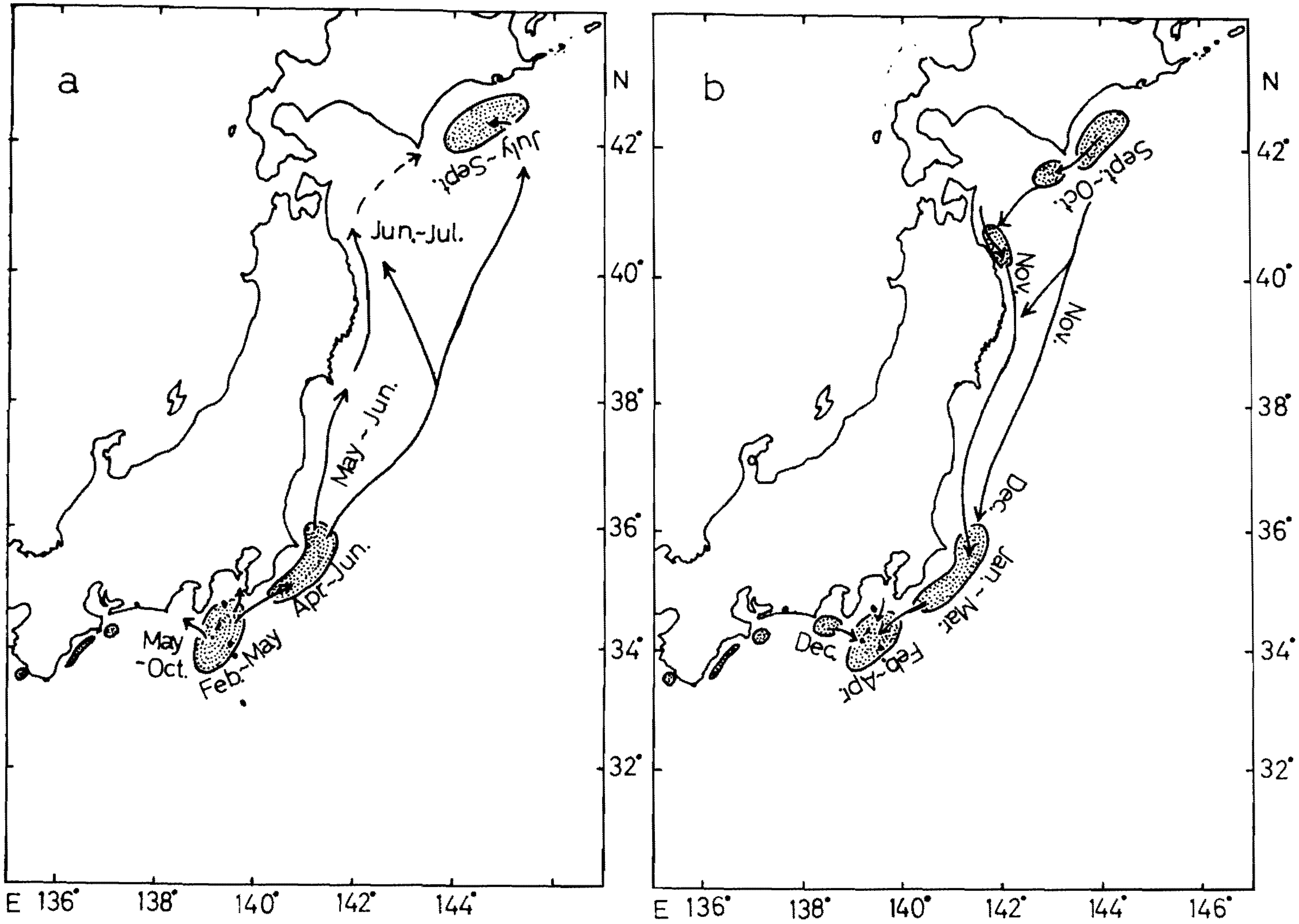

FIGURE 5. Distribution and migration of adult chub mackerel off the Pacific coast of Japan (from Watanabe, 1970).

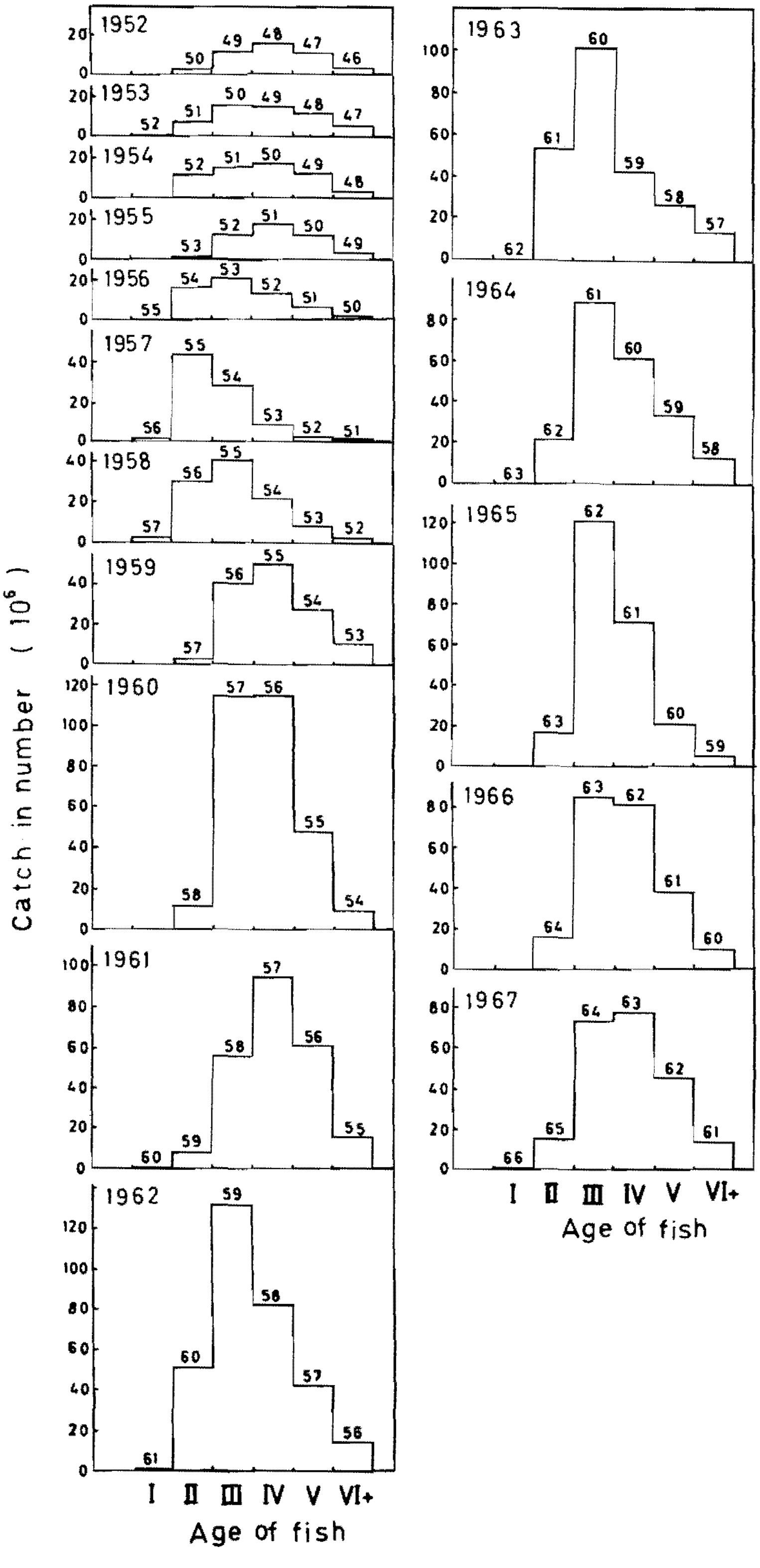

FIGURE 6. Age composition of the catches of chub mackerel taken by the pole-and-line fishery during the wintering and spawning periods (January-June) from Ibaraki to Shizuoka prefectures during 1952-1967 (from Watanabe, 1970).

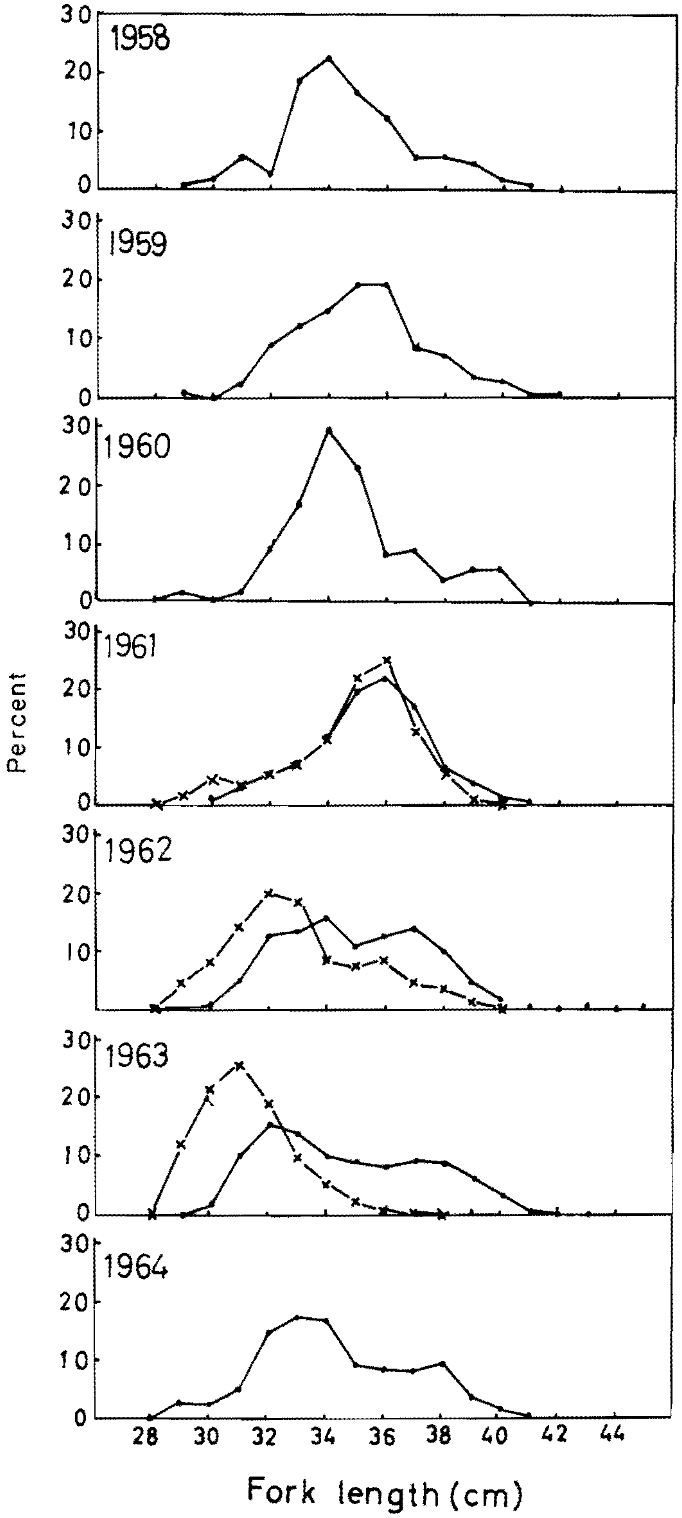

FIGURE 7. Length frequencies of chub mackerel caught in Japan during 1958-1964 (from Watanabe, 1970).

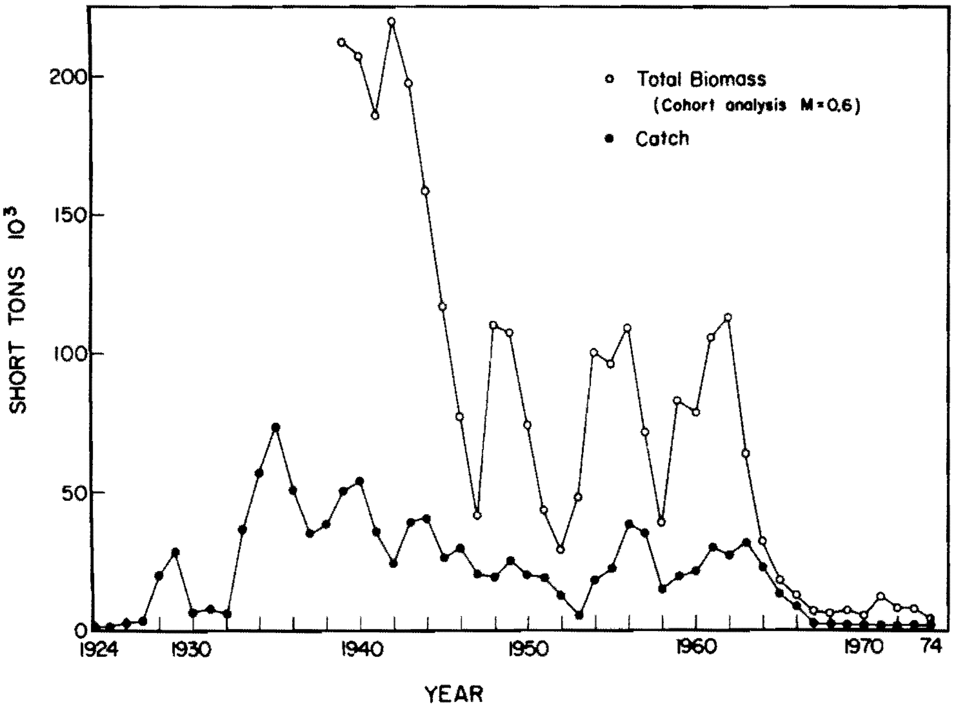

FIGURE 8. Annual catches and biomass estimates for chub mackerel in the northeastern Pacific (from MacCall et al., 1976).

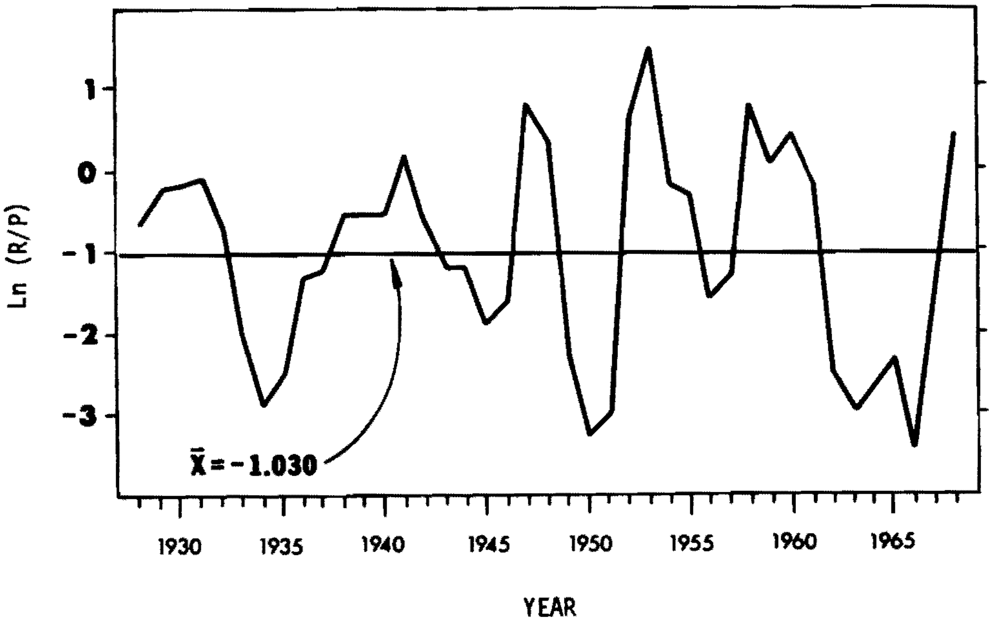

FIGURE 9. Time series of the natural log of the observed recruit biomass per spawning biomass for chub mackerel in the northeastern Pacific (from Parrish and MacCall, 1978).

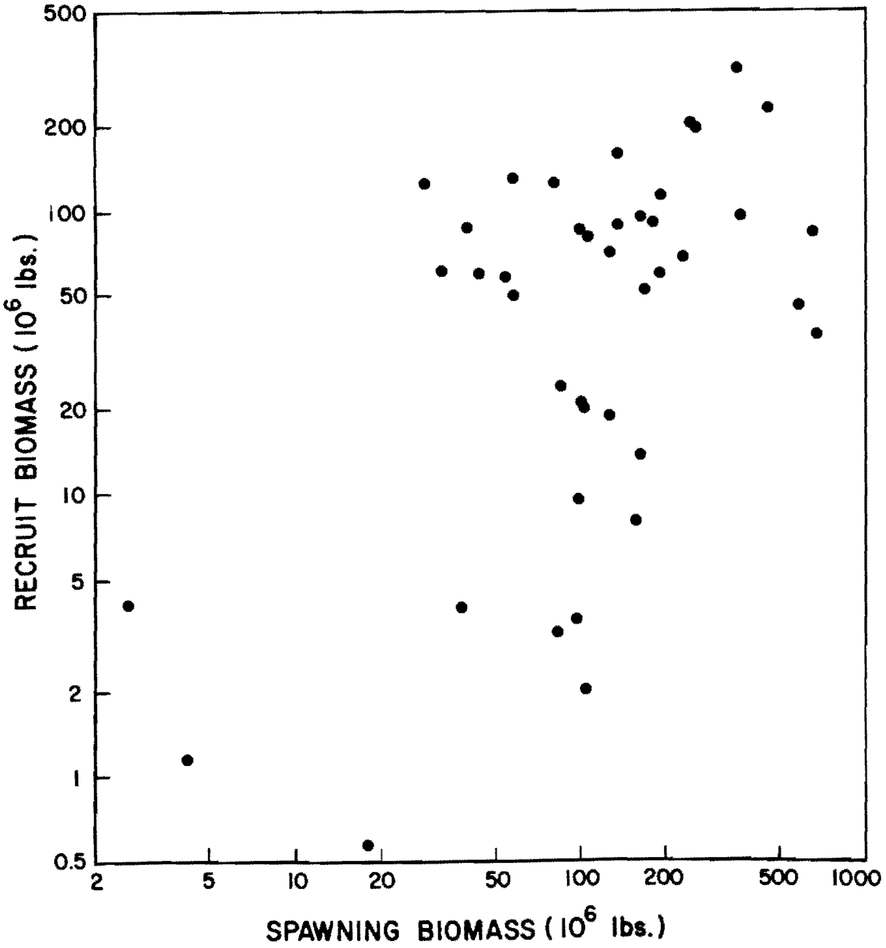

FIGURE 10. Spawner-recruit relationship for chub mackerel in the northeastern Pacific (from Parrish and MacCall, 1978).

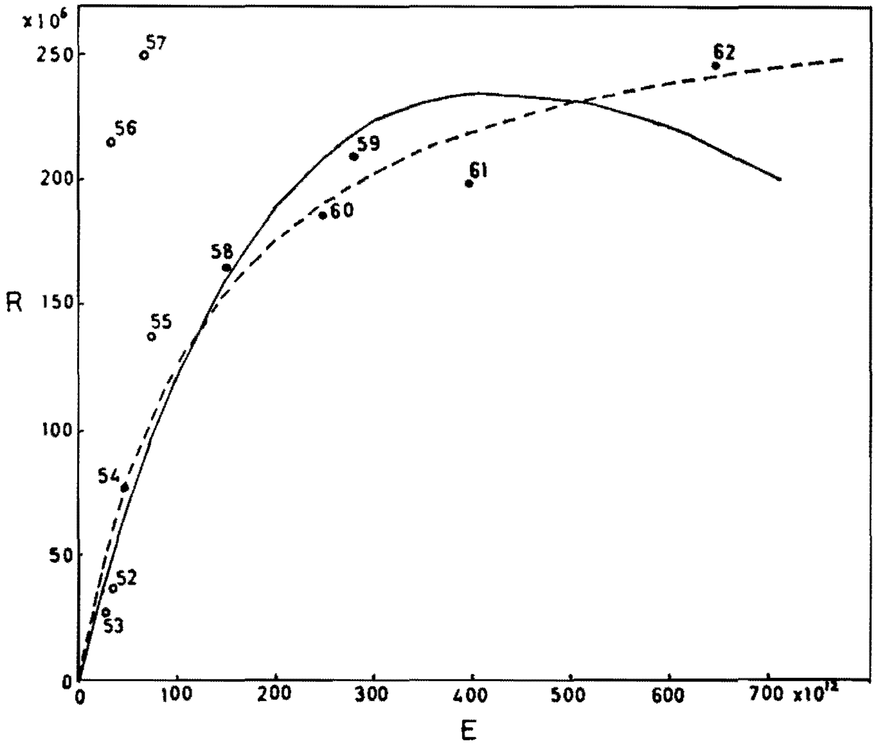

FIGURE 11. Relationship between egg abundance of chub mackerel in the northwestern Pacific in any year (E) and cumulative number of fish of the same brood at ages 3 to 5 in the pole-and-line catch in wintering and spawning periods (January-June) (R) (from Watanabe, 1970).

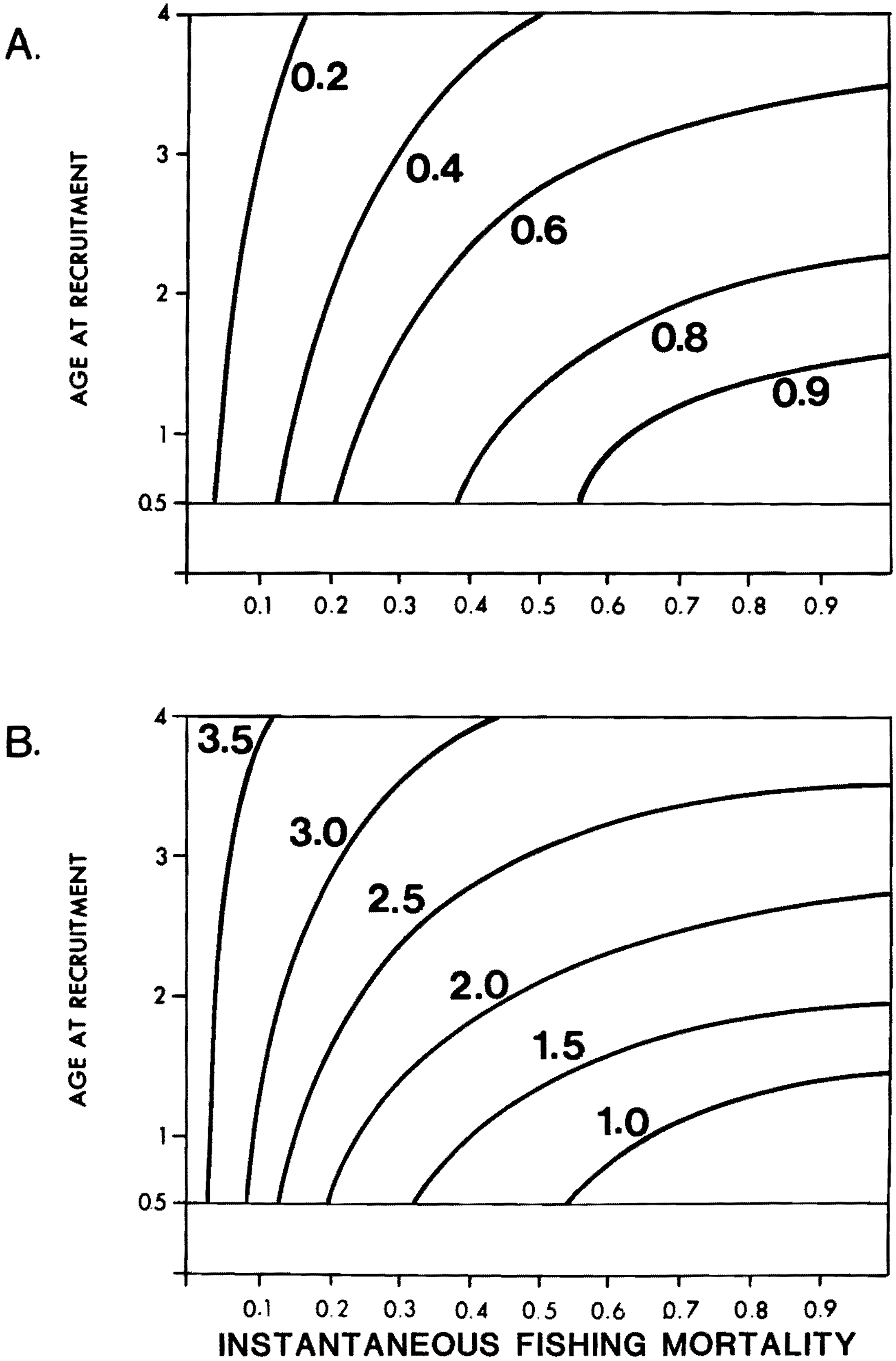

FIGURE 12. Yield per recruit model for chub mackerel in the northwestern Pacific with M = 0.5: A, yield per unit weight of age-1 recruits; B, resultant spawning biomass per unit weight of age-1 recruits (from Parrish and MacCall, 1978).

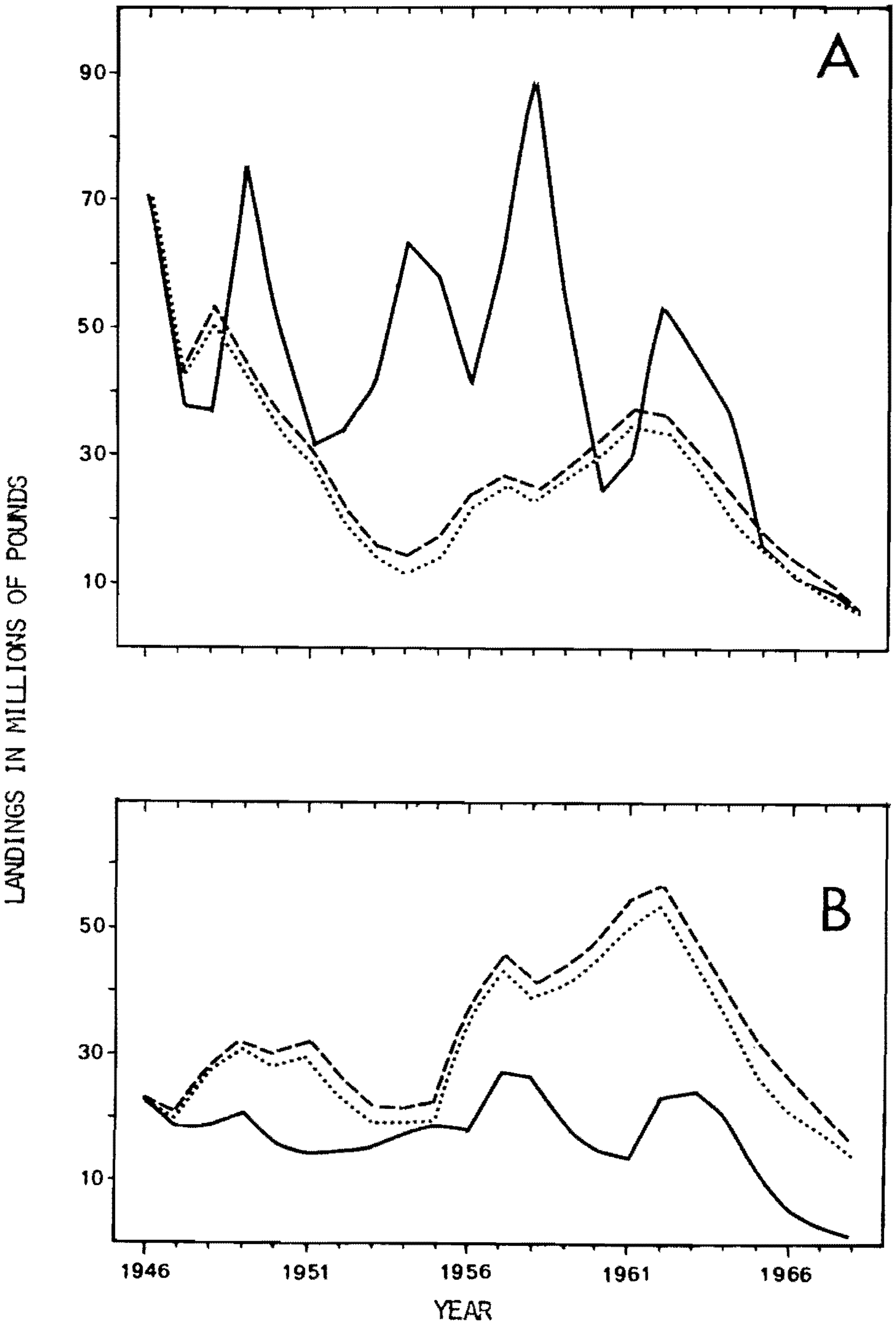

FIGURE 13. QUOTAE simulations for chub mackerel in the northeastern Pacific: A, recruitment at age 1, no minimum quota level, and a quota proportion of 0.7; B, present California regulations, recruitment at age 1, and an upper quota proportion of 0.3 (from Parrish and MacCall, 1978). The dotted line represents the Ricker sea level function, the dashed line the Ricker reduced sea level function, and the solid line the Ricker transport function.

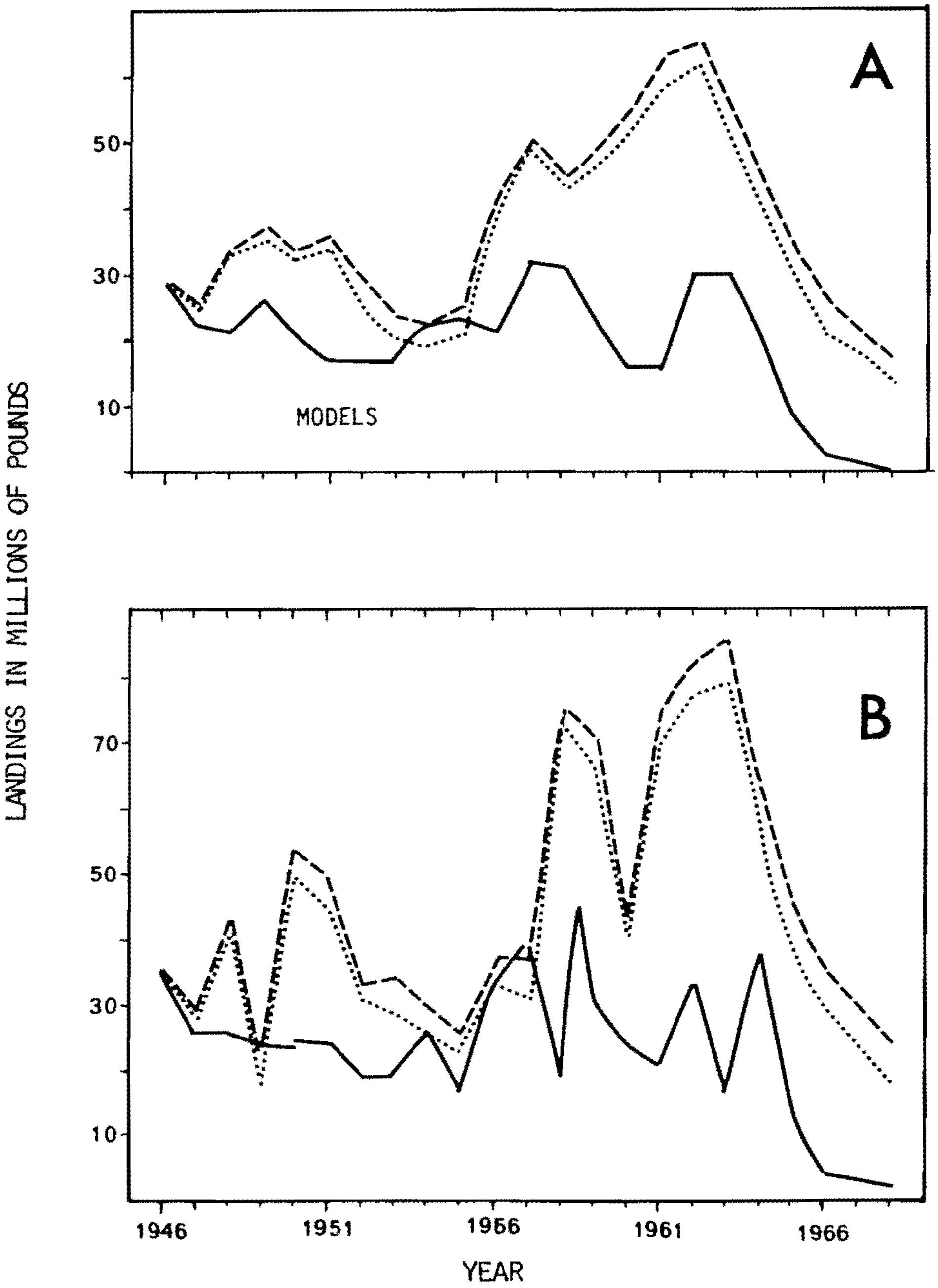

FIGURE 14. QUOTAE simulations for chub mackerel in the northeastern Pacific: A, recruitment at age 2 and an upper quota proportion of 0.4; B, recruitment at age 4 and an upper quota proportion of 0.5 (from Parrish and MacCall, 1978). The dotted line represents the Ricker sea level function, the dashed line the Ricker reduced sea level function, and the solid line the Ricker transport function.

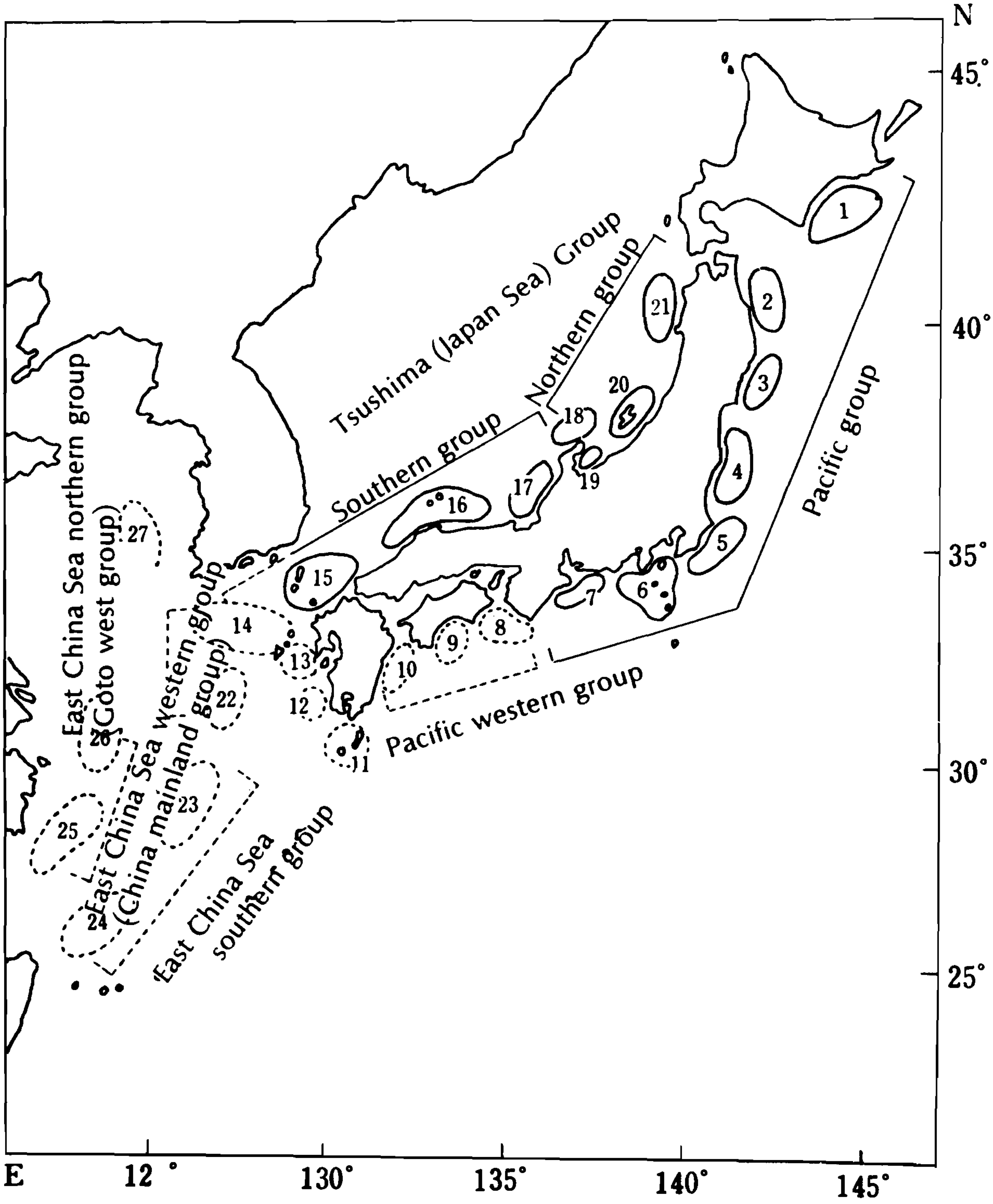

FIGURE 15. Principal fishing grounds for chub mackerel around Japan (from Usami, 1976).

TABLE 1. Condition factors of ocean- and laboratory-reared specimens of chub mackerel (from Kramer, 1969).

Ocean specimens[1]				Laboratory reared specimens[2]			
Number of fish	Body length range (mm)	Condition factor		Number of fish	Body length range (mm)	Condition factor	
		Mean	Range			Mean	Range
7	85-100	82.5	81.6-83.5	-	-	-	-
10	101-125	89.0	84.7-92.5	-	-	-	-
10	126-150	96.1	92.8-99.5	1	149	108.9	108.9
10	151-175	100.3	98.9-101.1	10	164-175	113.2	94.9-153.8
10	176-200	100.0	98.6-101.4	50	177-200	125.3	112.9-148.8
10	201-225	103.6	101.6-105.1	60	201-222	127.8	110.6-148.8
10	226-250	104.3	103.7-105.2	8	226-245	133.5	123.3-144.9
10	251-275	107.3	104.3-111.6	-	-	-	-
10	276-300	115.5	112.9-117.9	-	-	-	-
10	301-325	120.8	118.4-123.1	-	-	-	-
10	326-350	124.3	123.5-125.0	-	-	-	-
10	351-375	122.9	121.9-124.3	-	-	-	-
10	376-400	126.0	123.9-127.5	-	-	-	-
10	401-425	125.0	122.2-126.4	-	-	-	-

[1] From Fitch (1951).

[2] Reared at BCF Fishery-Oceanography Center, La Jolla, Calif. Hatched June 20, 1966, died December 28, 1966.

TABLE 2. Expected weights (in grams) of chub mackerel for given lengths at intervals of 10 mm (from Knaggs and Parrish, 1973).

Fork length	Expected weight	Fork length	Expected weight	Fork length	Expected weight	Fork length	Expected weight
130	20	220	122	310	389	400	924
140	26	230	141	320	433	410	1,005
150	33	240	163	330	481	420	1,090
160	41	250	188	340	532	430	1,181
170	51	260	214	350	587	440	1,277
180	62	270	243	360	646	450	1,378
190	74	280	275	370	709	460	1,485
200	88	290	310	380	776	470	1,597
210	104	300	348	390	848	480	1,716

TABLE 3. Length[1] and weight[2] by age of chub mackerel (from Parrish and MacCall, 1978)

Age		t	At beginning of season (birthday)		At capture	
			Length	Weight	Length	Weight
1	May	0.5	252 mm	192 g		
	Oct.	1.0			273 mm	253 g
2	May	1.5	292	317		
	Oct.	2.0			308	382
3	May	2.5	323	448		
	Oct.	3.0			336	512
4	May	3.5	348	574		
	Oct.	4.0			358	633
5	May	4.5	367	689		
	Oct.	5.0			375	741
6	May	5.5	382	789		
	Oct.	6.0			388	834

1. $L_t = 436.12\ (1-e^{-0.24444\ (t\ +\ 3.0222)})$

2. $W = 0.000001366\ L^{3.39358}$

TABLE 4. Catches by age and season of chub mackerel, in thousands of fish, landed in California (from Parrish and MacCall, 1978).

Season	0	1	2	3	4	5	6+	Total
1929-30*	26	11,469	20,724	19,204	4,804	3,574	4,592	64,396
1930-31*		1,224	6,296	4,252	1,684	589	60	14,105
1931-32*		848	8,851	5,484	1,158	667	512	17,520
1932-33*		130	2,899	5,259	1,254	846	685	11,073
1933-34		3,746	15,419	25,854	18,943	6,711	3,446	73,669
1934-35		3,369	36,726	24,504	28,090	10,675	6,074	109,438
1935-36*		7,621	8,929	43,255	44,738	23,577	6,771	134,891
1936-37*		1,705	15,477	13,198	25,079	26,669	6,201	88,329
1937-38*	137	1,273	2,236	6,931	13,724	22,461	10,560	57,322
1938-39*	2,058	11,036	30,473	15,755	4,108	10,375	9,805	83,610
1939-40	3,204	27,274	28,724	38,021	11,440	5,779	6,602	121,044
1940-41	2,408	21,646	72,164	26,297	14,107	1,502	1,722	115,792
1941-42	432	13,584	28,732	27,870	5,562	1,054	596	77,830
1942-43		32,193	10,087	13,916	5,776	901	285	63,158
1943-44	928	13,840	60,090	11,279	7,922	1,202	438	95,699
1944-45		17,640	20,295	36,126	8,217	1,722	473	84,473
1945-46	593	15,247	11,010	10,937	10,994	3,548	1,565	53,894
1946-47	626	10,429	28,865	13,271	5,210	2,564	2,802	63,767
1947-48	8,759	1,680	9,734	13,348	6,205	2,463	1,892	44,081
1948-49	1,180	70,410	3,530	841	1,229	477	325	77,992
1949-50	153	24,558	55,441	4,816	774	657	346	86,745
1950-51	7	4,659	23,247	19,134	1,133	87	169	48,436
1951-52	858	1,766	4,941	15,479	12,417	243	172	35,876
1952-53	104	56	630	1,555	11,471	3,333	40	17,189
1953-54	18,559	1,025	720	884	244	557	593	22,582
1954-55	852	60,482	5,881	314	107	0	59	67,695
1955-56	7,728	6,497	38,586	10,980	372	27	232	64,422
1956-57	30	70,145	21,252	20,777	5,167	88	0	117,459
1957-58	1,505	6,764	33,112	12,308	8,863	2,500	1,100	66,152
1958-59	17,304	1,342	6,217	11,419	3,671	1,182	306	41,441
1959-60	1,595	58,544	4,341	1,082	1,323	432	143	67,460
1960-61	2,928	20,726	23,316	9,004	2,354	487	302	59,117
1961-62	23,490	33,441	17,054	12,158	2,556	268	90	89,057
1962-63	60	30,235	13,936	10,056	3,867	398	41	58,593
1963-64	67	3,840	22,285	12,945	7,899	1,071	137	48,244
1964-65	140	7,006	5,410	10,210	13,527	1,740	152	38,195
1965-66	12,976	1,255	761	1,688	5,483	8,612	1,551	32,326
1966-67	2,627	7,453	1,438	1,106	935	2,512	1,569	17,640
1967-68	7,656	363	254	270	158	85	134	17,640
1968-69	7,069	548	204	356	86	81	122	8,920
1969-70	14	2,641	470	74	84	81	14	3,378

* Age composition estimated from length frequency. These data are unreliable.

TABLE 5. Information on the chub mackerel fishery in the vicinity of Japan (from Usami, 1976).

Fishing grounds	Fishing season	Methods of capture	Size of fish
Eastern Hokkaido (off Kushiro-Cape Erimo	June-October	Purse seine (drift net)	I- and II-year fish (medium-small)
Northern Sanriku (near Hachinohe)	June-December	-ditto-	0-, I-, and II-year fish (small-medium)
Off southern Sanriku	May-December	Purse seine, set net, pole and line	-ditto-
Off Joban	Year round (especially October-May)	Purse seine, set net	-ditto-
Off Kanto (May-June)	Year round (January-June)	"Skip" fishing, scoop net, purse seine, set net	Mainly III-year fish or over (large-medium)
(Off Boso Peninsula)	-ditto-	("Skip" fishing, purse seine, set net)	-ditto-
Near Izu Islands	-ditto	("Skip" fishing, scoop net)	-ditto-
Off Tokai district (Enshu Nada - Kumano Nada	Year round, after summer	Purse seine, pole and line	Small - medium
Off southern Kii and Kii Channel	Year round, especially in summer	Purse seine, lift net	0- and I-year fish (small)
Near Tosa Bay	-ditto-	Pole and line, long line, set net	-ditto-
Bungo Strait, Hyuga Nada	-ditto-	Purse seine, lift net	-ditto-
Satsunan	-ditto-	Purse seine, pole and line, long line	-ditto-
Sogo Retto	Year round, especially April-September	Purse seine, pole and line	small
Goto Nada-Amakusa Nada	Year round, especially January-March and August-November	Purse seine	-ditto-

TABLE 5. (continued)

Fishing grounds	Fishing season	Methods of capture	Size of fish
Off western Goto Is. -Cheju Island	Year round, especially October- February	Purse seine, lift net	-ditto-
Mi Island - Eastern Tsushima	Year round (spring, autumn)	Purse seine	I- and II-year fish (small-medium)
Sanin	-ditto-	Purse seine, set net	Small fish
Wakasa Bay	Year round (April-June)	-ditto-	I- and II-year fish (small-medium)
Near Noto Peninsula	-ditto-	-ditto-	-ditto-
Toyama Bay	-ditto-	Lift net, set net	I-year fish (small)
Uetsu	June-December (especially in summer)	Purse seine, set net	-ditto-
Near Tsugaru	-ditto-	Purse seine	-ditto-
Central part of East China Sea (Kakinose)	September-December	Purse seine	Small-medium fish (lean)
-ditto- (Kuchiminose)	-ditto-	-ditto-	-ditto-
Southern part of East China Sea (North-east, off Taiwan - Uotsuri Is.)	April-October	-ditto-	-ditto- (slightly chubby)
Off China mainland	June-December	-ditto-	-ditto- (chubby)
Off China mainland (off Chekiang)	September-December	-ditto-	-ditto-
Yellow Sea	Summer-autumn	-ditto-	Medium-small (over 25 cm)

TABLE 6. Estimates of the biomass of chub mackerel in the northeastern Pacific Ocean at the beginning of each season, in thousands of pounds (from Parrish and MacCall, 1978).

Year	Age 1	Age 2	Age 3	Age 4	Age 5+	Total biomass	Spawning biomass	Age 1 recruit biomass of resulting year class
1928	97,124	144,695	32,843	30,966	0	305,628	177,143	92,640
1929	92,640	104,583	109,226	22,301	45,179	373,929	247,553	199,914
1930	199,914	98,300	72,156	68,522	31,474	465,866	239,542	205,552
1931	205,552	214,703	72,230	53,521	64,945	610,951	348,739	321,127
1932	321,127	220,947	168,747	52,596	76,532	839,949	448,175	230,089
1933	230,089	345,729	177,479	128,910	82,379	964,586	633,805	84,509
1934	84,509	246,033	271,010	119,406	115,253	836,211	622,707	36,925
1935	36,924	89,447	177,079	194,218	157,021	654,689	576,125	46,621
1936	46,621	36,259	67,083	105,396	164,638	419,997	358,225	96,014
1937	96,014	49,416	20,022	42,430	121,672	329,554	224,652	69,185
1938	69,185	102,801	38,717	10,332	60,667	281,702	189,182	115,438
1939	115,438	69,453	64,410	18,254	23,563	291,118	159,706	96,374
1940	96,374	106,873	37,281	20,322	6,470	267,320	149,545	90,387
1941	90,387	80,230	50,977	12,488	4,506	238,588	132,451	159,222
1942	159,222	76,545	44,077	14,454	3,670	297,968	126,001	71,999
1943	71,999	136,733	53,936	25,514	5,341	290,523	185,444	60,555
1944	60,555	56,351	84,430	31,904	9,837	243,077	165,151	52,797
1945	52,797	49,285	32,546	32,607	17,573	184,808	124,346	18,933
1946	18,933	51,286	30,137	14,301	16,783	131,440	101,078	20,308
1947	20,308	13,535	22,294	11,340	8,941	76,418	56,661	130,928
1948	130,928	12,780	3,250	3,946	3,111	154,015	43,188	60,814
1949	60,814	92,240	8,205	1,572	2,410	165,241	92,269	9,648
1950	9,648	61,030	49,571	2,509	773	123,531	96,046	3,636
1951	3,636	6,788	38,252	23,587	1,011	73,274	64,647	3,255
1952	3,255	3,305	2,596	19,180	6,451	34,787	31,830	62,037
1953	62,037	2,926	2,244	513	3,207	70,927	28,092	125,313
1954	125,313	46,631	1,533	756	543	174,776	57,878	50,070
1955	50,070	84,374	34,066	766	1,044	170,320	104,728	81,795
1956	81,795	43,779	42,693	16,696	366	185,329	100,035	21,196
1957	21,196	47,760	23,617	15,188	6,815	114,576	84,594	24,184
1958	24,184	11,879	14,738	5,962	2,778	59,541	39,377	88,151
1959	88,151	29,150	7,930	3,830	2,047	131,108	53,892	58,799
1960	58,799	58,641	19,054	4,481	1,800	142,775	79,608	126,860
1961	126,860	67,164	29,087	5,352	892	229,355	96,783	86,791
1962	86,791	130,399	45,235	10,976	1,453	274,854	159,173	13,744
1963	13,744	61,556	90,361	22,556	4,112	192,339	155,462	8,160
1964	8,160	13,588	30,741	55,323	9,503	117,315	104,241	2,044
1965	2,044	3,218	4,129	11,932	19,188	40,511	38,057	4,021
1966	4,021	2,177	2,375	1,719	10,275	20,567	17,634	575
1967	575	1,122	675	626	1,727	4,725	4,111	1,141
1968	1,141	339	743	232	820	3,275	2,569	4,075
1969	4,075	194	140	210	280			

TABLE 7. Landings of chub mackerel in metric tons.

Year	Northeastern Pacific			Southeastern Pacific		Northwestern Pacific		
	California		Mexico	Peru	Chile	Japan	Rep. of Korea	USSR
	Commercial	Sport						
1926	1,634	22.7						
1927	2,934	22.7						
1928	17,911	22.7						
1929	25,770	22.7						
1930	5,821	45.5						
1931	6,887	45.5						
1932	4,932	45.5						
1933	33,125	45.5						
1934	51,575	91						
1935	66,540	91						
1936	45,793	91						
1937	32,021	91						
1938	34,575	91						
1939	45,937	91						
1940	48,889	91						
1941	32,616	45.5						
1942	21,918	45.5						
1943	35,365	45.5						
1944	36,721	45.5						
1945	23,638	45.5						
1946	26,771	45.5	853					
1947	18,013	135	1,265					
1948	17,365	185	516					
1949								

TABLE 7. (continued)

Year	Northeastern Pacific			Southeastern Pacific		Northwestern Pacific		
	California		Mexico	Peru	Chile	Japan	Rep. of Korea	USSR
	Commercial	Sport						
1949	22,755	86	1,355					
1950	15,405	61	2,033					
1951	14,502	43	1,323					
1952	9,190	70	1,055					
1953	4,013	55	1,180					
1954	12,368	286	5,692					
1955	12,226	137	9,819					
1956	25,993	110	10,747					
1957	25,563	138	2,039					
1958	11,262	125	450					
1959	18,765	81	496					
1960	17,761	72	2,988					
1961	20,137	104	5,977					
1962	20,570	106	3,238					
1963	15,550	134	7,982					
1964	11,307	92	8,636					
1965	3,450	138	7,631	3,800		668,600	7,300	
1966	1,852	186	5,301	7,600		624,400	2,000	
1967	628	98	950	13,400		687,500	2,800	6,100
1968	1,495	72	107	7,200		1,015,300	10,500	15,000
1969	810	109	201	7,200		1,011,400	42,100	15,300
1970								

TABLE 7. (continued)

Year	Northeastern Pacific			Southeastern Pacific		Northwestern Pacific		
	California		Mexico	Peru	Chile	Japan	Rep. of Korea	USSR
	Commercial	Sport						
1970	342	118	400	8,800		1,301,900	38,300	30,000
1971	86	204	500	10,100		1,252,600	60,600	62,000
1972	49	225	200	8,700		1,188,200	79,000	125,600
1973	26	171	100	65,000		1,133,700	74,200	195,400
1974	74	93	471	63,270		1,330,080	80,649	243,700
1975	158	118	1,809	23,588	15,235	1,317,492	70,123	168,490
1976	161	47	1,863	40,172	52,712	977,755	107,382	211,889
1977	3,323	441	3,688	46,071	141,263	1,353,388	113,051	149,325
1978	12,364	855	13,875	97,165	175,249	1,623,103	99,519	226,103

TABLE 8. Abundance index, effort index, and total mortality rate estimates for chub mackerel in the northeastern Pacific (from Parrish and MacCall, 1978).

Season	Night-light abundance index (% occurrence)	Total catch (1000 lb)	Effort index (f)	Total mortality rate (M = 0.5)
1950-51	17.3	38,497	2,225	1.363
1951-52	8.8	34,910	3,967	1.604
1952-53	2.6	22,692	8,728	2.397
1953-54	0	11,546	-	1.839
1954-55	23.4	40,364	1,725	0.729
1955-56	12.3	48,800	3,967	1.528
1956-57	15.2	81,070	5,334	1.046
1957-58	6.7	61,027	9,109	2.056
1958-59	3.9	26,040	6,677	1.854
1959-60	18.9	42,552	2,252	1.276
1960-61	11.7	45,805	3,915	2.019
1961-62	7.2	57,678	8,011	1.636

TABLE 9. Fishing mortality rates in the northeastern Pacific by season (from Parrish and MacCall, 1978).

Season	Age				4+ (fully recruited)	Exploitation rate age 4+	Proportion catch by scoop	F, purse seine and other	F, scoop
	0	1	2	3					
1928-29	-	0	(0.10)	(0.15)	(0.20)	(0.144)	-	(0.2)	-
1929-30	-	.055	.162	.201	.330	.224	-	.330	-
1930-31	0	.003	.052	.062	.033	.026	-	.033	-
1931-32	0	.002	.032	.080	.029	.022	-	.029	-
1932-33	0	.0002	.010	.032	.032	.025	-	.032	-
1933-34	0	.007	.034	.159	.214	.153	.06	.201	.013
1934-35	0	.017	.120	.096	.366	.245	.10	.331	.035
1935-36	0	.092	.079	.282	.357	.240	.04	.344	.013
1936-37	0	.016	.385	.221	.371	.248	.06	.349	.022
1937-38	.001	.006	.035	.425	.542	.337	.13	.472	.070
1938-39	.005	.071	.252	.519	.715	.414	.20	.574	.141
1939-40	.110	.110	.371	.858	1.553	.655	.59	.622	.911
1940-41	.009	.132	.686	1.075	1.648	.678	.57	.711	.937
1941-42	.001	.091	.364	.969	1.115	.553	.63	.412	.703
1942-43	0	.105	.125	.431	.825	.457	.78	.181	.644
1943-44	.005	.125	.411	.278	.694	.405	.61	.268	.426
1944-45	0	.084	.382	.689	.482	.307	.77	.113	.369
1945-46	.011	.152	.233	.530	.689	.403	.70	.205	.484
1946-47	.013	.379	.698	.717	.783	.441	.52	.379	.404
1947-48	.018	.061	1.166	1.387	1.532	.655	.45	.835	.697
1948-49	.004	.275	.241	.392	.634	.379	.75	.160	.474
1949-50	.005	.166	.522	.911	1.223	.583	.57	.520	.703
1950-51	.001	.298	.328	.495	.963	.471	.43	.488	.375
1951-52	.108	.268	.897	.549	1.164	.550	.16	.978	.186
1952-53	.001	.012	.200	1.348	1.897	.719	.03	.832	.065
1953-54	.049	.011	.301	.696	1.339	.612	.24	1.013	.326
1954-55	.005	.310	.110	.292	.229	.163	.49	.117	.112
1955-56	.029	.071	.479	.435	1.028	.526	.24	.780	.248

TABLE 9. (continued)

Season	Age				4+ (fully recruited)	Exploitation rate age 4+	Proportion catch by scoop	F, purse seine and other	F, scoop
	0	1	2	3					
1956-57	.001	.553	.498	.768	.546	.338	.11	.487	.059
1957-58	.019	.232	.840	.929	1.556	.660	.25	.161	.395
1958-59	.064	.028	.496	1.326	1.354	.616	.44	.764	.590
1959-60	.007	.449	.165	.206	.776	.438	.54	.361	.415
1960-61	.007	.158	.465	.902	1.519	.652	.04	1.461	.058
1961-62	.105	.146	.264	.702	1.136	.559	.05	.080	.056
1962-63	.002	.265	.114	.346	.760	.432	.01	.754	.006
1963-64	.003	.194	.456	.204	.748	.428	.02	.731	.017
1964-65	.017	.761	.667	.570	.487	.310	.01	.480	.007
1965-66	.620	.290	.234	.670	1.096	.547	.02	1.074	.022
1966-67	.937	1.539	.966	.952	1.800	.704	-	1.800	-
1967-68	1.180	.447	.244	.711	.481	.306	-	.481	-
1968-69	.494	.322	.727	.966	.781	.440	-	.781	-
1969-70	(.250)	(.500)	(.750)	(1.000)	(1.000)	(.518)	-	(1.000)	-

TABLE 10. Environmental-dependent spawner-recruit functions for chub mackerel in the northeastern Pacific Ocean (from Parrish and MacCall, 1978).

Function name	Period covered	R^2	F	DF
Ricker sea level $R = 51608P\,e^{-0.00000353P}\,e^{-2.5004\ \mathrm{SLEV}}$ $e^{-0.25594\ \mathrm{BARP}}\,e^{-0.53309\ \mathrm{SSTC}}$	1931-1968	0.587	11.72**	4,33
Cushing sea level $R = 100850000P^{0.095703}\,e^{-2.7680\ \mathrm{SLEV}}$ $e^{-0.09858\ \mathrm{BARP}}\,e^{0.65528\ \mathrm{SSTC}}$	1931-1968	0.597	12.22**	4,33
Reduced Ricker sea level $R = 4214.2P\,e^{-0.00000351\ P}\,e^{-2.1837\ \mathrm{SLEV}}$ $e^{-0.19759\ \mathrm{BARP}}\,e^{0.51148\ \mathrm{SSTC}}$	1931-1960	0.517	6.68**	4,25
Ricker transport $R = 0.97815P\,e^{-0.0000377\ P}\,e^{0.020787\ \mathrm{UP}}$ $e^{0.0039065\ \mathrm{ODI}}$	1946-1968	0.756	19.59**	3,19
Cushing transport $R = 43577000P^{-0.84881}\,e^{0.02350\ \mathrm{UP}}$ $e^{0.00469\ \mathrm{ODI}}$	1946-1968	0.676	13.31**	3,19

R —Recruit biomass at age 1 in thousands of pounds

P —Parent spawning biomass in thousands of pounds

SLEV —Mean May-July sea level at La Jolla, California in feet (corrected for atmospheric pressure)

BARP —Sea level barometric pressure at San Diego. May, June and July mean pressure prorated by the age composition of the spawning biomass (in millibars minus 1000 millibars)

SSTC —Mean April-June sea surface temperature in Marsden square quadrant 120(2), (in degrees celsius)

UP —Bakun's upwelling index at 30° N. April, May and June indices prorated by the spawning biomass (in M^3 per second across 100m width)

ODI —Bakun's (pers. comm.) offshoire divergence index at 30° N (Divergence of Ekman transport). April, May and June indices prorated by the spawning biomass (in mm per day positive upwards)

** —Significant at the 1% level

BIBLIOGRAPHY

Inter-American Tropical Tuna Commission
La Jolla, California
1980

BIBLIOGRAPHY

The numbers following the references refer to the species included in them. The code numbers are as follows: 1, Thunnus alalunga; 2, T. albacares; 3, T. maccoyii; 4, T. obesus; 5, T. thynnus; 6, Katsuwonus pelamis; 7, Euthynnus lineatus; 8, Scomber japonicus.

Anonymous. 1950. Giant skipjack found in mid-Pacific. Pacif. Fisherman, 48(4): 39.
6

Anonymous. 1954. Average year's fishing condition of tuna longline fisheries, 1952 edition (introduction and albacore section). Nippon Katsuo-Maguro Gyogyokumiai Rengokai (translation by Van Campen, W.G., 1956, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 169: 131pp).
1

Anonymous. 1957. Albacore tuna distribution boundaries found in Pacific. Comm. Fish. Rev., 19(3): 27.
1

Anonymous. 1958. Pacific Oceanic Fishery Investigations, annual report for fiscal year 1958. Comm. Fish. Rev., 20(9): 56-61.
126

Anonymous. 1959. Peru pioneered in all-nylon tuna seines. Pacif. Fisherman, 57(9): 22.

Anonymous. 1960. Studies show separate stocks of albacore tuna north and south of the equator in the central Pacific Ocean. Comm. Fish. Rev., 22(1): 31-32.
1

Anonymous. 1963. Skipjack ecology. In Van Campen, Wilvan G. (editor), Progress in 1961-62, U.S. Fish Wild. Serv., Circ., 163: 13-17.
6

Anonymous. 1965a. Illustration of Japanese Fishing Boat and Fishing Gear. Norinkyokai Japan Association for Agriculture and Forestry, Tokyo: 185pp.

Anonymous. 1965b. Submarine for underwater research brings new discoveries. Comm. Fish. Rev., 27(12): 29-30.
6

Anonymous. 1966. Showa 40 nen-do Chosasen Shoyo Maru Hokokusho (Cruise report of the R.V. Shoyo Maru for the 1965 fiscal year). Fish. Agency Japan: 272pp.

Anonymous. 1968a. Showa 42 nen-do Chosasen Shoyo Maru Hokokusho (Cruise report of the R.V. Shoyo Maru for the 1967 fiscal year). Fish. Agency Japan: 46pp.

Anonymous. 1968b. Southern bluefin tuna. Austral. Fish. Newsletter, 27(9): 42-43, 45.
3

Anonymous. 1969a. Showa 43 nen-do Chosasen Shoyo Maru Hokokusho (Cruise report of the R.V. Shoyo Maru for the 1968 fiscal year). Fish. Agency Japan. 43pp.

Anonymous. 1969b. Report of the IOFC working party on stock assessment in relation to immediate problems of management in the Indian Ocean. FAO, Fish. Rep., 82: 25pp.
1234

Anonymous. 1970. Inter-American Tropical Tuna Commission, Annual Report, 1969: 117pp.
246

Anonymous. 1971. Todo lo que se sabe sobre ocho especies alimenticias importantes. Pesca, 22(1): 10-16.
8

Anonymous. 1971-1979. Yearbook of fishery statistics. Catches and landings. FAO, Vols. 30-46.

Anonymous. 1972a. Inter-American Tropical Tuna Commission, Annual Report, 1971: 129pp.
26

Anonymous. 1972b. Biological proposition for better management of southern bluefin tuna longline fishery. Far Seas Fish. Res. Lab., S series, 6: 1-61.
3

Anonymous. 1973. Inter-American Tropical Tuna Commission, Annual Report, 1972: 166pp.
26

Anonymous. 1974a. Annual report of catch and effort statistics by area on Japanese longline fishery 1972. Fish. Agency Japan, Res. Develop. Dept.: 279pp.

Anonymous. 1974b. Inter-American Tropical Tuna Commission, Annual Report, 1973: 150pp.
256

Anonymous. 1974c. Progress report on tuna tagging during the 1973 fiscal year. Far Seas Fish. Res. Lab.: 25pp.
1356

Anonymous. 1974d. Report of the second session of the IPFC/IOFC ad hoc working party of scientists on stock assessment of tuna. FAO, Fish. Rep., 152: 19pp.
12346

Anonymous. 1974e. Annual catch statistics of Taiwan's tuna longline fishery--1972. Taiwan Xiang Yu Ye Ju (Taiwan Fish. Bur.) and Taiwan Da Xue Hai Yang Yan Jiu Suo (Nat. Taiwan Univ., Inst. Ocean.): 156pp.

Anonymous. 1974-1976. Fisheries yearbook Taiwan area. Prov. Govt. Taiwan, Dept. Agri. Fores., Taiwan Fish. Bur.

Anonymous. 1975a. Annual report of catch and effort statistics by area on Japanese longline fishery 1973. Fish. Agency Japan, Res. Develop. Dept.: 265pp.

Anonymous. 1975b. Inter-American Tropical Tuna Commission, Annual Report, 1974: 169pp.
267

Anonymous. 1975c. Report of the special southern bluefin tuna working party. FAO, Fish. Rep., 174: 29-43.
3

Anonymous. 1975d. Progress report on tuna tagging during the 1974 fiscal year. Far Seas Fish. Res. Lab.: 19pp.
1356

Anonymous. 1975e. Limit placed on bluefin tuna purse seiners. Austral. Fish., 34(6): 4.
3

Anonymous. 1975f. Annual catch statistics of Taiwan's tuna longline fishery--1973. Taiwan Xiang Yu Ye Ju (Taiwan Fish. Bur.) and Taiwan Da Xue Hai Yang Yan Jiu Suo (Nat. Taiwan Univ., Inst. Ocean.): 120pp.

Anonymous. 1975g. Annual catch statistics of Taiwan's tuna longline fishery--1974. Taiwan Xiang Yu Ye Ju (Taiwan Fish. Bur.) and Taiwan Da Xue Hai Yang Yan Jiu Suo (Nat. Taiwan Univ., Inst. Ocean.): 128pp.

Anonymous. 1976a. Annual report of catch and effort statistics by area on Japanese longline fishery 1974. Fish. Agency Japan, Res. Develop. Dept.: 267pp.

Anonymous. 1976b. Inter-American Tropical Tuna Commission, Annual Report, 1975: 176pp.
26

Anonymous. 1976c. Progress report on tuna tagging during the 1975 fiscal year. Far Seas Fish. Res. Lab.: 12pp.
136

Anonymous. 1976d. Anuario estadistico de pesca 1976. Chile, Minis. Agri., Serv. Agri. Ganad., Div. Protec. Pesq.: 70pp.
8

Anonymous. 1976e. Annual catch statistics of Taiwan's tuna longline fishery--1975. Taiwan Xiang Yu Ye Ju (Taiwan Fish. Bur.) and Taiwan Da Xue Hai Yang Yan Jiu Suo (Nat. Taiwan Univ., Inst. Ocean.): 128pp.

Anonymous. 1977a. Annual report of catch and effort statistics by area on Japanese longline fishery 1975. Fish. Agency Japan, Res. Develop. Dept.: 269pp.

Anonymous. 1977b. Inter-American Tropical Tuna Commission, Annual Report, 1976: 180pp.
26

Anonymous. 1977c. Keep it quiet for albacore. Fish Boat, 22(3): 29, 43-44.
1

Anonymous. 1977d. Progress report on tuna tagging during the 1976 fiscal year. Far Seas Fish. Res. Lab.: 23pp.
1236

Anonymous. 1977e. Annual catch statistics of Taiwan's tuna longline fishery--1976. Taiwan Xiang Yu Ye Ju (Taiwan Fish. Bur.) and Taiwan Da Xue Hai Yang Yan Jiu Suo (Nat. Taiwan Univ., Inst. Ocean.).

Anonymous. 1977f. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1972. Fish. Agency Japan, Res. Develop. Dept.: 266pp.

Anonymous. 1977g. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1973. Fish. Agency Japan, Res. Develop. Dept.: 272pp.

Anonymous. 1977h. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1974. Fish. Agency Japan, Res. Develop. Dept.: 293pp.

Anonymous. 1977i. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1975. Fish. Agency Japan, Res. Develop. Dept.: 310pp.

Anonymous. 1977j. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1976. Fish. Agency Japan, Res. Develop. Dept.: 291pp.

Anonymous. 1978a. Inter-American Tropical Tuna Commission, Annual Report, 1977: 155pp.
256

Anonymous. 1978b. Annual report of catch and effort statistics by area on Japanese longline fishery 1976. Fish. Agency Japan, Res. Develop. Dept.: 264pp.

Anonymous. 1978c. Progress report on tuna tagging during the 1977 fiscal year. Far Seas Fish. Res. Lab.: 15pp.
13456

Anonymous. 1978d. Report on 1977 research cruise of the R/V Shoyo-Maru: distribution of tunas and billfishes, and their larvae in the eastern Indian Ocean, October-December, 1977. Fish. Agency Japan, Res. Div.: 48pp.
12346

Anonymous. 1979a. Inter-American Tropical Tuna Commission, Annual Report, 1978: 163pp.
2456

Anonymous. 1979b. Fisheries research annual report 1978. Papua New Guinea, Dept. Primary Indus., Fish. Div.: 98pp.
26

Anonymous. 1979c. Japanese tuna seiner fleet expands. Fishing News Inter., 18(1): 7.

Anonymous. 1979d. Inst. Mar Peru, unpublished data.
8

Anonymous. 1979e. Chile, Inst. Fomento Pesq., unpublished data.
8

Anonymous. 1979f. Annual report of effort and catch statistics by area Japanese skipjack baitboat fishery 1977. Fish. Agency Japan, Res. Div.: 333pp.
6

Anonymous. 1979g. Environmental impact statement and fishery management plan for the jack mackerel fishery. Pacific Fish. Manag. Coun. and U.S. Nat. Mar. Fish. Serv.: 78pp (draft).
8

Anonymous. 1979h. Bluefin tuna reproduced from artificially raised fish in Japan. Asahi Shimbun, June 27, 1979 (translation in U.S. Nat. Mar. Fish. Serv., Foreign Fish. Info. Release 79-8).
5

Anonymous. 1979i. Bluefin tuna spawn in captivity--world's first record of artificial fertilization and hatching of bluefin tuna. Sogo, June 27, 1979 (translation by U.S. Nat. Mar. Fish. Serv., Honolulu Lab., No. 37).
5

Anonymous. 1979j. Annual report of catch and effort statistics by area on Japanese longline fishery 1977. Fish. Agency Japan, Res. Develop. Dept.: 235pp

Anonymous. 1979k. Report of 1978 research cruise of the R/V Shoyo-Maru: distribution of tunas and billfishes and their larvae in the eastern Indian Ocean, December 1978-January 1979. Fish. Agency Japan, Res. Div.: 97pp.
12346

Anonymous. 1979l. Tuna tag record. Austral. Fish., 38(4): 31.
3

Anonymous. 1980a. Inter-American Tropical Tuna Commission, Annual Report, 1979: 227pp.
24567

Anonymous. 1980b. Review of preliminary results from genetic analysis of skipjack blood samples collected by the skipjack survey and assessment programme. South Pacif. Comm., Skipjack Survey and Assessment Programme, Tech. Rep., 1: 23pp.
6

Anonymous. 1980c. World Record Game Fishes, 1980 Edition. International Game Fish Association, Fort Lauderdale: 287pp.
1234567

Anonymous. 1980d. Hawaii's first skipjack tuna spawn in captivity. Hawaiian Fishing News, 5(7): 27.
6

Anonymous. 1980e. First skipjack tuna spawned in captivity at government fisheries laboratory in Honolulu, Hawaii. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Tuna Newsletter, 72: 1-2.
6

Anonymous. 1980f. Otolith growth increments studied in skipjack tuna larvae. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Tuna Newsletter, 72: 2.
6

Anonymous. 1980g. Longlining ban off northern Queensland. Austral. Fish., 39(7): 8-9.
3

Anonymous. 1981. Inter-American Tropical Tuna Commission, Annual Report, 1980: in preparation.
24567

Abe, Tokiharu, and Takashi Hiragaki. 1979. A record of an albinistic southern bluefin tuna from the Tasman Sea. Uo, 30: 2-3.
3

Abramson, Norman J. 1963. A method for computing estimates and variances of relative log fishing powers of California albacore vessels. FAO, Fish. Rep., 6(3): 209-1215.
1

Ahlstrom, Elbert H. 1953. Pilchard eggs and larvae and other fish larvae, Pacific coast-1951. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 102: 55pp.
8

Ahlstrom, Elbert H. 1954. Pacific sardine (pilchard) eggs and larvae and other fish larvae, Pacific coast-1952. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 123: 76pp.
8

Ahlstrom, Elbert H. 1956. Eggs and larvae of anchovy, jack mackerel, and Pacific mackerel. Calif. Coop. Oceanic Fish. Inves., Prog. Rep., 1955-1956: 33-42.
8

Ahlstrom, Elbert H. 1958. Sardine eggs and larvae and other fish larvae, Pacific coast, 1956. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 251: 84pp.
8

Ahlstrom, Elbert H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. U.S. Fish Wild. Serv., Fish. Bull., 60(161): 107-146.
8

Ahlstrom, Elbert H. 1971. Kinds and abundance of fish larvae in the eastern tropical Pacific based on collections made on EASTROPAC I. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(1): 3-77.
14678

Ahlstrom, Elbert H. 1972. Kinds and abundance of fish larvae in the eastern tropical Pacific on the second multivessel EASTROPAC survey, and observations on the annual cycle of larval abundance. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(4): 1153-1242.
1468

Ahlstrom, Elbert H. 1979. U.S. Nat. Mar. Fish. Serv., personal communication.
8

Ahlstrom, Elbert H., and David Kramer. 1955. Pacific sardine (pilchard) eggs and larvae and other fish larvae, Pacific coast, 1953. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 155: 74pp.
8

Ahlstrom, Elbert H., and David Kramer. 1956. Sardine eggs and larvae and other fish larvae, Pacific coast, 1954. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 186: 79pp.
8

Ahlstrom, Elbert H., and David Kramer. 1957. Sardine eggs and larvae and other fish larvae, Pacific coast, 1955. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 224: 90pp.
8

Aikawa, Hiroaki, and Masuo Kato. 1938. Age determinations of fish-I. Jap. Soc. Sci. Fish., Bull., 7(1): 79-88 (translation by Van Campen, W. G., 1950, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 21: 22pp).
1256

Allen, K. Radway. 1973. The influence of random fluctuations in the stock-recruitment relationship on the economic return from salmon fisheries. Cons. Perm. Inter. Explor. Mer, Rapp. Proces-Verb., 164: 350-359.

Alverson, Franklin G. 1963. The food of yellowfin and skipjack tunas in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 7(5): 293-396.
26

Alverson, Franklin G., and Clifford L. Peterson. 1963. Synopsis of the biological data on bigeye tuna *Parathunnus sibi* (Temminck and Schlegel) 1894. FAO, Fish. Rep., 6(2): 482-514.
46

Arai, Yoro, and Koichi Matsumoto. 1953. On a new sporozoa, *Hexacapsula neothunni* gen. et sp. nov., from the muscle of yellowfin tuna, *Neothunnus macropterus*. Jap. Soc. Sci. Fish., Bull., 18(7): 293-298.
2

Asakawa, Suezo, and Akira Suda. 1957. Degenerate meat of tuna and marlins-I. Observations and statistical analyses of the meats collected in the Solomon Sea during the summer, 1953. Nankai Reg. Fish. Res. Lab., Rep., 5: 169-178.
24

Asano, Masahiro. 1964. Young albacore taken from northeastern sea area of Japan in August and September 1963. Tohoku Reg. Fish. Res. Lab., Bull., 24: 20-27.
1

Baker, Alan N. 1966. Food of marlins from New Zealand waters. Copeia, (4): 818-822.
16

Bakun, Andrew. 1973. Coastal upwelling indices, west coast of North America, 1946-71. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS SSRF-671: 103pp.

Baldwin, Wayne J. 1977. A review on the use of live baitfishes to capture skipjack tuna, *Katsuwonus pelamis*, in the tropical Pacific Ocean with emphasis on their behavior, survival, and availability. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS Circ., 408: 8-35.
6

Bardach, John E., John H. Ryther, and William O. McLarney. 1972. Aquaculture. The Farming and Husbandry of Freshwater and Marine Organisms. Wiley-Interscience, New York: xii, 868pp.
258

Barkley, Richard A., William H. Neill, and Reginald M. Gooding. 1978. Skipjack tuna, *Katsuwonus pelamis*, habitat based on temperature and oxygen requirements. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 76(3): 653-662.
6

Barrett, Izadore, and Frank J. Hester. 1964. Body temperature of yellowfin and skipjack tunas in relation to sea surface temperature. Nature, 203(4940): 96-97.
26

Barrett, Izadore, and Susumu Kume. 1965. Observations on bigeye tuna caught in the surface tuna fishery in the eastern Pacific Ocean. Calif. Fish Game, 51(4): 252-258.
4

Barrett, Izadore, and H. Tsuyuki. 1967. Serum transferrin polymorphism in some scombroid fishes. Copeia, (3): 551-557.
1256

Barrett, Izadore, and Alice A. Williams. 1965. Hemoglobin content of the blood of fifteen species of marine fishes. Calif. Fish Game, 51(3): 216-218.
1245

Barrett, Izadore, and Alice A. Williams. 1967. Soluble lens proteins of some scombroid fishes. Copeia, (2): 468-471.
1256

Bartoo, Norman W. 1979. U.S. Nat. Mar. Fish. Serv., personal communication.
1

Bartoo, N., and S. Kikawa. 1979. Report of the fourth north Pacific albacore workshop, Shimizu, Japan, June 25-26, 1979. U.S. Nat. Mar. Fish. Serv., unpublished manuscript.
1

Bartoo, Norman W., and Earl C. Weber. 1979. Status of the north Pacific albacore stock from the yield-per-recruit and recruitment standpoints. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., LJ-79-15: 12pp.
1

Batts, Billy S. 1972. Sexual maturity, fecundity, and sex ratios of the skipjack tuna, *Katsuwonus pelamis* (Linnaeus), in North Carolina waters. Amer. Fish. Soc., Trans., 101(4): 626-637.
6

Bayliff, William H. 1971. Estimates of the rates of mortality of yellowfin tuna in the eastern Pacific Ocean derived from tagging experiments. Inter-Amer. Trop. Tuna Comm., Bull., 15(4): 379-436.
2

Bayliff, William H. 1973. Observations on the growth of yellowfin tuna in the eastern Pacific Ocean derived from tagging experiments. Inter-Amer. Trop. Tuna Comm., Internal Rep., 7: 26pp.
2

Bayliff, William H. 1974. Further estimates of the rates of mortality of yellowfin tuna in the eastern Pacific Ocean derived from tagging experiments. Inter-Amer. Trop. Tuna Comm., Internal Rep., 8: 64pp.
2

Bayliff, William H. 1975. Organization, functions, and achievements of the Inter-American Tropical Tuna Commission. Inter-Amer. Trop. Tuna Comm., Special Rep., 1: 58pp.
124567

Bayliff, William H. 1977. Estimates of the rates of mortality of skipjack tuna in the eastern Pacific Ocean derived from tagging experiments. Inter-Amer. Trop. Tuna Comm., Internal Rep., 10: 59pp.
6

Bayliff, William H. 1979. Migrations of yellowfin tuna in the eastern Pacific Ocean as determined from tagging experiments initiated during 1968-1974. Inter-Amer. Trop. Tuna Comm., Bull., 17(6): 445-506.
2

Bayliff, William H., and Thomas P. Calkins. 1979. Information pertinent to stock assessment of northern bluefin, *Thunnus thynnus*, in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Internal Rep., 12: 78pp.
5

Bayliff, William H., and Brian J. Rothschild. 1974. Migrations of yellowfin tuna tagged off the southern coast of Mexico in 1960 and 1969. Inter-Amer. Trop. Tuna Comm., Bull., 16(1): 1-64.
2

Beamish, F.W.H. 1978. Swimming capacity. In Hoar, W.S., and D.J. Randall (editors), Fish Physiology, Volume VII, Academic Press, New York: 101-187.
2456

Beardsley, Grant L. 1971. Contribution to the population dynamics of Atlantic albacore with comments on potential yields. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(4): 845-857.
1

Bell, Robert R. 1962. Age determination of the Pacific albacore of the California coast. Calif. Fish Game, 48(1): 39-48.
1

Bell, Robert R. 1963a. Synopsis of biological data on California bluefin tuna *Thunnus saliens* Jordan and Evermann 1926. FAO, Fish. Rep., 6(2): 380-421.
58

Bell, Robert R. 1963b. Preliminary age determination of bluefin tuna, *Thunnus thynnus*. Calif. Fish Game, 49(4): 307.
5

Bell, Robert R. 1964. Weight-length relationship for bluefin tuna in the California fishery, 1963. Calif. Fish Game, 50(3): 216-218.
5

Bell, Robert R. 1970. Bluefin tuna *Thunnus thynnus orientalis* in the northeastern Pacific Ocean. Calif. Dept. Fish Game, unpublished manuscript.
5

Bell, Robert R. 1971. California marine fish landings for 1970. Calif. Dept. Fish Game, Fish Bull., 154: 50pp.

Bennett, Edward B., and Milner B. Schaefer. 1960. Studies of the physical, chemical, and biological oceanography in the vicinity of the Revilla Gigedo Islands during the "Island Current Survey" of 1957. Inter-Amer. Trop. Tuna Comm., Bull., 4(5): 217-317.

Ben-Yami, M. 1976. Fishing with Light. Fishing News Books Ltd., London: ix, 121pp.
8

Ben Yami, M'nakhem, and Roger E. Green. 1968. Designing an improved California tuna purse seine. U.S. Fish Wild. Serv., Fish. Ind. Res., 4(5): 183-207.

Bernabei, H. (editor). 1963. Bibliography. FAO, Fish. Rep., 6(4): vii, 1853-2272.

Berrien, Peter L. 1978. Eggs and larvae of *Scomber scombrus* and *Scomber japonicus* in continental shelf waters between Massachusetts and Florida. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 76(1): 95-115.
8

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Minis. Agri. Fish. Food, Fish. Invest., Ser. II, 19: 533pp.

Bini, Giorgio. 1952. Osservazioni sulla fauna marina delle coste de Chile e del Peru con speciale riguardo alle specie ittichi in generale ed ai tonni in particolare. Boll. Pesca Piscic. Idrobiol., 7: 11-60.
1267

Blackburn, Maurice. 1965. Oceanography and the ecology of tunas. Oceanogr. Mar. Biol. Ann. Rev., 3: 299-322.
12456

Blackburn, Maurice. 1969. Conditions related to upwelling which determine distribution of tropical tunas off western Baja California. U.S. Fish Wild. Serv., Fish. Bull., 68(1): 147-176.
26

Blackburn, Maurice, and Associates. 1962. Tuna oceanography in the eastern tropical Pacific. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 400: 48pp.
26

Blackburn, Maurice, and D.L. Serventy. 1981. Observations on distribution and life history of skipjack tuna, *Katsuwonus pelamis*, in Australian waters. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 79(1): in press.

Blackburn, Maurice, and Francis Williams. 1975. Distribution and ecology of skipjack tuna, *Katsuwonus pelamis*, in an offshore area of the eastern tropical Pacific Ocean. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(2): 382-411.
26

Blunt, C.E., Jr. 1958. California bluefin tuna--wary wanderer of the Pacific. Outdoor Calif., 19(9): 14.
5

Blunt, C.E., Jr. 1960. Observations on the food habits of longline caught bigeye and yellowfin tuna from the tropical eastern Pacific 1955-1956. Calif. Fish Game, 46(1): 69-80.
24

Blunt, C.E., Jr., and James D. Messersmith. 1960. Tuna tagging in the eastern tropical Pacific, 1952-1959. Calif. Fish Game, 46(3): 301-369.
26

Blunt, C.E., and Richard H. Parrish. 1969. The Pacific mackerel fishery: a summary of biological knowledge and the current status of the resource. Calif. Dept. Fish Game, MRO Ref., 69-7: 25pp.
8

Bour, W., and P. Galenon. 1979. The development of tuna fisheries in the western Pacific. South Pacific Comm., Occas. Pap., 12: 34pp.
12346

Brandhorst, Wilhelm. 1958. Thermocline topography, zooplankton standing crop, and mechanisms of fertilization in the eastern tropical Pacific. Cons. Perm. Inter. Explor. Mer, Jour., 24(1): 16-31.

Brill, Richard W. 1979. The effect of body size on the standard metabolic rate of skipjack tuna, *Katsuwonus pelamis*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 77(2): 494-498.
6

Brill, R.W., and A.E. Dizon. 1979a. Red and white muscle fibre activity in swimming skipjack tuna, *Katsuwonus pelamis* (L.). Jour. Fish Biol., 15(6): 679-685.
6

Brill, Richard W., and Andrew E. Dizon. 1979b. Effect of temperature on isotonic twitch of white muscle and predicted maximum swimming speeds of skipjack tuna, *Katsuwonus pelamis*. Env. Biol. Fish., 4(3): 199-205.
6

Broadhead, Gordon C. 1959. Morphometric comparisons among yellowfin tuna, *Neothunnus macropterus*, from the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 3(8): 353-391.
2

Broadhead, Gordon C. 1962. Recent changes in the efficiency of vessels fishing for yellowfin tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 6(7): 281-332.
2

Broadhead, Gordon C., and Izadore Barrett. 1964. Some factors affecting the distribution and apparent abundance of yellowfin and skipjack tuna in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 8(8): 417-473.
26

Broadhead, Gordon C., and Craig J. Orange. 1960. Species and size relationships within schools of yellowfin and skipjack tuna, as indicated by catches in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 4(7): 447-492.
26

Brock, Vernon E. 1938. A new tuna record from Washington. Copeia, (2): 98.
5

Brock, Vernon E. 1954. Some aspects of the biology of the aku, *Katsuwonus pelamis*, in the Hawaiian Islands. Pacif. Sci., 8(1): 94-104.
6

Brock, Vernon E. 1959. The tuna resource in relation to oceanographic features. U.S. Fish Wild. Serv., Circ., 65: 1-11.
12346

Brown, Clinton E., and Barry S. Muir. 1970. Anaylsis of ram ventilation of fish gills with application to skipjack tuna (*Katsuwonus pelamis*). Fish. Res. Bd. Canada, Jour., 27(9): 1637-1652.
6

Brun, Michel, and Witold L. Klawe. 1968. Landings of skipjack and yellowfin tuna at Papeete market (Tahiti). Comm. Fish. Rev., 30(4): 62-65.
1246

de Buen, Fernando. 1953. Contribuciones a la ictiologia-VII. Sobre la presencia del atun (*Thunnus thynnus*) en la costa de Chile central. Inves. Zool. Chilenas, 1(10): 3-4.
5

de Buen, Fernando L. 1958. Peces del suborden Scombroidei en aguas de Chile. Rev. Biol. Mar., 7(1-3): 3-38.
158

Bullis, Harvey R., Jr., and Rolf Juhl. 1967. Phalanx orientation in feeding behavior of the little tuna, *Euthynnus alletteratus*. Amer. Fish. Soc., Trans., 96(2): 122-125.

Buñag, Daniel M. 1956. Spawning habits of some Philippine tuna based on diameter measurements of the ovarian ova. Philip. Jour. Fish., 4(2): 145-177.
26

Calkins, Thomas P. 1965. Variation in size of yellowfin tuna (*Thunnus albacares*) within individual purse-seine sets. Inter-Amer. Trop. Tuna Comm., Bull., 10(8): 461-524.
2

Calkins, Thomas P. 1975. Geographical distribution of yellowfin and skipjack tuna catches in the eastern Pacific Ocean, and total catch statistics, 1971-1974. Inter-Amer. Trop. Tuna Comm., Bull., 17(1): 1-116.
26

Calkins, T.P., and B.M. Chatwin. 1967. Geographical distribution of yellowfin tuna and skipjack catches in the eastern Pacific Ocean, by quarters of the year, 1963-1966. Inter-Amer. Trop. Tuna Comm., Bull., 12(6): 433-508.
26

Calkins, T.P., and B.M. Chatwin. 1971. Geographical catch distribution of yellowfin and skipjack tuna in the eastern Pacific Ocean, 1967-1970, and fleet and total catch statistics, 1962-1970. Inter-Amer. Trop. Tuna Comm., Bull., 15(3): 283-377.
26

Calkins, Thomas P., and Witold L. Klawe. 1963. Synopsis of biological data on black skipjack *Euthynnus lineatus* Kishinouye 1920. FAO, Fish. Rep., 6(2): 130-146.
267

Carey, Francis G. 1973. Fishes with warm bodies. Sci. Amer., 228(2): 36-44.
256

Carey, Francis G., and Kenneth D. Lawson. 1973. Temperature regulation in free-swimming bluefin tuna. Comp. Biochem. Physiol., 44(2A): 375-392.
45

Carey, Francis G., and John M. Teal. 1966. Heat conservation in tuna fish muscle. Nat. Acad. Sci., Proc., 56(5): 1464-1469.
24

Carey, Francis G., and John M. Teal. 1969. Regulation of body temperature by the bluefin tuna. Comp. Biochem. Physiol., 28(1): 205-213.
2456

Carey, Francis G., John M. Teal, John W. Kanwisher, Kenneth D. Lawson, and James S. Beckett. 1971. Warm-bodied fish. Amer. Zool., 11(1): 135-143.
12456

Chatwin, Bruce M. 1959. The relationships between length and weight of yellowfin tuna (*Neothunnus macropterus*) and skipjack tuna (*Katsuwonus pelamis*) from the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 3(7): 305-352.
26

Chatwin, Bruce M., and Craig J. Orange. 1960. Recovery of tagged bluefin tuna (*Thunnus saliens*). Calif. Fish Game, 46(1): 107-109.
5

Chen, Ching-Ju, and Rong-Tszong Yang. 1973. Parasites of yellowfin in the waters southwest off Taiwan. Acta Ocean. Taiwanica, 3: 181-198.
26

Chi, Kwong-San, and Rong-Tszong Yang. 1973. Age and growth of skipjack tuna in the waters around the southern part of Taiwan. Acta Ocean. Taiwanica, 3: 199-221.
6

Chirinos de Vildoso, Aurora. 1960. Estudios sobre la reproduccion del "bonito" *Sarda chiliensis* (C. y V.) en aguas adyacentes a la costa Peruana. Peru, Minis. Agri., Direc. Pesq. Caza, Serie Divul. Cient., 14: 75pp.

Cleaver, Fred C., and Bell M. Shimada. 1950. Japanese skipjack (*Katsuwonus pelamis*) fishing methods. Comm. Fish. Rev., 12(11): 1-27.
6

Clemens, Harold B. 1955. Pacific albacore fishery moves offshore. Nat. Fisherman, 36(9): 17, 34.
1

Clemens, Harold B. 1956. Rearing larval scombrid fishes in shipboard aquaria. Calif. Fish Game, 42(1): 69-79.
7

Clemens, Harold B. 1957. Fishes collected in the tropical eastern Pacific, 1954. Calif. Fish Game, 43(4): 299-307.
7

Clemens, Harold B. 1961. The migration, age, and growth of Pacific albacore (*Thunnus germo*), 1951-1958. Calif. Dept. Fish Game, Fish Bull., 115: 128pp.
12456

Clemens, Harold B. 1962. The distribution of albacore in the north Pacific. Pacif. Mar. Fish. Comm., Ann. Rep., 14: 44-47.
1

Clemens, Harold B. no date. California bluefin tuna *Thunnus saliens*. In California ocean fisheries resources to the year 1960, Calif. Dept. Fish Game: 65-67.
5

Clemens, Harold B., and William L. Craig. 1965. An analysis of California's albacore fishery. Calif. Dept. Fish Game, Fish Bull., 128: 301pp.
1

Clemens, Harold B., and Glenn A. Flittner. 1969. Bluefin tuna migrate across the Pacific Ocean. Calif. Fish Game, 55 (2): 132-135.
5

Clemens, Harold B., and Robert A. Iselin. 1963. Food of Pacific albacore in the California fishery (1955-1961). FAO, Fish. Rep., 6(3): 1523-1535.
18

Clement, I.T. 1976. Distribution and abundance of skipjack, 1975-76. New Zealand, Minis. Agri. Fish., Fish. Res. Div Occas. Publ., 11: 36-39.
6

Clement, I.T. 1978. School fish sightings around New Zealand, 1976-77. New Zealand, Minis. Agri. Fish., Fish. Res. Div., Occas. Publ., 15: 35-42.
6

Cole, Jon S. 1979. Inter-Amer. Trop. Tuna Comm., personal communication.
8

Cole, Jon S. 1980. Synopsis of biological data on the yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 2: 71-150.
246

Collette, Bruce B. 1978. Adaptions and systematics of the mackerels and tunas. In Sharp, Gary D., and Andrew E. Dizon, The Physiological Ecology of Tunas, Academic Press, New York: 7-39.

Collette, Bruce B., and Labbish N. Chao. 1975. Systematics and morphology of the bonitos (*Sarda*) and their relatives (Scombridae, Sardini). U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(3): 516-625.

Collette, Bruce B., and Joseph L. Russo. 1979. An introduction to the Spanish mackerels, genus *Scomberomorus*. In Nakamura, Eugene L., and Harvey R. Bullis, Jr. (editors), Proceedings: colloquium on the Spanish and king mackerel resources of the Gulf of Mexico, Gulf States Mar. Fish. Comm.: 3-16.

Conand, Francois, and A.W. Argue. 1980. Preliminary observations on juvenile skipjack from the stomachs of adult skipjack caught by pole-and-line gear. South Pacif. Comm., Reg. Tech. Meeting Fish., 12: 21pp.
1246

Craig, William L. 1963. The California albacore fishery logbook system. FAO, Fish. Rep., 6(3): 1217-1225.
1

Cressey, Roger, and Hillary Boyle Cressey. 1980. Parasitic copepods of mackerel- and tuna-like fishes (Scombridae). Smithson. Contr. Zool., 311: iv, 186pp.
12345678

Croker, Richard S. 1933. The California mackerel fishery. Calif. Dept. Fish Game, Fish Bull., 40: 149pp.
8

Croker, Richard S. 1938. Historical account of the Los Angeles mackerel fishery. Calif. Fish Game, Fish Bull., 52: 62pp.
8

Cromwell, Townsend. 1953. Circulation in a meridional plane in the central equatorial Pacific. Jour. Mar. Res., 12(2): 196-213.
2

Cromwell, Townsend. 1958. Thermocline topography, horizontal currents and "ridging" in the eastern tropical Pacific. Inter-Amer. Trop. Tuna Comm., Bull., 3(3): 133-164.

Cromwell, Townsend, and Edward B. Bennett. 1959. Surface drift charts for the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 3(5): 215-237.

Cushing, D.H. 1971. The dependence of recruitment on parent stock in different groups of fishes. Cons. Perm. Inter. Explor. Mer, Jour., 33(3): 340-362.
2

Davidoff, Edwin B. 1963. Size and year class composition of catch, age and growth of yellowfin tuna in the eastern tropical Pacific Ocean, 1951-1961. Inter-Amer. Trop. Tuna Comm., Bull., 8(4): 199-251.
2

Davidoff, Edwin B. 1969. Variations in year-class strength and estimates of the catchability coefficient of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 14(1): 1-44.
2

De Fever, Arthur. 1968. Modern U.S. tuna vessel construction, design, and future trends. Univ. Wash. Publ. Fish., New Series, 4: 134-140.

Dekhnik, T.V. 1959. Razmnozhenie i razvitie iaponskoi skumbrii *Pneumatophorus japonicus* (Houttuyn) u beregov yuzhnogo Sakhalina (Reproduction and development of *Pneumatophorus japonicus* off the coast of southern Sakhalin). Isled. *Dal'nevost. Morei SSSR*, 6: 97-108.
8

Delsman, H.C. 1931. Fish eggs and larvae from the Java Sea-18. The genus *Cybium*, with remarks on a few other Scombridae. Treubia, 13: 401-410.

Diaz, Enrique L. 1963. An increment technique for estimating growth parameters of tropical tunas, as applied to yellowfin tuna (*Thunnus albacares*). Inter-Amer. Trop. Tuna Comm., Bull., 8(7): 381-416.
2

Dizon, Andrew E. 1977. Effect of dissolved oxygen concentration and salinity on swimming speed of two species of tunas. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 75(3): 649-653.
26

Dizon, Andrew E., and Richard W. Brill. 1979a. Thermoregulation in tunas. Amer. Zool., 19(1): 249-265.
256

Dizon, Andrew E., and Richard W. Brill. 1979b. Thermoregulation in yellowfin tuna, *Thunnus albacares*. Physiol. Zool., 52 (4): 581-593.
2

Dizon, Andrew E., Richard E. Brill, and Heeny S.H. Yuen. 1978. Correlations between environment, physiology, and activity and the effects of thermoregulation in skipjack tuna. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 233-259.
6

Dizon, Andrew E., William H. Neill, and John J. Magnuson. 1977. Rapid temperature compensation of volitional swimming speeds and lethal temperatures in tropical tunas (Scombridae). Envir. Biol. Fish., 2(1): 83-92.
26

Doi, Takeyuki. 1960. On the predatory relationships among bluefin tuna and coastal fishes in the southern waters of Japan. Jap. Soc. Sci. Fish., Bull., 26(2): 99-102.
5

Dollfus, Robert Ph. 1952. Parasites du *Germo alalunga* (J.F. Gmelin 1788). Cons. Perm. Explor. Mer, Jour., 18(1): 42-44.
1

Dollfus, Robert-Ph. 1962. Deux especes de trematodes monogenetiques parasites du "bluefin tuna" de California. Ann. Parasit. Humaine Comparee, 37(4): 517-529.
5

Donguy, Jean Rene, William Bour Patrick Galenon, and Jean Alfred Gueredrat. 1978. Les conditions oceanographiques et la peche de la bonite (*Katsuwonus pelamis*) dans le Pacifique occidental. Cah. ORSTOM, Ser. Ocean., 16(3-4): 309-317.
6

Dotson, Ronald C. 1977. U.S. Nat. Mar. Fish. Serv., unpublished data.
1

Dotson, Ronald C. 1978. Fat deposition and utilization in albacore. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 343-355.
1

Dotson, Ronald C. 1979. Fishing methods and equipment of the U.S. west coast albacore fleet. U.S. Nat. Mar. Fish. Serv., unpublished manuscript.
1

Doucet, W.F. 1965. Mercadeo de peces marinos de consumo en el Peru. Inst. Mar Peru, Informe, 5: 162pp.
8

Dragovich, Alexander. 1971. Food of skipjack tuna in the Caribbean Sea and adjacent oceanic waters. FAO, Fish. Rep., 71(2): 27-40.
6

Eldridge, Maxwell B., and Paul G. Wares. 1974. Some biological observations of billfishes taken in the eastern Pacific Ocean, 1967-1970. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS SSRF-675, Part 2: 89-101.
78

Evans, Douglas H., and Paul G. Wares. 1972. Food habits of striped marlin and sailfish off Mexico and Southern California. U.S. Fish Wild. Serv., Res. Rep., 76: 10pp.
8

Evans, R.H., D.R. McLain, and R.A. Bauer. 1979. Atlantic skipjack tuna: influences of the environment on their vulnerability to surface gear. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., LJ-79-38: 12pp.
6

Fink, Bernard D. 1965. Estimations, from tagging experiments, of mortality rates and other parameters respecting yellowfin and skipjack tuna. Inter-Amer. Trop. Tuna Comm., Bull., 10(1): 1-82.
26

Fink, Bernard D., and William H. Bayliff. 1970. Migrations of yellowfin and skipjack tuna in the eastern Pacific Ocean as determined by tagging experiments, 1952-1964. Inter-Amer. Trop. Tuna Comm., Bull., 15(1): 1-227.
26

Fischer, W., and P.J.P. Whitehead (editors). 1974. FAO species identification sheets for fishery purposes. FAO, Rome.

Fitch, John E. 1951. Age composition of the Southern California catch of Pacific mackerel, 1939-40 through 1950-51. Calif. Dept. Fish Game, Fish Bull., 83: 73pp.
8

Fitch, John E. 1952a. The decline of the Pacific mackerel fishery. Calif. Fish Game, 38(3): 381-389.
8

Fitch, John E. 1952b. Distributional notes on some Pacific coast marine fishes. Calif. Fish Game, 38(4): 557-564.
78

Fitch, John E. 1953a. Age composition of the Southern California catch of Pacific mackerel for the 1951-52 season. Calif. Fish Game, 39(1): 141-146.
8

Fitch, John E. 1953b. Age composition of the Southern California catch of Pacific mackerel for the 1952-53 season. Calif. Fish Game, 39(4): 553-558.
8

Fitch, John E. 1955. Age composition of the Southern California catch of Pacific mackerel for the 1953-54 season. Calif. Fish Game, 41(1): 107-112.
8

Fitch, John E. 1956. Pacific mackerel. Calif. Coop. Oceanic Fish. Inves., Prog. Rep., 1955-1956: 29-32.
8

Fitch, John E. 1958. Age composition of the Southern California catch of Pacific mackerel for the two seasons, 1955-56 and 1956-57. Calif. Dept. Fish Game, Fish Bull., 106: 19-26.
8

Flittner, Glenn A. 1963. Review of the 1962 seasonal movement of albacore tuna off the Pacific coast of the United States. Comm. Fish. Rev., 25(4): 7-13.
1

Flittner, Glenn A. 1966. Bluefin tuna in the north Pacific Ocean. Pacif. Sci. Congr., 11, unpublished manuscript: 18pp.
5

Forsbergh, Eric D. 1969. On the climatology, oceanography and fisheries of the Panama Bight. Inter-Amer. Trop. Tuna Comm., Bull., 14(2): 45-385.
26

Forsbergh, Eric D. 1980a. Inter-Amer. Trop. Tuna Comm., unpublished data.
6

Forsbergh, Eric D. 1980b. Synopsis of biological data on the skipjack tuna, *Katsuwonus pelamis* (Linnaeus, 1758), in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep., 2: 295-360.
1236

Forsbergh, Eric D., and Forrest R. Miller. 1980. Skipjack and the wind-mixing index. Inter-Amer. Trop. Tuna Comm., unpublished munuscript: 5pp.
6

Fowler, Henry W. 1928. The fishes of Oceania. Bernice Bishop Museum, Mem., 10: 540pp.
124568

Fowler, Henry W. 1932. The fishes obtained by the Pinchot south seas expedition of 1929, with description of one new genus and three new species. U.S. Nat. Mus., Proc., 80(6): 16pp.
56

Fowler, Henry W. 1938. The fishes of the George Vanderbilt south Pacific expedition, 1937. Philad. Acad. Nat. Sci., Monogr., 2, 349pp.
1245678

Fowler, Henry W. 1944. The fishes. In Results of the fifth George Vanderbilt expedition (1941), Philad. Acad. Nat. Sci., Monogr., 6: 57-529.
125678

Frade, F. 1953. Sur l'etat de maturete sexuelle d'un germon pris en Mer Tyrrhenienne. Cons. Perm. Inter. Explor. Mer, Jour., 19(1): 72-76.
1

Francis, Robert C. 1974. TUNPOP, a computer simulation model of the yellowfin tuna population and the surface tuna fishery of the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 16(3): 233-279.
2

Francis, Robert C. 1977. TUNPOP: a simulation of the dynamics and structure of the yellowfin tuna stock and surface fishery of the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 17(4): 213-269.
2

Frey, Herbert W. (editor). 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game: 148pp.

Frey, Herbert W., and Eric H. Knaggs. 1973. Status of Pacific mackerel spawning population, 1973. Calif. Dept. Fish Game, Mar. Res. Admin. Rep., 73-7: 16pp.
8

Fry, D.H., Jr. 1931. Mackerel. Calif. Dept. Fish Game, Fish Bull., 30: 35-37.
8

Fry, Donald H., Jr. 1936a. A description of the eggs and larvae of the Pacific mackerel (Pneumatophorus diego). Calif. Fish Game, 22(1): 28-29.
8

Fry, Donald H., Jr. 1936b. A preliminary summary of the life history of the Pacific mackerel. Calif. Fish Game, 22(1): 30-39.
8

Fry, Donald H., Jr., and Phil M. Roedel. 1949. Tagging experiments on the Pacific mackerel (Pneumatophorus diego). Calif. Fish Game, Fish Bull., 73: 64pp.
8

Fujino, Kazuo. 1970a. Immunological and biochemical genetics of tunas. Amer. Fish. Soc., Trans., 99(1): 152-178.
123456

Fujino, Kazuo. 1970b. Skipjack tuna subpopulation identified by genetic characteristics in the western Pacific. In Marr, John C. (editor), The Kuroshio: a Symposium on the Japan Current, East-West Center Press, Honolulu: 385-393.
6

Fujino, Kazuo. 1972. Range of the skipjack tuna subpopulation in the western Pacific Ocean. In Sugawara, K. (editor), The Kuroshio II: Proceedings of the Second CSK Symposium, Saikon Publishing Co., Ltd., Tokyo: 373-384.
6

Fujino, Kazuo. 1976. Subpopulation identification of skipjack tuna specimens from the southwestern Pacific Ocean. Jap. Soc. Sci. Fish., Bull., 42(11): 1229-1235.
6

Fujino, Kazuo, and Tagay Kang. 1968a. Transferrin groups of tunas. Genetics, 59: 79-91.
236

Fujino, Kazuo, and Tagay Kang. 1968b. Serum esterase groups of Pacific and Atlantic tunas. Copeia, (1): 56-63.
1246

Ganssle, David, and Harold B Clemens. 1953. California-tagged albacore recovered off Japan. Calif. Fish Game, 39(4): 443.
1

Gibbs, Robert H., Jr., and Bruce B. Collette. 1967. Comparative anatomy and systematics of the tunas, genus *Thunnus*. U.S. Fish Wild. Serv., Fish. Bull., 66(1): 65-130.

Goadby, Peter. 1970. Big Fish and Blue Water. Holt, Rinehart and Winston, New York: 334pp.
123456

Godsil, H.C. 1938. The high seas tuna fishery of California. Calif. Dept. Fish Game, Fish Bull., 51: 41pp.
126

Godsil, H.C. 1948. A preliminary population study of the yellowfin tuna and the albacore. Calif. Dept. Fish Game, Fish Bull., 70: 90pp.
12

Godsil, H.C. 1954a. A descriptive study of certain tuna-like fishes. Calif. Dept. Fish Game, Fish Bull., 97: 185pp.
78

Godsil, H.C. 1954b. A comparison of Japanese and Hawaiian specimens of the black skipjack *Euthynnus yaito*. Calif. Fish Game, 40(4): 411-413.

Godsil, H.C., and E.E. Greenhood. 1951. A comparison of the populations of the yellowfin tuna, *Neothunnus macropterus*, from the eastern and central Pacific. Calif. Dept. Fish Game, Fish Bull., 82: 33pp.
2

Gooding, Reginald M., and John J. Magnuson. 1967. Ecological significance of a drifting object to pelagic fishes. Pacif. Sci., 21(4): 486-497.
26

Gooding, Reginald M., William H. Neill, and Andrew E. Dizon. 1981. Respiration rates and low-oxygen tolerance limits in skipjack tuna, *Katsuwonus pelamis*. U.S. Nat. Mar. Fish Serv., Fish. Bull., 79(1): in press.
6

Gordon, Malcolm S. 1968. Oxygen consumption of red and white muscles from tuna fishes. Science, 159(3810): 87-90.
46

Gosline, William A. 1968. The suborders of perciform fishes. U.S. Nat. Mus., Proc., 124(3647): 78pp.

Graham, Jeffrey B. 1973. Heat exchange in the black skipjack, and the blood-gas relationship of warm-bodied fishes. Nat. Acad. Sci., Proc., 70(7): 1964-1967.
7

Graham, Jeffrey B. 1975. Heat exchange in yellowfin tuna, Thunnus albacares, and skipjack tuna, Katsuwonus pelamis, and the adaptive significance of elevated body temperatures in scombrid fishes. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(2): 219-229.
123456

Graham, Jeffrey B., and Douglas R. Diener. 1978. Comparative morphology of the central heat exchangers in the skipjacks Katsuwonus and Euthynnus. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 113-133.
67

Grandperrin, R., and M. Legand. 1971. Apercu sur la distribution verticale des germons dans les eaux tropicales de Pacifique sud: nouvelle orientation de la peche Japonaise et de la peche experimentale. Cah. ORSTOM, Ser. Ocean., 9(2): 197-202.
1

Green, Roger E. 1967. Relationship of the thermocline to success of purse seining for tuna. Amer. Fish. Soc., Trans., 96(2): 126-130.
26

Green, R.E., J.E. Jurkovich, and B. Petrich. 1971. Development and testing of the hybrid tuna purse seine. In Kristjonsson, Hilmar (editor), Modern Fishing Gear of the World: 3, Fishing News (Books) Ltd., London: 264-273.
256

Green, R.E., W.F. Perrin, and B.P. Petrich. 1971. The American tuna purse seine fishery. In Kristjonsson, Hilmar (editor), Modern Fishing Gear of the World: 3, Fishing News (Books) Ltd., London: 182-194.
256

Greenblatt, Paul R. 1979. Associations of tuna with flotsam in the eastern tropical Pacific. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 77(1): 147-155.
26

Gregory, Paul A. 1977. Tagging mortality experiments on Pacific mackerel, Pneumatophorus japonicus. Calif. Dept. Fish Game, Mar. Res. Tech. Rep., 40: 20pp (manuscript).
8

Gregory, William K., and G. Miles Conrad. 1937. The comparative osteology of the swordfish (Xiphias) and the sailfish (Istiophorus). Amer. Mus. Novit., 952: 25pp.

Gregory, William K., and G. Miles Conrad. 1943. The osteology of Luvarus imperialis, a scombroid fish: a study in adaptive evolution. Amer. Mus. Nat. Hist., Bull., 81: 225-283.

Gress, Franklin, Paul R. Kelly, David B. Lewis, and Daniel W. Anderson. 1980. Feeding activities and prey preference of brown pelicans breeding in the Southern California bight. unpublished manuscript: 38pp.
8

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part I. Fish population analysis. FAO, Manuals Fish. Sci., 4: 154pp.

Habib, George. 1977. Skipjack tuna resources off New Zealand. Austral. Fish., 36(1): 7-9, 38.
6

Habib, George. 1978. 1977-78 New Zealand tuna season analysed. Austral. Fish., 37(11): 20-23.
6

Habib, G., and R.M. Cade. 1978. The 1976-77 tuna fishery from small vessels. New Zealand, Minis. Agri. Fish., Fish. Res. Div., Occas. Publ., 15: 27-34.
16

Habib, G., I.T. Clement, and K.A. Fisher. 1980. The 1978-79 purse-seine skipjack fishery in New Zealand waters. New Zealand, Minis. Agri. Fish., Fish. Res. Div., Occas. Publ., 26: 39pp.
6

Habib, G., I.T. Clement, and K.A. Fisher. no date. The 1977-78 purse seine skipjack fishery in New Zealand waters. New Zealand, Minis. Agri. Fish., Fish. Res. Div., Occas. Publ., 25: unpublished.
6

Hanamoto, Eiji. 1974. Fishery biology of bigeye tuna-I. Depth of capture by tuna longline gear in the eastern tropical Pacific Ocean. La Mer (Bull. Soc. Franco-Japonaise Ocean.), 12(3): 128-136.
4

Hanamoto, Eiji. 1976. The swimming layer of bigeye tuna. Jap. Soc. Fish. Ocean., Bull., 29: 41-44 (translation by U.S. Nat. Mar. Fish. Serv.).
4

Harada, Teruo. 1978. Recent tuna culture research in Japan. Inter. Ocean Develop. Conf., 5(C1): 55-72 (preprint).
25

Harada, Teruo. 1980. Maguro-rui no yosei kenkyu no shinten to tenbo (Progress and future prospects in tuna culturing studies). Far Seas Fish. Res. Lab., Japan Tuna Research Conf., Proc., 1979: 50-58 (translation by Otsu, Tamio, U. S. Nat. Mar. Fish. Serv.).
256

Harada, Teruo, Hidemi Kumai, and Shigeru Okamoto. 1976. Record of rearing bluefin tuna and bonito for three years. Kinki Univ., Faculty Fish., Mem., 9: 21-28.
5

Harada, Teruo, Osamu Murata, and Seiji Oda. 1980. Rearing and morphological changes in larvae and juveniles of yellowfin tuna. Kinki Univ., Faculty Agri., Bull., 13: 33-36 (translation by Otsu, Tamio, U. S. Nat. Mar. Fish. Serv.).
2

Hasegawa, Akira. 1978. Economic aspects of bluefin culture in Japan. Inter. Ocean Develop. Conf., 5(C1): 41-47 (preprint).
5

Hatanaka, Masayoshi, Kiyonari Sekino, Masao Takahashi, and Takemi Ichimura. 1957. Growth and food consumption in young mackerel, *Pneumatophorus japonicus* (Houttuyn). Tohoku Jour. Agri. Res., 7(4): 351-368.
8

Hatanaka, Masayoshi, and Masao Takahashi. 1956. Utilization of food by mackerel, *Pneumatophorus japonicus* (Houttuyn). Tohoku Jour. Agri. Res., 7(1): 51-57.
8

Hatanaka, Masoyoshi A., and Masao Takahashi. 1960. Studies on the amounts of anchovy consumed by the mackerel. Tohoku Jour. Agri. Res., 11(1): 83-100.
8

Hayashi, Shigeichi. 1958. A review on age determination of the Pacific tunas. Indo-Pacif. Fish. Coun., Proc., 7(2-3): 53-64.
12456

Hayashi, Shigeichi. 1974. Stock assessment of southern bluefin tuna based on information up to September 1973--its conclusions and problems. Far Seas Fish. Res. Lab., Bull., 11: 51-65.
3

Hayashi, Shigeichi, and Misao Honma. 1971. Assessment of yellowfin tuna stocks in the Atlantic Ocean, 1956-1967. Far Seas Fish. Res. Lab., Bull., 4: 71-92.
2

Hayashi, Shigeichi, Misao Honma, and Chiomi Shingu. 1969. Assessment of the southern bluefin tuna stocks, 1960-66. Tuna Fishing, 84: 9-23 (translation by Australia, CSIRO).
3

Hayashi, Shigeichi, and Shoji Kikawa. 1970. A comparative study on efficiency of the surface and longline fisheries for exploitation of tuna and related species. Far Seas Fish. Res. Lab., S Series, 3: 97-114.
123456

Hayashi, Shigeichi, Tsutomu Koto, Susumu Kume, Chiomi Shingu, and Yasuo Morita. 1970. Status of the tuna fisheries resources in the Atlantic Ocean, 1956-1967. Far Seas Fish. Res. Lab., S Series, 3: 1-72.
123456

Hayashi, Shigeichi, Chiomi Shingu, and Koichi Hisada. 1972. An inference on rational utilization of southern bluefin tuna based on data obtained from 1957 to 1969. Far Seas Fish. Res. Lab., S Series, 6: 63-88.
3

Hearn, W.S. 1979. Growth of southern bluefin tuna (Thunnus maccoyii). Indo-Pacific Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, Background Pap., 14: 12pp.
3

Hearn, W.S. 1980. Australia, CSIRO, Div. Fish. Ocean., personal communication.
3

Hennemuth, Richard C. 1959. Additional information on the length-weight relationship of skipjack tuna from the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 4(2): 23-37.
6

Hennemuth, Richard C. 1961a. Size and year class composition of catch, age and growth of yellowfin tuna in the eastern tropical Pacific Ocean for the years 1954-1958. Inter-Amer. Trop. Tuna Comm., Bull., 5(1): 1-112.
2

Hennemuth, Richard C. 1961b. Year class abundance, mortality and yield-per-recruit of yellowfin tuna in the eastern Pacific Ocean, 1954-1959. Inter-Amer. Trop Tuna Comm., Bull., 6(1): 1-51.
2

Herre, Albert W. 1936. Fishes of the Crane Pacific Expedition. Field Mus. Nat. Hist., Zool. Ser., 21: 472pp.
256

Hester, Frank J. 1961. A method of predicting tuna catch by using coastal sea-surface temperatures. Calif. Fish Game, 47(4): 313-326.
1256

Hester, Frank J. 1979. Defining highly migratory tunas. United States Tuna Foundation, Publ., 79-1, 39pp.
1234567

Hester, Frank J., and Tamio Otsu. 1973. A review of the literature on the development of skipjack tuna fisheries in the central and western Pacific Ocean. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS SSRF-661: 13pp.
6

Hiatt, Robert W., and Vernon E. Brock. 1948. On the herding of prey and schooling of the black skipjack Euthynnus yaito Kishinouye. Pacif. Sci., 2(4): 297-298.

Higasa, Shichiro, Akima Suzuki, and Yasuyuki Shimidu. 1962. Biochemical studies on the growth and maturation of fish-XVI. On the body fat of albacore in north Pacific ground during the season of southward migration. Nankai Reg. Fish. Res. Lab., Rep., 16: 103-110.
1

Higgins, B.E. 1967. The distribution of juveniles of four species of tunas in the Pacific Ocean. Indo-Pacif. Fish. Coun., Proc., 12(2): 79-99.
1246

Higgins, Bruce E. 1970. Juvenile tunas collected by midwater trawling in Hawaiian waters, July-September 1967. Amer. Fish. Soc., Trans., 99(1): 60-73.
1246

Hildebrand, Samuel F. 1946. A descriptive catalog of the shore fishes of Peru. U.S. Nat. Mus., Bull., 189: 530pp.
2678

Hirota, Hitoshi, Masaichi Morita, and Nobuhiko Taniguchi. 1976. An instance of the maturation of 3 full years old bluefin tuna cultured in the floating net. Jap. Soc. Sci. Fish., Bull., 42(8): 939.
5

Hisada, Koichi. 1973. Investigation on tuna hand-line fishing ground and some biological observations on yellowfin and bigeye tunas in the northwestern Coral Sea. Far Seas Fish. Res. Lab., Bull., 8: 35-69.
24

Hisada, K., C. Shingu, and T. Yonemori. 1978. Recent status of the southern bluefin tuna stock. Inter. Comm. Conser. Atlan. Tunas, Coll. Vol. Sci. Pap., 8(2): 454-460.
3

Hisada, Koichi, Chiomi Shingu, and Tamotsu Yonemori. 1979. The bluefin fisheries in the northwestern Pacific and biological information obtained from them. Indo-Pacific Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, Background Pap., 10: 16pp.
5

Hiyama, Yoshio, and Fujio Yasuda. 1957. The methods of utilization of plankton by fishes. Rec. Ocean. Works Japan, Spec. No., 1: 67-70.
8

Holmes, Robert W., Milner B. Schaefer, and Bell M. Shimada. 1957. Primary production, chlorophyll, and zooplankton volumes in the tropical eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 2(4): 127-169.

Holt, S.J. 1959. Report of the international training center on the methodology and techniques of research on mackerel (Rastrelliger). FAO, Expanded Tech. Assis. Prog., 1095: 129pp.
8

Honma, Misao. 1973. Calculation of yield-per-recruit and relative stock fecundity for fish populations with age-dependent natural mortality. Far Seas Fish. Res. Lab., Bull., 9: 177-199.
3

Honma, Misao. 1974. Taiheiyo no kihada shigen hyoka (Stock assessment of yellowfin tuna in the Pacific). In Tuna Fisheries Research Council, minutes of meeting, Far Seas Fish. Res. Lab.: 193-213.
2

Honma, Misao, and Tadao Kamimura. 1957. Studies on the albacore-V. The fishing condition and size of albacore taken in the south Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 6: 84-90.
1

Honma, Misao, Tadao Kamimura, and Shigeiti Hayashi. 1971. Compilation of catch records for assessment of yellowfin tuna stocks in longline fishery in the Pacific Ocean, and application to data for the years of 1950 to 1964. Far Seas Fish. Res. Lab., Bull., 4: 1-26.
2

Honma, Misao, and Ziro Suzuki. 1978. Japanese tuna purse seine fishery in the western Pacific. Far Seas Fish. Res. Lab., S Series, 10: 66pp.
12456

Honma, Misao, Yukio Warashina, and Ziro Suzuki. 1973. Identification of young yellowfin and bigeye tunas in the western Pacific Ocean. Examination of practical standards based on external characteristics and the reliability in field survey. Far Seas Fish. Res. Lab., Bull., 8: 1-23.
24

Hotta, Hideyuki, Tokiharu Abe, and Yuriko Takashima. 1958. Notes on the head bones of the Japanese mackerels of the genus Pneumatophorus. Tohoku Reg. Fish. Res. Lab., Bull., 12: 101-105.
8

Hotta, Hideyuki, and Toru Ogawa. 1955. On the stomach contents of the skipjack, Katsuwonus pelamis. Tohoku Reg. Fish. Res. Lab., Bull., 4: 62-82.
6

Hsiao, Sidney C. 1952. Observations on the reaction of tuna to artificial light. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 91: 36-58.
2

Hsiao, Sidney C., and Albert L. Tester. 1955. Response of tuna to visual-chemical stimuli. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 130: 63-76.

Hu, Fei, and Rong-Tszong Yang. 1972. A preliminary study on sexual maturity and fecundity of skipjack tuna. Fish. Soc. Taiwan, Jour., 1(1): 88-98.
6

Hunter, John R., and Carol Kimbrell. 1979. Early life history of Pacific mackerel, Scomber japonicus. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 78(1): 89-101.
8

Hunter, John R., and Charles T. Mitchell. 1967. Association of fishes with flotsam in the offshore waters of Central America. U.S. Fish Wild. Serv., Fish. Bull., 66(1): 13-29.
26

Hunter, John R., and Charles T. Mitchell. 1968. Field experiments on the attraction of pelagic fish to floating objects. Cons. Perm. Inter. Explor. Mer, Jour., 31(3): 427-434.
27

Hunter, John R., John H. Taylor, and H. Geoffrey Moser. 1979. Effect of ultraviolet irradiation on eggs and larvae of the northern anchovy, Engraulis mordax, and the Pacific mackerel, Scomber japonicus, during the embryonic stage. Photochem. Photobiol., 29(2): 325-338.
8

Hunter, John R., and James R. Zweifel. 1971. Swimming speed, tail beat frequency, tail beat amplitude, and size in jack mackerel, Trachurus symmetricus, and other fishes. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(2): 253-266.
8

Hyatt, Harold. 1960. Age composition of the Southern California catch of Pacific mackerel, Pneumatophorus diego, for the 1957-1958 season. Calif. Fish Game, 46(2): 183-188.
8

Hynd, J.S. 1965. Southern bluefin tuna populations in southwest Australia. Austral. Jour. Mar. Fresh. Res., 16(1): 25-32.
3

Hynd, J.S. 1969. New evidence on southern bluefin stocks and migrations. Austral. Fish., 28(5): 26-30.
3

Hynd, J.S. 1974. Unusual bluefin tuna season in N.S.W. Austral. Fish. 33(4): 9-11.
3

Hynd, J.S., G.L. Kesteven, and J.P. Robins. 1966. Tuna in southern Australian waters. Food. Tech. Austral., 18(4): 190-200.

Hynd, J.S., and C. Lucas. 1974. Population dynamics of the southern bluefin tuna. Indo-Pacif. Fish. Coun., Proc., 15(3): 424-435.
3

Hynd, J.S., and J.P. Robins. 1967. Tasmanian tuna survey--report of first operational period. Australia, CSIRO, Div. Fish. Ocean., Tech. Pap., 22: 55pp.
136

Inostroza C., Felix. 1979. Chile, Inst. Fomento Pesq., personal communication.
1

Inoue, Makoto. 1959. On the relation of behaviours of skipjack and tuna shoals to their catch inferred from the data for seine fishery. Jap. Soc. Sci. Fish., Bull., 25(1): 12-16.
256

Inoue, Motoo. 1973. Possibility of artificial culture of the Pacific tunas. Review of the studies. Tokai Univ., Jour. Fac. Mar. Sci. Tech., 7: 297-312.
25

Inoue, Motoo, Ryohei Amano, Yukinobu Iwasaki, and Mitsuyoshi Aoki. 1967. Ecology of various tunas under captivity-I. Preliminary rearing experiments. Tokai Univ., Jour. Fac. Coll. Mar. Sci. Tech., 2: 197-209.
256

Inoue, Motoo, Mitsuyoshi Aoki, and Y. Tanaka. 1969. Preservation of mackerel sperm by rapid freezing. Tokai Univ., Mar. Inst., Appl. Mar. Ecol. Ser., 3: 2pp (mimeographed).
8

Inoue, Motoo, Yukinobu Iwasaki, Ryohei Amano, Mitsuyoshi Aoki, and Minoru Yamauti. 1970. Ecology of various tunas under captivity-II. Behavior of tuna shown against light and darkness. Tokai Univ., Jour. Fac. Coll. Mar. Sci. Tech., 4: 53-58.
5

Inoue, Motoo, Kouhei Tutumi, Hideo Nagaoka, and Toyoteru Nagata. 1974. Some notes on the artificial fertilization and rearing of larvae in the skipjack tuna. Tokai Univ., Jour. Fac. Mar. Sci. Tech., 8: 37-42.
6

Isao, Okachi. 1963. Studies on the distribution and structure of the fish fauna in the Japan Sea by catch statistics-II. Supplement of seasonal distribution and fishing condition of bluefin tuna. Japan Sea Reg. Fish. Res. Lab., Bull., 11: 9-21.
5

Ishida, Rikiichi. 1975. Skipjack tuna fishery and fishing grounds. In Reports pertaining to effects of ocean disposal of solid radioactive wastes on living marine resources. Tokai Reg. Fish. Res. Lab., Tohoku Reg. Fish. Res. Lab., and Far Seas Fish. Res. Lab.: 89-92 (translation by U.S. Nat. Mar. Fish Serv.).
6

Ishii, Kazumi, and Motoo Inoue., 1956. Some notes on the ovary of albacore, *Germo germo*, taken from the Coral Sea. Jap. Soc. Sci. Fish., Bull., 22(2): 89-93.
1

Ishii, Takeo. 1967a. Studies on estimating parameters of a fish population supplied by sequential recruitment-I. The effect on estimates for Pacific yellowfin tuna. Jap. Soc. Sci. Fish., Bull., 33(6): 513-523.
2

Ishii, Takeo. 1967b. Studies on estimating parameters of a fish population supplied by sequential recruitment-II. A method of simultaneous estimation by minimizing the tracing index. Jap. Soc. Sci. Fish., Bull., 33(8): 738-745.
2

Ishii, Takeo. 1967c. Biometrical studies on the variability of population density of tuna and marlin species caught by tuna longline in the south Pacific Ocean. Univ. Tokyo, Ocean Res. Inst., Bull., 2: 86pp.
124

Ishii, Takeo. 1969. Studies on estimating parameters of a fish population supplied by sequential recruitment-V. Simultaneous estimation of parameters with the transfer effect of Pacific yellowfin tuna. Jap. Soc. Sci. Fish., Bull., 35(6): 537-545.
2

Iversen, Robert T.B. 1962. Food of the albacore, *Thunnus germo* (Lacepede), in the central and northeastern Pacific. U.S. Fish Wild. Serv., Fish. Bull., 62(214): 459-481.
16

Iversen, Robert T.B. 1967. Response of yellowfin tuna (*Thunnus albacares*) to underwater sound. In Tavolga, William N. (editor), Marine Bio-acoustics, Vol. 2, Pergamon, New York: 105-121.
2

Iversen, R.T.B. 1969. Auditory thresholds of the scombrid fish *Euthynnus affinis*, with comments on the use of sound in tuna fishing. FAO, Fish. Rep., 62(3): 849-859.

Iversen, Robert T.B., Eugene L. Nakamura, and Reginald M. Gooding. 1970. Courting behavior in skipjack tuna, *Katsuwonus pelamis*. Amer. Fish. Soc., Trans., 99(1): 93.
6

Iverson, Ingrid L.K. 1971. Albacore food habits. Calif. Dept. Fish Game, Fish Bull., 152: 11-46.
18

Iwai, Tamotsu, Izumi Nakamura, and Kiyomatsu Matsubara. 1965. Taxonomic study of the tunas. Kyoto Univ., Misaki Mar. Biol. Inst., Spec. Rep., 2: 51pp.

Iwasa, Kentaro, and Shoichi Mizuno. 1979. Report of feasibility study 1978 on skipjack pole-and-line fisheries in the Micronesian waters. Japan Mar. Fish. Resource Research Center, Rep., 18: 131pp.
246

de Jager, B. 1963. Synopsis of biological data on bluefin tuna Thunnus thynnus orientalis (Temminck and Schlegel) 1842, longfin tuna Thunnus alalunga (Bonnaterre) 1788, yellowfin tuna Thunnus albacares (Bonnaterre) 1788 and bigeye tuna Thunnus obesus (Lowe) 1839 (South Africa). FAO, Fish. Rep., 6(2): 588-607.
12346

de Jager, B. van D., C.S. de V. Nepgen, and R.J. van Wyk. 1963. A preliminary report on South African west coast tuna. South Africa, Div. Sea Fish., Inves. Rep., 47: 40pp.
1234

Johnson, James H. 1962. Sea temperatures and the availability of albacore off the coasts of Oregon and Washington. Amer. Fish. Soc., Trans., 91(3): 269-274.
1

Jones, Everet C. 1971. Isistius brasiliensis, a squaloid shark, the probable cause of crater wounds on fishes and cetaceans. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(4): 791-798.
126

Jordan, David Starr, and Barton W. Evermann. 1908. American Food and Game Fishes. Doubleday, Page and Company, New York: 1, 572pp.
158

Jordan, David Starr, and Eric Knight Jordan. 1922. A list of the fishes of Hawaii, with notes and descriptions of new species. Carneg. Mus., Mem., 10(1): 1-92.

Jordan Sotelo, Romulo. 1979. Inst. Mar Peru, personal communication to Clifford L. Peterson, Inter-Amer. Trop. Tuna Comm.
8

Jordan Sotelo, Romulo, Jorge Csirke Barcelli, and Isabel Tsukayama Kikumoto. 1978. Situacion de los recursos anchoveta, sardina, jurel y caballa a junio 1978. Inst. Mar Peru, Informe, 56: 21pp.
8

Joseph, James. 1963. The fecundity of yellowfin tuna (Thunnus albacares) and skipjack (Katsuwonus pelamis) from the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 7(4): 255-292.
26

Joseph, James. 1970. Management of tropical tunas in the eastern Pacific Ocean. Amer. Fish. Soc., Trans., 99(3): 629-648.
26

Joseph, James. 1972. International arrangements for the management of tuna: a world resource. In Rothschild, Brian J. (editor), World Fisheries Policy--Multidisciplinary Views, Univ. Washington Press, Seattle: 90-120.
26

Joseph, J. 1973a. Scientific management of the world stocks of tunas, billfishes, and related species. Fish. Res. Bd. Canada, Jour., 30(12): 2471-2482.

Joseph, James. 1973b. Tropical tuna management in the eastern Pacific. Fishing News Inter., 12(2): 12-14, 17.
26

Joseph, James. 1977. The management of highly migratory species--some important concepts. Marine Policy, 1(4): 275-288.
26

Joseph, James, Franklin G. Alverson, Bernard D. Fink, and Edwin B. Davidoff. 1964. A review of the population structure of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 9(2): 53-112.
2

Joseph, James, and Thomas P. Calkins. 1969. Population dynamics of the skipjack tuna (*Katsuwonus pelamis*) of the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 13(1): 1-273.
6

Joseph, James, and Joseph W. Greenough. 1979. International Management of Tuna, Porpoise, and Billfish--Biological, Legal, and Political Aspects. Univ. Washington Press., Seattle: xv, 253pp.
26

Joseph, James, and Witold L. Klawe. 1974. The living pelagic resources of the Americas. Ocean. Devel. Inter. Law Jour., 2(1): 37-64.
2567

Joseph, James, Witold Klawe, and Pat Murphy. 1979. Tuna and Billfish--Fish without a Country. Inter-American Tropical Tuna Commission, La Jolla: vii, 46pp.

Joseph, James, Witold Klawe, and Pat Murphy. 1980. Tuna and Billfish--Fish Without a Country, second edition. Inter-American Tropical Tuna Commission, La Jolla: vii, 46pp.

Josse, E., J C. Le Guen, R. Kearney, A. Lewis, A. Smith, L. Marec, and P.K Tomlinson. 1979. Growth of skipjack. South Pacific Comm., Occas. Pap., 11: 83pp.
6

Juhl, Rolf. 1955. Notes on the feeding habits of subsurface yellowfin and bigeye tunas of the eastern tropical Pacific Ocean. Calif. Fish Game, 41(1): 99-101.
24

June, Fred C. 1950. Preliminary fisheries survey of the Hawaiian-Line Islands area. Part I. The Hawaiian long-line fishery. Comm. Fish. Rev., 12(1): 1-23.
124

June, Fred C. 1952. Observations on a specimen of bluefin tuna (*Thunnus thynnus*) taken in Hawaiian waters. Pacif. Sci., 6(1): 75-76.
5

June, Fred C. 1953. Spawning of yellowfin tuna in Hawaiian waters. U.S. Fish Wild. Serv., Fish. Bull., 54(77): 47-64.
2

Kabata, Z. 1970. Copepoda parasitic on Australian fishes-X. Families Eudactylinidae and Pseudocycnidae. Jour. Nat. Hist., 4: 159-173.
12456

Kamimura, Tadeo (discussion leader). 1966. Stock assessment. Jap. Soc. Sci. Fish., Bull., 32(9): 756-786, 829.
1245

Kamimura, Tadeo, and Misao Honma. 1963. Distribution of the yellowfin tuna *Neothunnus macropterus* (Temminck and Schlegel) in the tuna longline fishing grounds of the Pacific Ocean. FAO, Fish. Rep., 6(3): 1299-1328.
2

Kamiya, Takayuki. 1925. The pelagic eggs and larvae of fishes in the Tateyawa Bay (Pref. Chiba), 3rd report. Imp. Fish. Inst., Jour., 21(3): 27-36.
8

Kanasashi, Yoshiaki. 1960. Longline fishing: deck design and equipment. In Traung, Jan-Olof (editor), Fishing Boats of the World: 2, Fishing News (Books) Ltd., London: 73-83.

Kariya, Teiji, and Masao Takahashi. 1969a. The relationship of food intake to the stomach contents in the mackerel, *Scomber japonicus*. Jap. Soc. Sci. Fish., Bull., 35(4): 386-390.
8

Kariya, Teiji, and Masao Takahashi. 1969b. On the feeding behavior of the mackerel. Jap. Soc. Sci. Fish., Bull., 35(7): 619-623.
8

Kasahara, H., and H. Ito. 1953. Fish. Sci. Ser. 7, 1 (cited in Hatanaka and Takahashi, 1960).
8

Kasahara, Kohei. 1977. The trends in the southern water skipjack tuna fishery. Suisan Sekai, 26(3): 28-33 (translation by U.S. Nat. Mar. Fish. Serv.).
6

Kasahara, Kohei. 1978. Atlas of catch and CPUE of skipjack tuna in the Japanese bait-boat fishery, 1972-1976. Tohoku Reg. Fish. Res. Lab.
6

Kawakami, Takeo. 1962. Studies on the movement of mackerel shoals and related environmental factors-I. Migration of mackerels in the Ishikari Bay, Hokkaido. Jap. Soc. Sci. Fish., Bull., 28(12): 1179-1183.
8

Kawasaki, Tsuyoshi. 1964. Population structure and dynamics of skipjack in the north Pacific and its adjacent waters. Tohoku Reg. Fish. Res. Lab., Bull., 24: 28-47.
6

Kawasaki, Tsuyoshi. 1965a. Ecology and dynamics of the skipjack population-II. Resource and fishing conditions. Jap. Fish. Resources Conser. Assoc., Study Ser., 8-2: 49-108 (translation by U.S. Joint Publications Research Service).
6

Kawasaki, Tsuyoshi. 1965b. Ecology and dynamics of the skipjack population-I. Resource and fishing conditions. Jap. Fish. Resources Conser. Assoc., Study Ser., 8-1: 1-49 (translation by Makoto Peter Miyake, Inter-Amer. Trop. Tuna Comm.).
6

Kawasaki, Tsuyoshi. 1972. The skipjack tuna resource. Suisan Shuho, 660: 32-38 (translation by Otsu, Tamio, 1973, Mar. Fish. Rev., 35(5-6): 1-7).
6

Kearney, R.E. 1977. An estimation of Papua New Guinea's tuna fisheries potential. South Pacif. Comm., Occas. Pap., 3: 35pp.
246

Kearney, R.E. 1978. Some hypotheses on skipjack (*Katsuwonus pelamis*) in the Pacific Ocean. South Pacif. Comm., Occas. Pap., 7: 23pp.
6

Kearney, R.E. 1979. An overview of recent changes in the fisheries for highly migratory species in the western Pacific Ocean and projections for future developments. South Pacif. Bur. Econ. Coop., SPEC (79)17: 99pp.
12346

Kearney, R.E. 1980. Skipjack survey and assessment programme annual report for the year ending 31 December 1979. South Pacif. Comm.: 18pp.
1246

Kearney, R.E., and R.D. Gillett. 1980. Interim report of the activities of the skipjack survey and assessment programme in the waters of the Pitcairn Islands (2-5 February 1980). South Pacif. Comm., Skipjack Survey and Assessment Programme, Preliminary Country Report, 22: 9 pp.
246

Kearney, R.E., and J.P. Hallier. 1980. Second interim report of the activities of the skipjack survey and assessment programme in the waters of the Trust Territory of the Pacific Islands (2-21 November 1979). South Pacif. Comm., Skipjack Survey and Assessment Programme, Preliminary Country Report, 19: 18pp.
246

Kerr, Alan. 1978. Year sees new fisheries rise to prominence. New Zealand, Minis. Agri. Fish., Catch '78, 5(11): 10-11.
16

Kikawa, Shoji. 1953. Observations on the spawning of the big-eyed tuna (*Parathunnus mebachi* Kishinouye) near the southern Marshall Islands. Nankai Reg. Fish. Res. Lab., Contr., 1(42): 10pp.
4

Kikawa, Shoji. 1959. Notes on the regional difference of spawning season of Pacific yellowfin tuna. Nankai Reg. Fish. Res. Lab., Rep., 11: 59-76.
2

Kikawa, Shoji. 1961. The group maturity of bigeye tuna *Parathunnus mebachi* (Kishinouye) in the spawning area of the Pacific. Nankai Reg. Fish. Res. Lab., Rep., 13: 35-46.
4

Kikawa, Shoji. 1962. Studies on the spawning activity of Pacific tunas, *Parathunnus mebachi* and *Neothunnus macropterus*, by the gonad index examination. Nankai Reg. Fish. Res. Lab., Occas. Rep., 1: 43-56.
24

Kikawa, Shoji. 1964a. Estimated number of eggs spawned out of the ovaries of an indomaguro (*Thunnus thynnus maccoyii*?). Nankai Reg. Fish. Res. Lab., Rep., 20: 27-35.
3

Kikawa, Shoji. 1964b. A study on indomaguro (*Thunnus thynnus maccoyii*?) in the area south of 20°S lat. from the examination of ovary weight and maturity. Nankai Reg. Fish. Res. Lab., Rep., 20: 37-57.
3

Kikawa, Shoji. 1966. The distribution of maturing bigeye and yellowfin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. Nankai Reg. Fish. Res. Lab., Rep., 23: 131-208.
24

Kikawa, Shoji. 1971. Maguro ni tsuite--magurorui no hyoshiki horyu no genjo (On tunas--the present conditions of tagging experiments for tunas). Seikai Reg. Fish. Res. Lab., Hyoshiki horyu ni yoru shigen Kaisohi ni Kansuru sinpojum gijiroku: 13-19.

Kikawa, Shoji. 1975. Synopsis on the biology of the shortbill spearfish, Tetrapturus angustirostris Tanaka, 1914 in the Indo-Pacific areas. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS SSRF-675, Part 3: 39-54.
6

Kikawa, Shoji, Tsutomu Koto, Chiomi Shingu, and Yasuo Nishikawa. 1968. The status of the tuna fisheries of the Indian Ocean as of 1968. Far Seas Fish. Res. Lab., S Series, 2: 28pp.
12346

Kikawa, Shoji, Toshio Shiohama, Yasuo Morita, and Susumu Kume. 1977. Preliminary study on the movement of the north Pacific albacore based on the tagging. Far Seas Fish. Res. Lab., Bull., 15: 101-113.
1

Kikawa, Shoji, and Ikuo Warashina. 1972. The catch of the young yellowfin tuna by the skipjack pole-and-line fishery in the southern area of the western Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 6: 39-49.
26

Kimura, Kinosuke. 1932. Growth curves of blue-fin tuna and yellow-fin tuna based on the catches near Sigedera on the west coast of prov. Izu. Jap. Soc. Sci. Fish., Bull., 1(1): 1-4 (translation by Van Campen, W. G., 1950, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 22: 11-16).
25

Kimura, Kinosuke, Mitsuo Iwashita, and Toshio Hattori. 1952. Image of skipjack and tuna recorded on echo sounding machine. Tohoku Reg. Fish. Res. Lab., Bull., 1: 15-19.
6

King, Joseph E., and Thomas S. Hida. 1957. Zooplankton abundance in the central Pacific, Part II. U.S. Fish Wild. Serv., Fish. Bull., 57(118): 365-395.
26

King, Joseph E., and Isaac I. Ikehara. 1956. Comparative study of food of bigeye and yellowfin tuna in the central Pacific. U.S. Fish Wild. Serv., Fish. Bull., 57(108): 61-85.
246

Kirkwood, G.P. 1980. Generalized models for the estimate of rates of tag shedding by southern bluefin tuna (Thunnus maccoyii). Cons. Inter. Explor. Mer, Jour., 39: in press.
3

Kishinouye, Kamakichi. 1923. Contributions to the comparative study of the so-called scombroid fishes. Tokyo Univ., Coll. Agri., Jour., 8(3): 293-475.

Kitchell, James F., William H. Neill, Andrew F. Dizon, and John J. Magnuson. 1978. Bioenergetic spectra of skipjack and yellowfin tunas. In Sharp, Gary D. and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 357-368.
26

Kitchell, Jennifer A. 1980. Skipjack hot-bodied bullets of the sea. Oceans, 13(6): 36-41.
6

Klawe, W.L. 1959. Nuevo examen de atunes jovenes capturados frente a la costa occidental de Mexico durante la quinta expedicion George Vanderbilt (1941). Ciencia Mex., 18 (11-12): 245-247.
25

Klawe, Witold L. 1963. Observations on the spawning of four species of tuna (Neothunnus macropterus, Katsuwonus pelamis, Auxis thazard and Euthynnus lineatus) in the eastern Pacific Ocean, based on the distribution of their larvae and juveniles. Inter-Amer. Trop. Tuna Comm., Bull., 6(9): 447-540.
267

Klawe, W.L. 1977a. What is a tuna? Mar. Fish. Rev., 39(11): 1-5.

Klawe, Witold L. 1977b. Inter-Amer. Trop. Tuna Comm., personal communication to Tamio Otsu, U.S. Nat. Mar. Fish. Serv.
7

Klawe, W.L. 1978. World catches of tunas and tuna-like fishes in 1975. Inter-Amer. Trop. Tuna Comm., Internal Rep., 11: 191pp.

Klawe, Witold L. 1979. Inter-Amer. Trop. Tuna Comm., personal communication to Douglas B. Gordon, Atlan. States Mar. Fish. Comm.
7

Klawe, Witold L., Izadore Barrett, and Barbara M. Hillsdon Klawe. 1963. Haemoglobin content of the blood of six species of scombroid fishes. Nature, 198(4875): 96.
2678

Klawe, Witold L., and Thomas P. Calkins. 1965. Length-weight relationship of black skipjack tuna, Euthynnus lineatus. Calif. Fish Game, 51(3): 214-216.
7

Klawe, Witold L., and Makoto Peter Miyake. 1967. An annotated bibliography on the biology and fishery of the skipjack tuna, Katsuwonus pelamis, of the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 12(4): 137-363.
6

Klawe, W.L., J.J. Pella, and W.S. Leet. 1970. The distribution, abundance and ecology of larval tunas from the entrance to the Gulf of California. Inter-Amer. Trop. Tuna Comm., Bull., 14(4): 505-544.
27

Klingbeil, Richard A. 1976. Status of Pacific mackerel spawning population, 1976. Calif. Dept. Fish Game, Mar. Res. Admin. Rep., 76-12: 22pp.
8

Klingbeil, Richard A. 1977. Status of Pacific mackerel spawning population, 1977. Calif. Dept. Fish Game: 25pp (draft).
8

Klingbeil, Richard A. 1979. Calif. Dept. Fish Game, personal communication.
8

Klingbeil, Richard A. 1980. Calif. Dept. Fish Game, personal communication.
8

Knaggs, Eric H. 1972a. Southern California Pacific mackerel fishery and age composition of commercial landings during the 1968-69 and 1969-70 seasons. Calif. Fish Game, 58(2): 116-120.
8

Knaggs, Eric H. 1972b. San Pedro wetfish fleet: major purse-seine gear changes, 1952-1972. Comm. Fish. Rev., 34(5-6): 11-32.
8

Knaggs, Eric H. 1974. Status of the Pacific mackerel spawning population, 1974. Calif. Dept. Fish Game, Mar. Res. Admin. Rep., 74-5: 10pp.
8

Knaggs, Eric H., and Richard H. Parrish. 1973. Maturation and growth of Pacific mackerel, <u>Scomber japonicus</u> Houttuyn. Calif. Fish Game, 59(2): 114-120.
8

Knaggs, Eric H., and John S. Sunada. 1975. Status of Pacific mackerel spawning population, 1975. Calif. Dept. Fish Game, Mar. Res. Admin. Rep., 75-5: 12pp.
8

Knudsen, Phyllis Farrington. 1977. Spawning of yellowfin tuna and the discrimination of subpopulations. Inter-Amer. Trop. Tuna Comm., Bull., 17(2): 117-169.
2

Koga, Shigeyuki. 1968. A study of the fishing condition of the tuna and marlin in the Tasman Sea. Shimonoseki Univ. Fish., Jour. 16(2,3): 51-70.
1234

Kojima, Shumpei. 1962. On the movements of the mackerel, <u>Scomber japonicus</u> Houttuyn, tagged in the neighboring waters of Oki Islands. Jap. Soc. Sci. Fish., Bull., 28(1): 17-25.
8

Konagaya, Shiro, Kazuoki Yamabe, and Keishi Amano. 1969. On body temperatures of tunas at the time of haulage. Jap. Soc. Sci. Fish., Bull., 35(4): 410-416.
12346

Koski, Robert T. 1967. Age and growth determination of bluefin tuna in the north Pacific Ocean. Calif. State College, Long Beach, M.A. thesis: vi, 51pp.
5

Koto, Tsutomu. 1963. Studies on the albacore-IX. The length frequency distribution of albacore caught by the swordfish longline, so called "Yonawa," in the north of the north Pacific albacore longline fishing ground. Nankai Reg. Fish. Res. Lab., Rep.,17: 93-103.
1

Koto, Tsutomu. 1964. Studies on the albacore-X. The length frequency distribution of albacore in the central north Pacific longline ground. Nankai Reg. Fish. Res. Lab., Rep., 20: 17-25.
1

Koto, Tsutomu. 1966. Studies on albacore-XI. Distribution of albacore in the tuna longline fishing grounds of the south Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 23: 43-53.
1

Kramer, David. 1960. Development of eggs and larvae of Pacific mackerel and distribution and abundance of larvae 1952-56. U.S. Fish Wild. Serv., Fish. Bull., 60(174): 393-438.
8

Kramer, David. 1969. Synopsis of the biological data on the Pacific mackerel *Scomber japonicus* Houttuyn (northeast Pacific). U.S. Fish Wild. Serv., Circ., 302: 18pp.
8

Kramer, David, and Paul E. Smith. 1970. Seasonal and geographic characteristics of fishery resources, California Current region-IV. Pacific mackerel. Comm. Fish. Rev., 32(10): 47-49.
8

Kume, Susumu. 1962. A note on the artificial fertilization of bigeye tuna, *Parathunnus mebachi* (Kishinouye). Nankai Reg. Fish. Res. Lab., Rep., 15: 79-84.
4

Kume, Susumu. 1967. Distribution and migration of bigeye tuna in the Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 25: 75-80.
4

Kume, Susumu. 1969a. Ecological studies on bigeye tuna-V. A critical review on distribution, size composition and stock structure of bigeye tuna in the north Pacific Ocean (north of 16°N). Far Seas Fish. Res. Lab., Bull., 1: 57-75.
4

Kume, Susumu. 1969b. Ecological studies on bigeye tuna-VI. A review on distribution and size composition of bigeye tuna in the equatorial and south Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 1: 77-98.
4

Kume, S. 1974. Tuna fisheries and their resources in the Pacific Ocean. Indo-Pacif. Fish. Coun., Proc., 15(3): 390-423.
12345

Kume, Susumu, and Koichi Hisada. 1969. Showa 44 nen-do minami Taiseiyo maguro haenawa shin gyojo kaihatsu chosa, Dai 1-ji kokai no gaiyo (Research and exploitation of the new tuna longline fishing ground in the South Atlantic in the fiscal year of 1966--outline of the first cruise). Tuna Fishing, New Series, 5: 14-20.

Kume, Susumu, and James Joseph. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese longline fishery in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 11(2): 45-99.
4

Kume, Susumu, and James Joseph. 1969. The Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean east of 130°W, 1964-1966. Inter-Amer. Trop. Tuna Comm., Bull., 13(2): 275-418.
124

Kume, Susumu, and Yasuo Morita. 1966. Ecological studies on bigeye tuna-III. On bigeye tuna, *Thunnus obesus*, caught by "nighttime longline" in the north Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 24: 21-30.
4

Kume, Susumu, and Yasuo Morita. 1967. Ecological studies on bigeye tuna-IV. Size composition of bigeye tuna, *Thunnus obesus* (Lowe), caught by pole-and-line fishery in the north-western Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 25: 81-90.
4

Kume, Susumu, and Milner B. Schaefer. 1966. Studies on the Japanese long-line fishery for tuna and marlin in the eastern tropical Pacific Ocean during 1963. Inter-Amer. Trop. Tuna Comm., Bull., 11(3): 101-170.
124

Kurogane, Kenji, and Yoshio Hiyama. 1957a. Morphometric characteristics of the albacore, *Germo germo*, from the northwest Pacific. Rec. Ocean. Works Japan, 4(1): 67-75.
1

Kurogane, Kenji, and Yoshio Hiyama. 1957b. Morphometric comparison of the yellowfin taken from the equatorial Pacific. Jap. Soc. Sci. Fish., Bull., 23(7-8): 388-393.
2

Laevastu, Taivo, and Horacio Rosa, Jr. 1963. Distribution and relative abundance of tunas in relation to their environment. FAO, Fish. Rep., 6(3): 1835-1851.
124567

Lasker, Reuben. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(3): 453-462.

Lasker, Reuben. 1978. The relation between oceanographic conditions and larval anchovy food in the California current: identification of factors contributing to recruitment failure. Cons. Perm. Inter. Explor. Mer, Rapp. Proces-Verb., 173: 212-230.

Lasker, Reuben. 1980. Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California Current: contrasting years, 1975 through 1978. Cons. Perm. Inter. Explor. Mer, Rapp. Proces-Verb., 178: in press.

Laurs, R. Michael. 1979a. U.S. Nat. Mar. Fish. Serv., personal communication.
1

Laurs, R. Michael. 1979b. Results from north Pacific albacore tagging studies. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep. , LJ-79-17: 10pp.

1

Laurs, R. Michael, Harold B. Clemens, and Larry H. Hreha. 1976. Nominal catch-per-unit effort of albacore, *Thunnus alalunga* (Bonnaterre), caught by U.S. jig vessels during 1961-1970. Mar. Fish. Rev., 38(5): 1-32.

1

Laurs, R. Michael, Ronald C. Dotson, Andrew Dizon, and Al Jemison. 1980. Observations on swimming depth and ocean temperature telemetered from free-swimming albacore. U.S. Nat. Mar. Fish. Serv., unpublished manuscript.

1

Laurs, R. Michael, and Ronald J. Lynn. 1977. Seasonal migration of north Pacific albacore, *Thunnus alalunga*, into North American coastal waters: distribution, relative abundance, and association with Transition Zone waters. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 75(4): 795-822.

1

Laurs, R. Michael, and Robert N. Nishimoto. 1973. Food-habits of albacore caught in offshore area. In Laurs, R. Michael, and Associates, Report of joint National Marine Fisheries Service-American Fishermen's Research Foundation albacore studies conducted during 1973, U.S. Nat. Mar. Fish. Serv.: 36-40.

1

Laurs, R. Michael, and Robert N. Nishimoto. 1979. Preliminary results from experiment to evaluate otolith daily ring increment method for age determination in north Pacific albacore. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., LJ-79-18: 10pp.
1

Laurs, R. Michael, Richard Ulevitch, and David C. Morrison. 1978. Estimates of blood volume in the albacore tuna. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 135-139.
1

Laurs, R. Michael, and Jerry A. Wetherall. 1979. Estimates of growth rates for north Pacific albacore, Thunnus alalunga (Bonnaterre), based on an analysis of tag returns. U.S. Nat. Mar. Fish. Serv., unpublished manuscript.
1

Laurs, R. Michael, Heeny S.H. Yuen, and James H. Johnson. 1977. Small-scale movements of albacore, Thunnus alalunga, in relation to ocean features as indicated by ultrasonic tracking and oceanographic sampling. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 75(2): 347-355.
1

Lee, Jang Uk, Jong Soo Hue, and Bong An Kim. 1978. A study of the relative growth of albacore, Thunnus alalunga Bonnaterre, caught by pole and line fishery in the Pacific Ocean. Korea, Fish. Res. Develop. Agency, 20: 77-83.
1

Legand, M. 1960. Longueur, repartition des sexes et maturation sexuelle des thons a nageoires jaunes de Nouvelle-Caledonie. ORSTOM, Nouvelle-Caledonie, Rapp. Sci., 11: 6-20.
2

Legand, M. 1961. Taille, repartition sexuelle, cycle annuel de l'albacore dans l'ouest de la Nouvelle-Caledonie. Nouvelle-Caledonie, Inst. Fran. Ocean., Cent. Ocean., Rapp. Sci., 24 (summary in U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 415: 30-31).
1

Legand, M., and B. Wauthy. 1961. Importance presumee d'Alepisaurus sp. dans le cycle biologique des thons de longue-ligne au large de la Nouvelle-Caledonie. Nouvelle-Caledonie, Inst. Fran. Ocean., Cent. Ocean., Rapp. Sci., 24 (summary in U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 415: 29-30).
1

Le Guen, J.-C., J.-R. Donguy, and C. Henin. 1977. Perspectives thonieres dans le Pacifique sud. La Peche Maritime, 1186: 20-28.
6

Lenarz, William H., and James R. Zweifel. 1979. A theoretical examination of some aspects of the interaction between longline and surface fisheries for yellowfin tuna, *Thunnus albacares*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 76(4): 807-825.
2

Leong, Roderick. 1977. Maturation and induced spawning of captive Pacific mackerel, *Scomber japonicus*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 75(1): 205-211.
8

Lewis, A.D. 1980. Tagging of skipjack tuna (*Katsuwonus pelamis*) in Papua New Guinea waters, 1971-1972. Papua New Guinea, Dept. Primary Indus., Res. Bull., 25: 25 pp.
6

Lewis, A.D., B.R. Smith, and R.E. Kearney. 1974. Studies on tunas and baitfish in Papua New Guinea waters-II. Papua New Guinea, Dept. Agri. Stock Fisheries, Res. Bull., 11.
26

Lindberg, G.U. 1971. Fishes of the World. A Key to Families and a Checklist. John Wiley and Sons, New York: v, 545pp.

Linthicum, D. Scott, and Francis G Carey. 1972. Regulation of brain and eye temperatures by the bluefin tuna. Comp. Biochem. Physiol., 43(2A): 425-433.
1245

Love, Milton S., and Mike Moser. 1977. Parasites of California, Oregon, and Washington marine and estuarine fishes. Univ. Calif. Santa Barbara, Mar. Sci. Inst.: 530pp.
1245678

Lucas, C. 1974. Working paper on southern bluefin tuna population dynamics. Inter. Comm. Conser. Atlan. Tunas, Coll. Vol. Sci. Pap., 3: 110-124.
3

MacCall, Alec. 1973. The status of the Pacific mackerel resource and its management. Calif. Dept. Fish Game, Mar. Res. Tech. Rep., 12: 13pp (manuscript).
8

MacCall, Alec D. 1979. Calif. Dept. Fish Game, personal communication.
8

MacCall, Alec D., Gary D. Stauffer, and Jean-Paul Troadec. 1976. Southern California recreational and commercial marine fisheries. Mar. Fish. Rev., 38(1): 1-32.
8

MacGregor, John S. 1966. Synopsis on the biology of the jack mackerel (*Trachurus symmetricus*). U.S. Fish. Wild. Serv., Spec. Sci. Rep. Fish., 526: 16pp.

MacGregor, John S. 1976. Ovarian development and fecundity of five species of California Current fishes. Calif. Coop. Ocean. Fish. Inves., Rep., 18: 181-188.
8

Maeda, Kazumi, and Masato Shiota. 1979. Distribution and catch variations of infant bluefin tuna in the waters west of Kyushu. High Seas Fish. Res. Soc., Nansei-kai Regional Block, Proc. Brief: 50-58.
5

Magnuson, John J. 1969a. Digestion and food consumption by skipjack tuna (*Katsuwonus pelamis*). Amer. Fish. Soc., Trans., 98(3): 379-392.
6

Magnuson, J.J. 1969b. Swimming activity of the scombrid fish *Euthynnus affinis* as related to search for food. FAO, Fish. Rep., 62(2): 439-451.

Magnuson, John J. 1970. Hydrostatic equilibrium of *Euthynnus affinis*, a pelagic teleost without a gas bladder. Copeia, (1): 56-85.

Magnuson, John J. 1973. Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphoid fishes. U.S. Nat. Fish. Mar. Serv., Fish. Bull., 71(2): 337-356.
2468

Magnuson, John J. 1978a. Foreword. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: xi-xiii.

Magnuson, John J. 1978b. Locomotion by scombrid fishes: hydromechanics, morphology, and behavior. In Hoar, W. S., and D. J. Randall (editors), Fish Physiology, Volume VII, Academic Press, New York: 239-313.
1245678

Magnuson, John J., and Jean G. Heitz. 1971. Gill raker apparatus and food selectivity among mackerels, tunas, and dolphins. U S. Nat. Mar. Fish. Serv., Fish. Bull., 69(2): 361-370.
12468

Magnuson, John J., and John H. Prescott. 1966. Courtship, locomotion, feeding, and miscellaneous behaviour of the Pacific bonito (*Sarda chiliensis*). Animal Behav., 14(1): 54-67.

Magnuson, John J., and David Weininger. 1978. Estimation of minimum sustained speed and associated body drag of scombrids. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 293-311.
12468

Mais, Kenneth F. 1974. Pelagic fish surveys in the California Current. Calif. Dept. Fish Game, Fish Bull., 162: 79pp.
8

Mais, Kenneth F., and Tom Jow. 1960. Exploratory longline fishing for tunas in the eastern tropical Pacific, September, 1955 to March, 1956. Calif. Fish Game, 46(2): 117-150.
2467

Manacop, Porfirio R. 1956. A preliminary systematic study of the Philippine chub mackerels, family Scombridae genera *Pneumatophorus* and *Rastrelliger*. Philip. Jour. Fish., 4(2): 79-101.
8

Mann, Herbert J. 1955. Construction details of improved tuna long-line gear used by Pacific Oceanic Fishery Investigations. Comm. Fish. Rev., 17(12): 1-10.

Mann F., Guillermo. 1954. Vida de los Peces en Aguas Chilenas. Ministerio de Agricultura and Universidad de Chile, Santiago: 342pp.
12568

Marcille, Jacques. 1980. ORSTOM, Noumea, New Caledonia, personal communication.

Marcille, J., A. Asine, L. Marec, and P. Mariterangi. 1979. La peche bonitiere a Tahiti. ORSTOM, Papeete, unpublished manuscript: 38pp.
6

Marr, John C. 1948. Observations on the spawning of oceanic skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Neothunnus macropterus*) in the northern Marshall Islands. U.S. Fish Wild. Serv., Fish. Bull., 51(44): 201-206.
26

Martinez F., Carlos. 1974. Prospeccion de atunes y peces espadas en el Oceano Pacifico oriental al este de 110°W: los segundo semestre de 1971. Com. Perm. Pacif. Sur, Rev. Secretaria General, 2: 7-57.
1246

Matsui, Tetsuo. 1967. Review of the mackerel genera *Scomber* and *Rastrelliger* with description of a new species of *Rastrelliger*. Copeia, (1): 71-83.
8

Matsui, Tetsuo. 1979. Scripps Inst. Ocean., personal communication.
8

Matsumoto, Walter M. 1958. Description and distribution of larvae of four species of tuna in central Pacific waters. U.S. Fish Wild. Serv., Fish. Bull., 58(128): 31-72.
26

Matsumoto, Walter M. 1961. Collection and description of juvenile tunas from the central Pacific. Deep Sea Res., 8(3-4): 279-286.
26

Matsumoto, Walter M. 1962. Identification of larvae of four species of tuna from the Indo-Pacific region I. Dana Report, 55: 16pp.
145

Matsumoto, Walter M. 1966a. Distribution and abundance of tuna larvae in the Pacific Ocean. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 221-230.
12456

Matsumoto, Walter M. 1966b. Catch and effort statistics for the eastern Pacific tuna fishery. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 131-146.
12456

Matsumoto, Walter M. 1974. The skipjack tuna, *Katsuwonus pelamis*, an under-utilized resource. Mar. Fish. Rev., 36(8): 26-33.
6

Matsumoto, Walter M. 1975. Distribution, relative abundance, and movement of skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean based on Japanese tuna long-line catches, 1964-1967. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep., NMFS SSRF-695: 30pp.
6

Matsumoto, Walter M. 1976. Second record of black skipjack, *Euthynnus lineatus*, from the Hawaiian islands. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 74(1): 207.
7

Matsumoto, Walter M., Elbert H. Ahlstrom, S. Jones, Witold L. Klawe, William J. Richards, and Shoji Ueyanagi. 1972. On the clarification of larval tuna identification particularly the genus *Thunnus*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(1): 1-12.
12345

Matsumoto, Walter M., and Tagay Kang. 1967. The first record of black skipjack, *Euthynnus lineatus*, from the Hawaiian Islands. Copeia, (4): 837-838.
7

Matsumoto, Walter M., and Robert A. Skillman. in press. Synopsis of biological data on skipjack tuna, *Katsuwonus pelamis* (Linnaeus). U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep., NMFS SSRF.
1246

Mayo, Charles Atkins. 1973. Rearing, growth, and development of the eggs and larvae of seven scombrid fishes from the Straits of Florida. Univ. Miami, Ph.D. dissertation: 127pp.

McAllister, Robert. 1975. California marine fish landings for 1973. Calif. Dept. Fish Game, Fish Bull., 163: 53pp.

McAllister, Robert. 1976. California marine fish landings for 1974. Calif. Dept. Fish Game, Fish Bull., 166: 53pp.

McGary, James W., Joseph J. Graham, and Tamio Otsu. 1960. Oceanography and north Pacific albacore. Calif. Coop. Ocean. Fish. Inves., Rep., 8: 45-53.
1

McGary, James W., Everet C. Jones, and Joseph J. Graham. 1958. Enrichment in the Transition Zone between the subarctic and central water masses of the central north Pacific. Pacif. Sci. Cong., Proc., 9(16): 82-89.
1

McHugh, J.L. 1952. The food of albacore (*Germo alalunga*) off California and Baja California. Scripps Inst. Ocean., Bull., 6(4): 161-172.
1

McKenzie, Margaret K. 1964. The distribution of tuna in relation to oceanographic conditions. New Zealand Ecol. Soc., Proc., 11: 6-10.
1236

McNeely, Richard L. 1961. The purse seine revolution in tuna fishing. Pacif. Fisherman, 59(7): 27-58.

Mead, Giles M. 1951. Postlarval *Neothunnus macropterus*, *Auxis thazard*, and *Euthynnus lineatus* from the Pacific coast of Central America. U.S. Fish Wild. Serv., Fish. Bull., 52(63): 121-127.
27

Meehan, James M. 1965. First occurrence of bigeye tuna on the Oregon coast. Oregon Fish Comm., Res. Briefs, 11(1): 53-54.
4

Messersmith, J.D., and Harold Hyatt. 1965. Pacific mackerel, the commercial fishery, and age composition of the Southern California catch for the 1961-62, 1962-63 and 1963-64 seasons. Calif. Fish Game, 51(3): 168-182.
8

Miller, Forrest R., and Richard H. Evans. 1979. The oceanic environment of the eastern tropical Pacific as related to purse seining. Inter-Amer. Trop. Tuna Comm. and U.S. Nat. Mar. Fish. Serv., unpublished manuscript.
26

Miller, Forrest R., and R. Michael Laurs. 1975. The el Niño of 1972-1973 in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 16(5): 401-448.
8

Miller, John M. 1979. Nearshore abundance of tuna (Pisces: Scombridae) larvae in the Hawaiian Islands. Bull. Mar. Sci., 29(1): 19-26.
1456

Mimura, Koya. 1958. Fishing condition of the so-called indomagro (*Thunnus maccoyii*?) in the eastern seas of the Indian Ocean. Nankai Reg. Fish. Res. Lab., Rep., 7: 49-58.
3

Mimura, Koya. 1962. Studies on indomaguro, *Thunnus maccoyii*? Nankai Reg. Fish. Res. Lab., Occas. Rep., 1: 15-22.
3

Mimura, Koya, and Ikuo Warashina. 1962. Studies on indomaguro (*Thunnus maccoyii*?). Description of the development of the fishery, geographical difference and seasonal change of distribution and relation which is seen among indomaguro, southern bluefin, and goshumaguro. Nankai Reg. Fish. Res. Lab., Rep., 16: 135-154.
3

Mimura, Koya, et al. 1963. Synopsis of biological data on yellowfin tuna *Neothunnus macropterus* Temminck and Schlegel 1842 (Indian Ocean). FAO, Fish. Rep., 6(2): 319-349.
2

Mitchell, Charles T., and John R. Hunter. 1970. Fishes associated with drifting kelp, *Macrocystis pyrifera*, off the coast of Southern California and northern Baja California. Calif. Fish Game, 56(4): 288-297.
18

Miyake, Iwao. 1952. Observations on sound production and response in tuna. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 91: 59-68.
2

Miyake, Iwao, and Walter R. Steiger. 1957. The response of tuna and other fish to electrical stimuli. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 223: 23pp.
2

Miyake, Makoto Peter. 1968. Distribution of skipjack in the Pacific Ocean, based on records of incidental catches by the Japanese longline tuna fishery. Inter-Amer. Trop. Tuna Comm., Bull., 12(7): 509-608.
6

Moore, Harvey L. 1951. Estimation of age and growth of yellowfin tuna (*Neothunnus macropterus*) in Hawaiian waters by size frequencies. U.S. Fish Wild. Serv., Fish. Bull., 52(65): 133-149.
2

Mori, Keiichiro. 1970. A consideration on the spawning of the tunas, especially of the yellowfin tuna (*Thunnus albacares*) in the adjacent sea of the Pacific coast of Japan. Far Seas Fish. Res. Lab., Bull., 3: 215-228.
2456

Mori, Keiichiro. 1972. Geographical distribution and relative apparent abundance of some scombroid fishes based on the occurrences in the stomachs of apex predators caught on tuna longline-I. Juvenile and young of skipjack tuna (*Katsuwonus pelamis*). Far Seas Fish. Res. Lab., Bull., 6: 111-168.
123456

Mori, Keiichiro, Shoji Ueyanagi, and Yasuo Nishikawa. 1971. The development of artificially fertilized and reared larvae of the yellowfin tuna, *Thunnus albacares*. Far Seas Fish. Res. Lab., Bull., 5: 219-232.
2

Morita, Tomokazu. 1960. Fishing-ground constitutional studies on the white marlin, *Marlina marlina* Jordan and Hill, over the east China Sea-I. On the fishing-ground constitution occurring with the seasonal change of the environment. Jap. Soc. Sci. Fish., Bull., 26(9): 887-893.
68

Morrison, David C., R. Michael Laurs, and Richard J. Ulevitch. 1978. Activity of albacore serum complement reflects its thermoregulatory capacity. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 141-150.
1

Moser, H. Geoffrey, Elbert H. Ahlstrom, David Kramer, and Elizabeth G. Stevens. 1974. Distribution and abundance of the fish eggs and larvae in the Gulf of California. Calif. Coop. Ocean. Fish. Inves., Rep., 17: 112-128.
78

Muramatsu, Shogo. 1960. Pole and line fishing: deck design and equipment. In Traung, Jan-Olof (editor), Fishing Boats of the World: 2, Fishing News (Books) Ltd., London: 84-93.

Murphy, Garth I. 1969. Effect of water clarity on albacore catches. Limnol. Ocean., 4(1): 86-93.
1

Murphy, Garth I. 1977. New understanding of southern bluefin tuna. Austral. Fish., 36(1): 2-6.
3

Murphy, G.I. 1979. Situation report southern bluefin tuna. Indo-Pacific Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, Background Pap., 12: 4pp.
3

Murphy, Garth I., and Richard S. Shomura. 1953. Longline fishing for deep-swimming tunas in the central Pacific, January-June 1952. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 108: 32pp.
1246

Murphy, Garth I., and Richard S. Shomura. 1955. Longline fishing for deep-swimming tunas in the central Pacific, August-November 1952, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 137: 42pp.
1246

Murphy, Garth I., and Richard S. Shomura. 1972. Pre-exploitation abundance of tunas in the equatorial central Pacific. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 875-913.
1246

Murphy, Garth I., and Helen Sutherland. 1979. Mortality rates in the southern bluefin tuna. Indo-Pacific Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, Background Pap., 13: 6pp.
3

Murphy, Richard C. 1971. The structure of the pineal organ of the bluefin tuna, *Thunnus thynnus*. Jour. Morphol., 133: 1-16.
5

Murphy, T.C., and G.T. Sakagawa. 1977. A review and evaluation of estimates of natural mortality rates of tunas. Inter. Comm. Conser. Atlan. Tunas, Coll. Vol. Sci. Pap., 6(1): 117-123.
1245

Naganuma, Akira. 1979. On spawning activities of skipjack tuna in the western Pacific Ocean. Tohoku Reg. Fish. Res. Lab., Bull., 40: 1-13.
6

Nakagome, Jun. 1969. On the cause of annual variation of albacore catch in the Coral and Tasman Seas-III. Monthly and annual variation of distribution of sea surface temperature. Jap. Soc. Sci. Fish., Bull., 35(1): 50-54.
1

Nakamura, Eugene L. 1962. Observations on the behavior of skipjack tuna, *Euthynnus pelamis*, in captivity. Copeia, (3): 499-505.
6

Nakamura, Eugene L. 1965. Food and feeding habits of skipjack tuna (*Katsuwonus pelamis*) from the Marquesas and Tuamotu Islands. Amer. Fish. Soc., Trans., 94(3): 236-242.
6

Nakamura, Eugene L. 1968. Visual acuity of two tunas, *Katsuwonus pelamis* and *Euthynnus affinis*. Copeia, (1): 41-49.
6

Nakamura, E.L. 1969. A review of field observations on tuna behavior. FAO, Fish. Rep., 62(2): 59-68.
123568

Nakamura, Eugene L., and John J. Magnuson. 1965. Coloration of the scombrid fish *Euthynnus affinis* (Cantor). Copeia, (2): 234-235.

Nakamura, Eugene L., and Walter M. Matsumoto. 1967. Distribution of larval tunas in Marquesan waters. U.S. Fish Wild. Serv., Fish. Bull., 66(1): 1-12.
1246

Nakamura, Eugene L., and James H. Uchiyama. 1966. Length-weight relations of Pacific tunas. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 197-201.
1246

Nakamura, Hiroshi. 1969. Tuna Distribution and Migration. Fishing News (Books) Ltd., London: 76pp.
12345

Nakamura, Hiroshi, Tadeo Kamimura, and Yoichi Yabuta. 1953. Size composition of albacore and bigeye tuna of the north Pacific fishing grounds. Nankai Reg. Fish. Res. Lab., Contr., 1 (translation by Van Campen, W.G., 1956, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 182: 1-5).
14

Nakamura, Izumi, and Yukio Warashina. 1965. Occurrence of bluefin tuna, *Thunnus thynnus* (Linnaeus) in the eastern Indian Ocean and the eastern south Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 22: 9-12.
5

Neave, Ferris. 1959. Records of fishes from waters off the British Columbia coast. Fish. Res. Bd. Canada, Jour., 16(3): 383-384.
56

Neill, William H. 1976. Merchanisms of behavioral thermoregulation in fishes. Electric Power Res. Inst., Spec. Rep., 38: 156-169.

Neill, William H., Randolph K.C. Chang, and Andrew E. Dizon. 1976. Magnitude and ecological implications of thermal inertia in skipjack tuna, *Katsuwonus pelamis* (Linnaeus). Envir. Biol. Fish., 1(1): 61-80.
6

Nishikawa, Yasuo, Shoji Kikawa, Misao Honma, and Shoji Ueyanagi. 1978. Distribution atlas of larval tunas, billfishes and related species--results of larval surveys by R/V *Shunyo Maru* and *Shoyo Maru*, 1956-1975. Far Seas Fish. Res. Lab., S Series, 9: 99pp.
123456

Nishimoto, Robert N. 1979. U.S. Nat. Mar. Fish. Serv., personal communication.
1

Nose, Yukio, Hiroshi Kawatsu, and Yoshio Hiyama. 1957. Age and growth of Pacific tunas by scale reading. In Collection of Works on Fisheries Science, Jubilee Publication of Professor I. Amemiya, Univ. Tokyo Press: 701-716.
124

Nowell, John C. 1961. New northern record for black skipjack (*Euthynnus lineatus*). Calif. Fish Game, 47(4): 415.
7

O'Connell, Charles P. 1963. The structure of the eye of *Sardinops caerulea*, *Engraulis mordax*, and four other pelagic marine teleosts. Jour. Morphol., 113(2): 287-329.
8

O'Connell, Charles P., and James R. Zweifel. 1972. A laboratory study of particulate and filter feeding of the Pacific mackerel, *Scomber japonicus*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 973-981.
8

Odate, Shigero. 1961. Study on the larvae of the fishes in the north-eastern sea area along the Pacific coast of Japan. Part I. Mackerel, *Pneumatophorus japonicus* (Houttuyn). Tohoku Reg. Fish. Res. Lab., Bull., 19: 98-108.
8

Ogawa, Yadai. 1979. Accumulation of unfavorable conditions results in record low skipjack tuna landings. Suisan Sekai, 28(2): 34-39 (translation by U.S. Nat. Mar. Fish. Serv.).
6

Okachi, Isao. 1963a. Studies on the distribution and structure of the fish fauna in the Japan Sea by catch statistics. II. Supplement of seasonal distribution and fishing condition of the bluefin tuna. Japan Sea Reg. Fish. Res. Lab., Bull., 11: 9-21.
5

Okachi, Isao. 1963b. Studies on the distribution and structure of the fish fauna in the Japan Sea by catch statistics. III. Type of migration. Japan Sea Reg. Fish. Res. Lab., Bull., 11: 23-32.
58

Okiyama, Muneo. 1974. Occurrence of the postlarvae of bluefin tuna, *Thunnus thynnus*, in the Japan Sea. Japan Sea Reg. Fish. Res. Lab., Bull., 25. 89-97.
5

Okiyama, Muneo. 1979. Successful spawning of some holoepipelagic fishes in the Sea of Japan and zoogeographical implications. Japan-Soviet Joint Symp. Aquaculture, 7: 223-233.
5

Oliphant, M.S. 1973. California marine fish landings for 1971. Calif. Dept. Fish Game, Fish Bull., 159: 49pp.

Oliphant, M.S. 1979. California marine fish landings for 1976. Calif. Dept. Fish Game, Fish Bull., 170: 56pp.

Olson, Robert J. 1980. Inter-Amer. Trop. Tuna Comm., personal communication.

van Olst, Jon C., and John R. Hunter. 1970. Some aspects of the organization of fish schools. Fish. Res. Bd. Canada, Jour., 27(7): 1225-1238.
8

Olvera Limas, Rosa Ma. 1975. Distribucion de larvas de macarela (*Scomber japonicus* Houttuyn) en las areas sur y central del Golfo de California, en abril de 1972. Mexico, Inst. Nat. Pesca, Serie Cient., INP/SC: 12: 15pp.
8

Orange, Craig J. 1961. Spawning of yellowfin tuna and skipjack in the eastern tropical Pacific, as inferred from studies of gonad development. Inter-Amer. Trop. Tuna Comm., Bull., 5(6): 457-526.
26

Orange, Craig J. 1980. Inter-Amer. Trop. Tuna Comm., personal communication.

Orange, Craig J., and Gordon C. Broadhead. 1959. 1958-1959--a turning point for tuna purse seine fishing? Pacif. Fisherman, 57(7): 20, 22, 25, 27.
256

Orange, Craig J., and Bernard D. Fink. 1963. Migration of a tagged bluefin tuna across the Pacific Ocean. Calif. Fish Game, 49(4): 307-308.
5

Orange, Craig J., Milner B. Schaefer, and Fred M. Larmie. 1957. Schooling habits of yellowfin tuna (*Neothunnus macropteus*) and skipjack (*Katsuwonus pelamis*) in the eastern Pacific Ocean as indicated by purse seine catch records, 1946-1955. Inter-Amer. Trop. Tuna Comm., Bull., 2(3): 81-126.
26

Orton, Grace L. 1953. Development and migration of pigment cells in some teleost fishes. Jour. Morphol., 93(1): 69-99.
8

Otsu, Tamio. 1954. Analysis of the Hawaiian long-line fishery, 1948-1952. Comm. Fish. Rev., 16(9): 1-17.
124

Otsu, Tamio. 1960. Albacore migration and growth in the north Pacific Ocean as estimated from tag recoveries. Pacif. Sci., 14(3): 257-266.
1

Otsu, Tamio. 1966. The south Pacific long-line fishery for albacore tuna, 1954-64. Comm. Fish. Rev., 28(7): 9-12.
1

Otsu, Tamio. 1980. U.S. Nat. Mar. Fish. Serv., personal communication.
6

Otsu, Tamio, and Richard J. Hansen. 1962. Sexual maturity and spawning of the albacore in the central south Pacific Ocean. U.S. Fish Wild. Serv., Fish. Bull., 62(204): 51-161.
1

Otsu, Tamio, and Ray F. Sumida. 1968. Distribution, apparent abundance, and size composition of albacore (*Thunnus alalunga*) taken in the longline fishery based in American Samoa, 1954-65. U.S. Fish Wild. Serv., Fish. Bull., 67(1): 47-69.
1

Otsu, Tamio, and Ray F. Sumida. 1970. Albacore of Hawaiian waters, *Thunnus alalunga*. Comm. Fish. Rev., 32(5): 8-26.
1

Otsu, Tamio, and Richard N. Uchida. 1956. Tagged bigeye tuna recovered. Pacif. Sci., 10(2): 236.
4

Otsu, Tamio, and Richard N. Uchida. 1959a. Sexual maturity and spawning of albacore in the Pacific Ocean. U.S. Fish Wild. Serv., Fish. Bull., 59(148): 287-305.
1

Otsu, Tamio, and Richard N. Uchida. 1959b. Study of age determination by hard parts of albacore from central north Pacific and Hawaiian waters. U.S. Fish Wild. Serv., Fish. Bull., 59(150): 353-363.
1

Otsu, Tamio, and Richard N. Uchida. 1963. Model of the migration of albacore in the north Pacific Ocean. U.S. Fish Wild. Serv., Fish. Bull., 63(1): 33-44.

Otsu, T., and H. O. Yoshida. 1966. Distribution and migration of albacore (*Thunnus alalunga*) in the Pacific Ocean. Indo-Pacif. Fish. Coun., Proc., 12(2): 49-64.
1

Otsu, Tamio, and Howard O. Yoshida. 1971. American Samoa fisheries. In Shapiro, Sidney (editor), Our Changing Fisheries, U.S. Nat. Mar. Fish. Serv., Washington: 310-323.
12346

Parin, N. V. 1968. Ichthyofauna of the epipelagic zone. USSR, Acad. Sci., Inst. Ocean.: 206pp (Israel Program for Scientific Translation, 1970).
1235678

Parrish, Richard H. 1974. Exploitation and recruitment of Pacific mackerel, *Scomber japonicus*, in the northeastern Pacific. Calif. Coop. Ocean. Fish. Inves., Rep., 17: 136-140.
8

Parrish, Richard H., and Eric H. Knaggs. 1971. Revision of the age composition of the Southern California catch of Pacific mackerel for the 1958-59 through 1963-64 seasons. Calif. Fish Game, 57(3): 182-201.
8

Parrish, Richard H., and Eric H. Knaggs. 1972. The Southern California Pacific mackerel fishery and age composition of the catch for the 1964-65 through 1967-68 seasons. Calif. Fish Game, 58(1): 13-21.
8

Parrish, Richard H., and Alec D. MacCall. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. Calif. Dept. Fish Game, Fish Bull., 167: 110pp.
8

Partlo, J. M. 1955a. Distribution, age and growth of eastern Pacific albacore (*Thunnus alalunga* Gmelin). Fish. Res. Bd. Canada, Jour., 12(1): 35-60.
1

Partlo, J. M. 1955b. Histological studies on albacore (*Thunnus alalunga*) gonads from the eastern Pacific. Fish. Res. Bd. Canada, Jour., 12(1): 61-67.
1

Pearcy, William G., and James L. Mueller. 1970. Upwelling, Columbia River plume and albacore tuna. International Symposium on Remote Sensing of Enviroment, Proc., 6(2): 1101-1113.
1

Pearcy, William G., Daniel A. Panshin, and Donald F. Keene. 1975. Catches of albacore at different times of the day. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(3): 691-693.
1

Pella, Jerome J., and Christopher T. Psaropulos. 1975. Measures of tuna abundance from purse-seine operations in the eastern Pacific Ocean, adjusted for fleet-wide evolution of fishing power, 1960-1971. Inter-Amer. Trop. Tuna Comm., Bull., 16(4): 281-400.
26

Pella, Jerome J., and Patrick K. Tomlinson. 1969. A generalized stock production model. Inter-Amer. Trop. Tuna Comm., Bull., 13(3): 419-496.
2

Perrin, William F. 1968. The porpoise and the tuna. Sea Frontiers, 14(3): 166-174.
26

Perrin, William F. 1969. Using porpoise to catch tuna. World Fishing, 18(6): 42-45.
26

Perrin, William F., R.R. Warner, C.H. Fiscus, and D.B. Holts. 1973. Stomach contents of porpoise, *Stenella* spp. and yellowfin tuna, *Thunnus albacares*, in mixed-species aggregations. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 71(4): 1077-1092.
2

Peterson, C.L., and W.L. Klawe. 1977. Abundancia, distribucion y potencial de tres pequeños atunes subexplotados, *Sarda*, *Euthynnus* y *Auxis*, de la costa del Pacifico de las Americas. Inst. Tec. Est. Sup. Monterrey, Esc. Cien. Mar. Alimentarias, V Congreso Nac. Ocean., Mem,: 490-499.
7

Petrich, Borti. 1968. Tuna purse seines of today and tomorrow. Univ. Wash. Publ. Fish., New Series, 4: 169-170.

Pinkas, Leo. 1971. Bluefin tuna food habits. Calif. Dept. Fish Game, Fish Bull., 152: 47-63.
58

Pinkas, Leo. 1974. California marine fish landings for 1972. Calif. Dept. Fish Game, Fish Bull., 161: 1-53.

Pinkas, Leo. 1977. California marine fish landings for 1975. Calif. Dept. Fish Game, Fish Bull., 168: 55pp.

Pownall, Peter. 1979. Fisheries of Australia. Fishing News Books Ltd., Franham, U.K.: x, 149pp.
36

Radovich, John. 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures particularly during 1957 through 1959. Calif. Dept. Fish Game, Fish Bull., 112: 62pp.
12456

Radovich, John. 1963. Effects of water temperature on the distribution of some scombrid fishes along the Pacific coast of North America. FAO, Fish. Rep., 6(3): 1459-1475.
12456

Radovich, John, and Earl D. Gibbs. 1954. The use of a blanket net in sampling fish populations. Calif. Fish Game, 40(4): 353-365.
8

Raju, G. 1964. Studies on the spawning of the oceanic skipjack *Katsuwonus pelamis* (Linnaeus) in Minicoy waters. Mar. Biol. Assoc. India, Proc. Symp. Scombroid Fishes, 2: 744-768.
6

Rayner, M.D., and M.J. Keenan. 1967. Role of red and white muscles in the swimming of the skipjack tuna. Nature, 214(5086): 392-393.
6

Reintjes, John W., and Joseph E. King. 1953. Food of yellowfin tuna in the central Pacific. U.S. Fish Wild. Serv., Fish. Bull., 54(81): 91-110.
246

Richards, William J., and G. Robert Dove. 1971. Internal development of young tunas of the genera *Katsuwonus*, *Euthynnus*, *Auxis*, and *Thunnus* (Pisces, Scombridae). Copeia, (1): 72-78.
12456

Richards, William J., and Witold L. Klawe. 1972. Indexed bibliography of the eggs and young of tuna and other scombrids (Pisces, Scombridae), 1880-1970. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS SSRF-652: 107pp.

Richards, W.J., and T. Potthoff. 1973. Analysis of the taxonomic characters of young scombrid fishes, genus Thunnus. In Blaxter, J.H.S. (editor), The Early Life History of Fish, Springer-Verlag, Berlin: 623-648.
12345

Richardson, B.J. 1978a. Skipjack tuna stock identification. South Pacif. Comm., Fish. Newsletter, 16: 8-10.
6

Richardson, B.J. 1978b. Skipjack tuna stock identification. New Zealand, Minis. Agri. Fish., Fish. Res. Div., Occas. Publ., 15: 63-64.
6

Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada, Bull., 119: 300pp.

Ricker, W.E. 1973. Linear regression in fishery research. Fish. Res. Bd. Canada, Jour., 30(3): 409-434.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Canada, Bull., 191: 382pp.

Rivas, Luis Rene. 1953. The pineal apparatus of tunas and related scombrid fishes as a possible light receptor controlling phototactic movements. Bull. Mar. Sci. Gulf Carib., 3(3): 168-180.
56

Roberts, John L., and Jeffrey B. Graham. 1979. Effect of swimming speed on the excess temperatures and activities of heart and red and white muscles in the mackerel, Scomber japonicus. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 76(4): 861-867.
8

Roberts, P.E. 1974. Albacore off the north-west coast of New Zealand, February 1972. New Zealand Jour. Mar. Fresh. Res., 8(3): 455-472.
1

Roberts, P.E., and G.D. James. 1974. Juvenile albacore from New Zealand. New Zealand Jour. Mar. Fresh. Res., 8(2): 437-440.
1

Robins, J.P. 1952. Further observations on the distribution of striped tuna, Katsuwonus pelamis L., in eastern Australian waters, and its relation to surface temperature. Austral. Jour. Mar. Fresh. Res., 3(2): 101-110.
6

Robins, J.P. 1963. Synopsis of biological data on bluefin tuna Thunnus maccoyii (Castelnau) 1872. FAO, Fish. Rep., 6(2): 562-587.
1236

Robins, J.P. 1975. Some aspects of tuna and its potential in the oceanic waters off Western Australia. West. Austral., Dept. Fish. Wild., Rep., 17: 59pp.
12346

Roden, Gunnar I. 1970. Aspects of the mid-Pacific Transition Zone. Jour. Geophys. Res., 75(6): 1097-1109.

Roedel, Phil M. 1948. Occurrence of the black skipjack (Euthynnus lineatus) off Southern California. Calif. Fish Game, 34(1): 38-39.
7

Roedel, Phil M. 1949a. Notes on the spawning grounds and early life history of the Pacific mackerel. Calif. Fish Game, 35(3): 147-153.
8

Roedel, Phil M. 1949b. Movements of Pacific mackerel as demonstrated by tag recoveries. Calif. Fish Game, 35(4): 281-291.
8

Roedel, Phil M. 1952a. A review of the Pacific mackerel (Pneumatophorus diego) fishery of the Los Angeles region with special reference to the years 1939-1951. Calif. Fish Game, 38(2): 253-273.
8

Roedel, Phil M. 1952b. A racial study of the Pacific mackerel, Pneumatophorus diego. Calif. Dept. Fish Game, Fish Bull., 84: 53pp.
8

Roedel, Phil M., and David C. Joseph. 1954. The Pacific mackerel fishery in the 1951-52 and 1952-53 seasons. Calif. Fish Game, 40(1): 55-59.
8

Rosa, Horacio, Jr. 1950. Scientific and common names applied to tunas, mackerels and spear fishes of the world with notes on their geographical distribution. FAO, Washington: 235pp.

Rosa, H., Jr. 1965. Preparation of synopses on the biology of species of living aquatic organisms. FAO, Fish. Synop., 1 (Revision 1): 75pp.

Rossi-Fanelli, A., and E. Antonini. 1960. Oxygen equilibrium of haemoglobin from Thunnus thynnus. Nature, 186(4728): 895-896.
5

Rossi-Fanelli, A., E. Antonini, and R. Giuffre. 1960. Oxygen equilibrium of myoglobin from Thunnus thynnus. Nature, 186(4728): 896-897.
5

Rothschild, Brian J. 1965. Hypotheses on the origin of exploited skipjack tuna (Katsuwonus pelamis) in the eastern and central Pacific Ocean. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 512: 20pp.
6

Rothschild, Brian J. 1966. Preliminary assessment of the yield potential of the skipjack tuna in the central Pacific Ocean. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 251-258.
6

Rothschild, Brian J., and Richard N. Uchida. 1968. The tuna resources of the oceanic regions of the Pacific Ocean. Univ. Wash. Publ. Fish., New Series, 4: 19-51.
1246

Rothschild, Brian J., and Marian Y.Y. Yong. 1970. Apparent abundance, distribution, and migrations of albacore, *Thunnus alalunga*, on the north Pacific longline grounds. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 623: 37pp.
1

Roughley, T.C. 1951. Fish and Fisheries of Australia. Angus and Robertson, Ltd., Sydney: xv, 328pp.
1236

Rounsefell, George A., and Edwin H. Dahlgren. 1934. The occurrence of mackerel in Alaska. Copeia, (1): 42.
8

Royce, William F. 1953. Preliminary report on a comparison of the stocks of yellowfin tuna. Indo-Pacif. Fish. Coun., Proc., 4(2): 130-145.
2

Royce, William F. 1964. A morphometric study of yellowfin tuna *Thunnus albacares* (Bonnaterre). U.S. Fish Wild. Serv., Fish. Bull., 63(2): 395-443.
2

Saito, Shoji. 1973. Studies on fishing of albacore (*Thunnus alalunga* Bonnaterre) by experimental deep-sea tuna longline. Hokkaido Univ., Mem. Fac. Fish., 21(2): 107-184.
1

Sakamoto, Hisao. 1967. Regional change in the age composition of bigeye caught by longline gear in the Indian Ocean. Nankai Reg. Fish. Res. Lab., Rep., 25: 59-66.
4

Sanchez T., Jose, and Roberto Lam C. 1970. Algunas caracteristicas fisicas y quimicas de las principales especies para consumo humano y sus rendimientos en productos pesqueros, en el Peru. Inst. Mar Peru, Informe, 33: 92pp.
8

Sandoval, Eliseo. 1970. Distribucion de los atunes en el primer trimestre del ano en relacion con las condiciones oceanograficas generales frente a Chile y Peru. Chile, Inst. Fom. Pesq., Bol. Cien., 14: 86pp.
124

Sandoval T., Eliseo. 1971. The summer distribution of tuna in relation to the general oceanographic conditions off Chile and Peru. Far Seas Fish. Res. Lab., Bull., 5: 23-88.
124

Sano, Osamu, Masaki Tamura, and Atsushi Iizuka. 1956. Concentration of mackerel eggs of the west coast of Hokkaido in association with particular diatom communities. Hokkaido Reg. Fish. Res. Lab., Bull., 14: 35-56.
8

Sanzo, L. 1932. Uova e primi stadi larvali di *Pelamys sarda*. C.V. Com. Talassogr. Ital., Mem., 188: 3-9.

Sanzo, L. 1933. Uova e primi stadi larvali di alalonga (*Orcynus germo* Ltkn.). C.V. Com. Talassogr. Ital., Mem., 198: 1-10.
1

Schaefer, Milner B. 1948. Spawning of Pacific tunas and its implications to the welfare of the Pacific tuna fisheries. North Amer. Wild. Conf., Trans., 13: 365-371.
1267

Schaefer, Milner B. 1952. A comparison of yellowfin tuna of Hawaiian waters and of the American west coast. U.S. Fish Wild. Serv., Fish. Bull., 52(72): 353-373.
2

Schaefer, Milner B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter-Amer. Trop. Tuna Comm., Bull., 1(2): 25-56.

Schaefer, Milner B. 1955. Morphometric comparison of yellowfin tuna from southeast Polynesia, Central America, and Hawaii. Inter-Amer. Trop. Tuna Comm., Bull., 1(4): 89-136.
2

Schaefer, Milner B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 2(6): 245-285.
2

Schaefer, Milner B. 1961. Tuna oceanography programs in the tropical central and eastern Pacific. Calif. Coop. Ocean. Fish. Inves., Rep., 8: 41-44.
1246

Schaefer, Milner B. 1967. Fishery dynamics and present status of the yellowfin tuna population of the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 12(3): 87-136.
2

Schaefer, Milner B., Gordon C. Broadhead, and Craig J. Orange. 1963. Synopsis on the biology of yellowfin tuna *Thunnus (Neothunnus) albacares* (Bonnaterre) 1788 (Pacific Ocean). FAO, Fish. Rep., 6(2): 538-561.
2

Schaefer, Milner B., Bruce M. Chatwin, and Gordon C. Broadhead. 1961. Tagging and recovery of tropical tunas, 1955-1959. Inter-Amer. Trop. Tuna Comm., Bull., 5(5): 341-455.
26

Schaefer, Milner B., and John C. Marr. 1948. Juvenile *Euthynnus lineatus* and *Auxis thazard* from the Pacific Ocean of Central America. *Pacif. Sci., 2(4): 262-271.*
7

Schaefer, Milner B., and Craig J. Orange. 1956. Studies of the sexual development and spawning of yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*) in three areas of the eastern Pacific Ocean, by examination of gonads. Inter-Amer. Trop. Tuna Comm., Bull., 1(6): 281-349.
26

Schmidt, Peter G., Jr. 1959. The Puretic power block and its effect on modern purse seining. In Kristjonsson, Hilmar (editor), Modern Fishing Gear of the World: 3, Fishing News (Books) Ltd., London: 400-413.

Schmitt, Waldo L., and Leonard P. Schultz. 1940. List of fish taken on the presidential cruise of 1938. Smithson. Misc. Coll., 98(25): 10pp.
7

Schultze, Donald L., and Robson A. Collins. 1977. Age composition of California landings of bluefin tuna, *Thunnus thynnus*, 1963 through 1969. Calif. Dept. Fish Game, Mar. Res. Tech. Rep., 38: 44pp (manuscript).
5

Scofield, N.B. 1914. The tuna canning industry of Southern California. Calif. Fish Game Comm., Biennial Rep., 23: 111-122.
1

Scofield, W.L. 1951. Purse seines and other round haul nets in California. Calif. Dept. Fish Game, Fish Bull., 81: 83pp.

Scofield, W.L. 1956. Trolling gear in California. Calif. Dept. Fish Game, Fish Bull., 103: 45pp.
1

Scott, James Michael. 1969. Tuna schooling terminology. Calif. Fish Game, 55(2): 136-140.
256

Scott, J. Michael, and Glenn A. Flittner. 1972. Behavior of bluefin tuna schools in the eastern north Pacific Ocean as inferred from fishermen's logbooks. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 915-927.
5

Seale, Alvin. 1940. Report of fishes from Allan Hancock expeditions in the California Academy of Sciences. Allan Hancock Pacif. Exped., 9(1): 1-46.
2678

Seckel, Gunter R. 1963. Climatic parameters and the Hawaiian skipjack fishery. FAO, Fish. Rep., 6(3): 1201-1208.
6

Seckel, Gunter R. 1972. Hawaiian-caught skipjack tuna and their physical environment. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 763-787.
6

Serventy, D.L. 1941. The Australian tunas. Austral., Coun. Sci. Indus. Res., Div. Fish., Rep., 4: 48pp.
1236

Serventy, D.L. 1956. The southern bluefin tuna, *Thunnus thynnus maccoyii* (Castelnau), in Australian waters. Austral. Jour. Mar. Fresh. Res., 7(1): 1-43.
3

Sette, Oscar Elton. 1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part II. Migrations and habits. U.S. Fish Wild. Serv., Fish. Bull., 51(49): 251-358.

Sette, Oscar E., *et al*. 1954. Progress in Pacific Oceanic Fishery Investigations 1950-53. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 116: 75pp.
26

Shapiro, Sidney. 1950. The Japanese long-line fishery for tunas. Comm. Fish. Rev., 12(4): 1-26.

Sharp, Gary D. 1969. Electrophoretic study of tuna hemoglobins. Comp. Biochem. Physiol., 31(5): 749-755.
12456

Sharp, Gary D. 1973. An electrophoretic study of hemoglobins of some scombrid fishes and related forms. Comp. Biochem. Physiol., 44(2B): 381-388.
1245678

Sharp, Gary D. 1978. Behavioral and physiological properties of tuna and their effects on vulnerability to fishing gear. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 397-449.
1246

Sharp, Gary D. no date. A summary of results and questions derived from studies of biochemical and morphological adaptation of tuna-like species and their energetics. In Vernberg, F. John, and A.V. Zhirmunsky (editors), Workshop on Joint USSR-USA Research Program on Physiology and Biochemistry of Marine Animals, U.S. Dept. of Commerce, NOAA, and Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina: 67-79 and 228-229.
12345678

Sharp, Gary D., and Andrew E. Dizon (editors). 1978. The Physiological Ecology of Tunas. Academic Press, New York: xvi, 485pp.

1234567

Sharp, Gary D., and Ronald C. Dotson. 1977. Energy for migration in albacore, *Thunnus alalunga*. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 75(2): 447-450.

1

Sharp, Gary D., and Robert C. Francis. 1976. An energetics model for the exploited yellowfin tuna, *Thunnus albacares*, population in the eastern Pacific Ocean. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 74(1): 36-51.

2

Sharp, Gary D., and Suellen Pirages. 1978. The distribution of red and white swimming muscles, their biochemistry, and the biochemical phylogeny of selected scombrid fishes. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 41-78.

12345678

Sharp, Gary D., and William J. Vlymen III. 1978. The relation between heat generation, conservation, and the swimming energetics of tunas. In Sharp, Gary D., and Andrew E. Dizon (editors), The Physiological Ecology of Tunas, Academic Press, New York: 213-232.

123456

Shaver, John A. 1962. Purse seining for Pacific albacore. Calif. Fish Game, 48(1): 81-82.

1

Shiino, Sueo M. 1959a. Revision der auf Goldmakarele, *Coryphaena hippurus* L., schmarotzenden Caligidenarten. Mie Pref. Univ., Ann. Rep., Sect. 2, Nat. Sci., Bd. 3: 34pp.

Shiino, Sueo M. 1959b. Ostpazifische parasitierende Copepoden. Mie Pref. Univ., Rep. Fac. Fish., 3(2): 267-333.

27

Shimada, Bell M. 1951a. Contributions to the biology of tunas from the western equatorial Pacific. U.S. Fish Wild. Serv., Fish. Bull., 52(62): 111-119.

12456

Shimada, Bell M. 1951b. Japanese tuna-mothership operations in the western equatorial Pacific Ocean. Comm. Fish. Rev., 13(6): 1-26.

12456

Shimada, Bell M., and Milner B. Schaefer. 1956. A study of changes in fishing effort, abundance, and yield for yellowfin and skipjack tuna in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull., 1(7): 351-469.

26

Shingu, Chiomi. 1965. Studies on the southern bluefin *Thunnus maccoyii* (Castelnau)-II. On the distribution of the southern bluefin in the south western Pacific Ocean and on the size of fish taken by the longline fishery. Nankai Reg. Fish. Res. Lab., Rep., 22: 95-106.
3

Shingu, Chiomi. 1967. Distribution and migration of the southern bluefin tuna. Nankai Reg. Fish. Res. Lab., Rep., 25: 19-36.
3

Shingu, Chiomi. 1970. Studies relevant to distribution and migration of the southern bluefin tuna. Far Seas Fish. Res. Lab., Bull., 3: 57-113.
3

Shingu, Chiomi. 1978. Ecology and stock of southern bluefin. Japan Assoc. Fish. Res. Protection, Fish. Stud. Ser., 31: 85pp (translation by Hintze, M.A., 1980, Australia, CSIRO, Div. Fish. Ocean., Rep.: in press).
3

Shingu, Chiomi, and Koichi Hisada. 1971. Fluctuations in amount and age composition of catch of southern bluefin tuna in longline fishery, 1957-1969. Far Seas Fish. Res. Lab., Bull., 5: 195-218.
3

Shingu, Chiomi, and Koichi Hisada. 1979. Recent status of the southern bluefin tuna stock. Indo-Pacific Tuna and Billfish Stock Assessment Workshop, Shimizu, Japan, Background Pap., 11: 7pp.
3

Shingu, Chiomi, Patrick K. Tomlinson, and Clifford L. Peterson. 1974. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1967-1970. Inter-Amer. Trop. Tuna Comm., Bull., 16(2): 65-230.
124

Shingu, Chiomi, and Ikuo Warashina. 1965. Studies on the southern bluefin, *Thunnus maccoyii* (Castelnau)-I. Morphometric comparison of southern bluefin. Nankai Reg. Fish. Res. Lab., Rep., 22: 85-94.
3

Shingu, Chiomi, Yukio Warashina, and Norio Matsuzaki. 1974. Distribution of bluefin tuna exploited by longline fishery in the western Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 10: 109-140.
5

Shiroto, Akihiko. 1970. Studies on the mouth size of fish larvae. Jap. Soc. Sci. Fish., Bull., 36(4): 353-368.
1568

Shomura, Richard S. 1966. Age and growth studies of four species of tunas in the Pacific Ocean. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 203-219.
1246

Shomura, Richard S., and Betty Ann Keala. 1963. Growth and sexual dimorphism in growth of bigeye tuna (*Thunnus obesus*) a preliminary report. FAO, Fish. Rep., 6(3): 1409-1417.
4

Shomura, Richard S., and Garth I. Murphy. 1955. Longline fishing for deep-swimming tunas in the central Pacific, 1953. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 157: 70pp.
1246

Shomura, Richard S., and Tamio Otsu. 1956. Central north Pacific albacore surveys, January 1954-February 1955. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 173: 29pp.
1246

Sidwell, Virginia D., Pauline R. Foncannon, Nancy S. Moore, and James C. Bonnet. 1974. Composition of the edible portion of raw (fresh or frozen) crustaceans, finfish, and mollusks. 1. Protein, fat, moisture, ash, carbohydrate, energy value, and cholesterol. Mar. Fish. Rev., 36(3): 21-35.
124568

Silas, E.G. 1967. Parasites of scombroid fishes. Part I. Monogenetic trematodes, digenetic trematodes, and cestodes. Mar. Biol. Assoc. India, Proc. Symp. Scombroid Fishes, 3: 799-875.
1245678

Silas, E.G., and A.N.P. Ummerkutty. 1967. Parasites of scombroid fishes. Part II. Parasitic Copepoda. Mar. Biol. Assoc. India, Proc. Symp. Scombroid Fishes, 3: 876-993.
1568

Silliman, Ralph P. 1966. Estimates of yield for Pacific skipjack and bigeye tunas. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent. Pacif. Fish. Resources, Proc.: 243-249.
46

Silva, Vaughn M. 1980. Inter-Amer. Trop. Tuna Comm., personal communication.
6

Sivasubramaniam, K. 1966. Predators and competitors of tuna. Pacif. Sci. Cong., 11(7): 14-14'.

Skillman, Robert A. 1975. An assessment of the south Pacific albacore, *Thunnus alalunga*, fishery, 1953-72. Mar. Fish. Rev., 37(3): 9-17.
1

Skillman, Robert A. 1978. Recent trends in catch, fishing effort, and catch per unit effort for the south Pacific albacore fishery based in American Samoa, 1954-76. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., 8H: 12pp.
1

Slack, E.B. 1969. A commercial catch of albacore in New Zealand. New Zealand, Mar. Dept., Fish. Tech. Rep., 46: 26pp.
1

Slack, E.B. 1972. The albacore (*Thunnus alalunga* (Bonnaterre)) fishery in New Zealand. Commercial catches at New Plymouth 1970. New Zealand, Mar. Dept., Fish. Tech. Rep., 80: 23pp.
1

Smith, Albert C. 1962. The electrophoretic characteristics of albacore, bluefin tuna, and kelp bass eye lens proteins. Calif. Fish Game, 48(3): 199-201.
15

Smith, Albert C. 1963. Variant hemoglobin and electrophoretic whole blood studies in two tunas and three other fish species. Calif. Fish Game, 49(1): 44-49.
15

Smith, Albert C. 1966. Electrophoretic studies of soluble protein from lens-nuclei of bluefin tuna, *Thunnus thynnus*, from California and Australia. Amer. Zool., 6(4): 577.
5

Smith, Albert C. 1971. The soluble proteins in eye lens nuclei of albacore, bluefin tuna and bonito. Comp. Biochem. Physiol., 39(4B): 719-724.
15

Smith, Albert C., and Harold B. Clemens. 1973. A population study by proteins from the nucleus of bluefin tuna eye lens. Amer. Fish. Soc., Trans., 102(3): 578-583.
5

Snodgrass, Robert Evans, and Edmund Heller. 1905. Papers from the Hopkins-Stanford Galapagos Expedition, 1898-1899. XVII. Shore fishes of the Revillagigedo, Clipperton, Cocos, and Galapagos Islands. Wash. Acad. Sci., Proc., 6: 333-427.
1256

Sprague, Lucian M. 1967. Multiple molecular forms of serum esterase in three tuna species from the Pacific Ocean. Hereditas, 57: 198-204.
234

Squire, James L., Jr. 1972. Apparent abundance of some pelagic marine fishes off the southern and central California coast as surveyed by an airborne monitoring program. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 1005-1019.
12568

Starks, Edwin Chapin. 1910. The osteology and mutual relationships of the fishes belonging to the family Scombridae. Jour. Morphol., 21(1): 77-100.
1568

Steffel, Sherry, Andrew E. Dizon, John J. Magnuson, and William H. Neill. 1976. Temperature discrimination by a captive free-swimming tuna, *Euthynnus affinis*. Amer. Fish. Soc., Trans., 105(5): 588-591.

Stevens, E.D. 1972. Some aspects of gas exchange in tuna. Jour. Exper. Biol., 56(3): 809-823.
6

Stevens, E. Don, and F.E.J. Fry. 1971. Brain and muscle temperatures in ocean caught and captive skipjack tuna. Comp. Biochem. Physiol., 38(1A): 203-211.
6

Stevens, E. Don., How Man Lam, and J. Kendall. 1974. Vascular anatomy of the counter-current heat exchanger of skipjack tuna. Jour. Exper. Biol., 61(1): 145-153.
6

Stevens, E. Don, and William H. Neill. 1978. Body temperature relations of tunas, especially skipjack. In Hoar, W. S., and D. J. Randall (editors), Fish Physiology, Volume VII, Academic Press, New York: 315-359.
1234567

Strasburg, Donald W. 1960. Estimates of larval tuna abundance in the central Pacific. U.S. Fish Wild. Serv., Fish. Bull., 60(167): 231-255.
26

Strasburg, Donald W. 1969. Billfishes of the central Pacific Ocean. U.S. Fish. Wild. Serv., Circ., 311: 11pp.
1246

Strasburg, Donald W., Everet C. Jones, and Robert T.B. Iversen. 1968. Use of a small submarine for biological and oceanographic research. Cons. Perm. Inter. Explor. Mer, Jour., 31(3): 410-426.
6

Strasburg, Donald W., and Heeny S.H. Yuen. 1960. Preliminary results of underwater observations of tuna schools and practical applications of these results. Indo-Pacif. Fish. Coun., Proc., 8(3): 84-89.
6

Suda, Akira. 1954. Studies on the albacore-I. Size composition in the north Pacific ground between the period of its southward migration. Jap. Soc. Sci. Fish., Bull., 20(6): 460-468 (translation by Van Campen, W.G., 1956, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 182: 6-14).
1

Suda, Akira. 1956. Studies on the albacore-III. Size compositions classified by ocean current. Jap. Soc. Sci. Fish., Bull., 21(12): 1194-1198 (translation by Van Campen, W.G., 1956, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 182: 43-47).
1

Suda, Akira. 1958. Catch variations in the north Pacific albacore-I. Recruitment and dispersion of the north Pacific albacore. Nankai Reg. Fish. Res. Lab., Rep., 9: 103-116.
1

Suda, Akira. 1960. Fishing ground investigation. In Report of tuna fishing investigation in the Caribbean Sea, north-west Atlantic, and the waters south of Australia, Fish. Agency Japan: 5-63 (cited in Nakamura, 1969).

Suda, Akira. 1962a. Studies on the albacore-VIII. Ecological considerations on the albacore in the Philippine Sea. Nankai Reg. Fish. Res. Lab., Rep., 16: 127-134.
1

Suda, Akira. 1962b. Studies on the population structure and catch variation of the north Pacific albacore. Nankai Reg. Fish. Res. Lab., Rep. 15: 1-37.
1

Suda, Akira. 1963a. Catch variations in the north Pacific albacore-IV. The survival-rate in the fishing ground of the north west Pacific. Nankai Reg. Fish. Res. Lab., Rep., 17: 103-110.
1

Suda, Akira. 1963b. Structure of the albacore stock and fluctuation in the catch in the north Pacific areas. FAO, Fish. Rep., 6(3): 1237-1277.
1

Suda, Akira. 1964. Catch variations in the north Pacific albacore-V. The speculations about the influences of fisheries on the catch and abundance of albacore in the north-west Pacific by use of some simplified mathematical models. Nankai Reg. Fish. Res. Lab., Rep., 20: 1-16.
1

Suda, Akira. 1966a. Catch variations in the north Pacific albacore-VI. The speculations about the influences of fisheries on the catch and abundance of the albacore in the north Pacific by use of some simplified mathematical models. Nankai Reg. Fish. Res. Lab., Rep., 24: 1-14.
1

Suda, Akira. 1966b. Catch variations in the north Pacific albacore-VII. Considerations on the sustainable yield. Nankai Reg. Fish. Res. Lab., Rep., 24: 103-114.
1

Suda, Akira. 1971. Tuna fisheries and their resources in the IPFC area. Far Seas Fish. Res. Lab., S Series, 5: 58pp.
12346

Suda, Akira. 1972. The skipjack fishery of the future. Gyosen, 182: 44-52 (translation by U.S. Nat. Mar. Fish. Serv.).
6

Suda, Akira. 1973a. Observation on the recent status of the tuna longline fishery in the Indian Ocean. Far Seas Fish. Res. Lab., S Series, 7: 41-69.
1234

Suda, Akira. 1973b. Possible problems involved in the regulation of tuna longline fishery. Far Seas Fish. Res. Lab., S Series, 7: 71-98.
1234

Suda, Akira. 1974. Recent status of resources of tuna exploited by longline fishery in the Indian Ocean. Far Seas Fish. Res. Lab., Bull., 10: 27-62.
1234

Suda, Akira, and Susumu Kume. 1967. Survival and recruit of bigeye tuna in the Pacific Ocean, estimated by the data of tuna longline catch. Nankai Reg. Fish. Res. Lab., Rep., 25: 91-103.
4

Suda, Akira, Susumu Kume, and Toshio Shiohana. 1969. An indicative note on a role of permanent thermocline as a factor controlling the longline fishery for bigeye tuna. Far Seas Fish. Res. Lab., Bull., 1: 99-114.
4

Suda, Akira, and Milner B. Schaefer. 1965a. General review of the Japanese tuna long-line fishery in the eastern tropical Pacific Ocean 1956-1962. Inter-Amer. Trop. Tuna Comm., Bull., 9(6): 305-462.
124

Suda, Akira, and Milner B. Schaefer. 1965b. Size-composition of catches of yellowfin tuna in the Japanese long-line fishery in the eastern tropical Pacific east of 130°W. Inter-Amer. Trop. Tuna Comm., Bull., 10(4): 265-331.
2

Sun', Tszi-Dzen'. 1960. Lichinki i mal'ki tuntsov, parusnikov i mech-ryby (Thunnidae, Istiophoridae, Xiphiidae) tsentral'noi i zapadnoi chasti Tikhogo okeana (Larvae and juveniles of tunas, sailfishes, and swordfish (Thunnidae, Istiophoridae, Xiphiidae) from the central and western part of the Pacific Ocean). Trudy Inst. Okeanol., 41: 175-191.
26

Sunada, John S. 1977. Review of the pelagic wet-fisheries for 1975. Calif. Coop. Ocean. Fish. Inves., Rep., 19: 19-20.
8

Sund, Paul N., Maurice Blackburn, and Francis Williams. 1980. Tunas and their environment in the Pacific Ocean: a review. Oceanogr. Mar. Biol. Ann. Rev., 18: in press.
123456

Sund, Paul N., and James A. Renner. 1959. The Chaetognatha of the Eastropic expedition, with notes as to their possible value as indicators of hydrographic conditions. Inter-Amer. Trop. Tuna Comm., Bull., 3(9): 393-436.

Suzuki, Akima. 1962a. Serological studies of the races of tuna-VI. Bigeye-3 antigen occurred in the albacore. Nankai Reg. Fish. Res. Lab., Rep., 16: 67-70.
14

Suzuki, Akima. 1962b. On the blood types of yellowfin and bigeye. Amer. Natur., 96(889): 239-246.
24

Suzuki, Ziro. 1971. Comparison of growth parameters estimated for the yellowfin tuna in the Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 5: 89-105.
2

Suzuki, Z., P.K. Tomlinsion, and M. Honma. 1978. Population structure of Pacific yellowfin tuna. Inter-Amer. Trop. Tuna Comm., Bull., 17(5): 273-441.
2

Suzuki, Ziro, Yukio Warashina, and Masamichi Kishida. 1977. The comparison of catches by regular and deep longline gears in the western and central equatorial Pacific. Far Seas Fish. Res. Lab., Bull., 15: 51-89.
124

Sverdrup, H.U., Martin W. Johnson, and Richard H. Fleming. 1942. The Oceans. Their Physics, Chemistry, and General Biology. Prentice-Hall, Inc., New York: x, 1087pp.

Takayama, Shigene. 1963. Fishing techniques for tunas and skipjack. FAO, Fish. Rep., 6(3): 1067-1076.

Takeuchi, Shoichi, and Yuji Taneishi. 1976. Studies on the selection of tuna long-line fishing grounds-I. Deterministic model simulation of southern bluefin tuna fishery. Jap. Soc. Sci. Fish., Bull., 42(6): 637-644.
3

Talbot, F.H., and M.J. Penrith. 1963. Synopsis of biological data on species of the genus Thunnus (sensu lato) (South Africa). FAO, Fish. Rep., 6(2): 608-646.
1234

Tamura, Tamotsu. 1957. A study of visual perception in fish, especially on resolving power and accommodation. Jap. Soc. Sci. Fish., Bull., 22(9): 536-557.
8

Tan, Hui-Chong, Yukio Nose, and Yoshio Hiyama. 1965. Age determination and growth of yellowfin tuna, Thunnus albacares Bonnaterre by vertebrae. Jap. Soc. Sci. Fish., Bull., 31(6): 414-422.
2

Tatsuki, Kyogoro, Masami Uto, and Katsumi Kitamura. 1963. On the landings of the yokowa (young bluefin) and its size composition off the Cape Shionomisaki. Nankai Reg. Fish. Res. Lab., Rep., 17: 55-61.
5

Tauchi, Morisaburo. 1940a. On the stock of *Thunnus orientalis* (Temminck et Schlegel). Jap. Soc. Sci. Fish., Bull., 9(4): 133-135 (translation by Van Campen, W.G., 1950, U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 16: 1-6).
5

Tauchi, Morisaburo. 1940b. On the stock of *Germo germo* (Lacepede). Jap. Soc. Sci. Fish., Bull., 9(4): 139-141.
1

Tester, Albert L. 1952. Establishing tuna and other pelagic fishes in ponds and tanks. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 71: 20pp.
26

Tester, Albert L. 1959. Summary of experiments on the response of tuna to stimuli. In Kristjonsson, Hilmar (editor), Modern Fishing Gear of the World, Fishing News (Books) Ltd., London: 538-542.
26

Tester, Albert L., P.B. van Weel, and John J. Naughton. 1955. Response of tuna to chemical stimuli. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 130: 1-62.
26

Tester, Albert L., Heeny Yuen, and Michio Takata. 1954. Reaction of tuna to stimuli, 1953. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 134: 33pp.
26

Thomas, P.T., and G. Raju. 1964. Gonadial abnormalities in scombroid fishes. Mar. Biol. Assoc. India, Proc. Symp. Scombroid Fishes, 2: 719-724.
6

Thompson, Will F. 1917. Temperature and the albacore. Calif. Fish Game, 3(4): 153-159.
1

Tomiyama, Tetuo (supervision). 1975. Fisheries in Japan. Tuna. Japan Marine Products Photo Materials Association, Tokyo: 179pp.
12345

Tomiyama, Tetuo, and Takashi Hibiya (supervision). 1976. Fisheries in Japan. Skipjack and Mackerel. Japan Marine Products Photo Materials Association, Tokyo: 162pp.
68

Uchida, Keitaro, Sadahiko Imai, Satoshi Mito, Shiro Fujita, Masaaki Ueno, Yoichi Shojima, Tetsushi Senta, Masaharu Tahuku, and Yosie Dotu. 1958. Studies on the eggs, larvae and juvenile of Japanese fishes. Kyushu Univ., Fac. Agri., Fish. Dept.: 89pp.
8

Uchida, Richard N. 1961. Hermaphroditic skipjack. Pacif. Sci., 15(2): 294-296.
6

Uchida, Richard N. 1975. Recent development in fisheries for skipjack tuna, *Katsuwonus pelamis*, in the central and western Pacific and the Indian Ocean. FAO, Fish. Tech. Paper, 144: 1-57.
6

Uchida, Richard N. 1976. Reevaluation of fishing effort and apparent abundance in the Hawaiian fishery for skipjack tuna, *Katsuwonus pelamis*, 1948-70. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 74(1): 59-69.
6

Uchida, Richard N., and Tamio Otsu. 1961. Analysis of sizes of albacore occurring in various Pacific fisheries--a preliminary report. Pacif. Tuna Biol. Conf.: 10pp (mimeographed) (summary in U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 415: 38-39).
1

Uchiyama, James H., and Paul Struhsaker. 1979. Age and growth of skipjack tuna, *Katsuwonus pelamis*, and yellowfin tuna, *Thunnus albacares*, as indicated by daily growth increments of sagittae. U.S. Nat. Mar. Fish. Serv., unpublished manuscript.
26

Uda, Michitaka. 1953. On the convergence and divergence in the NW Pacific in relation to the fishing grounds and productivity. Jap. Soc. Sci. Fish., Bull., 19(4): 435-438.
1256

Uda, Michitaka. 1957. A consideration on the long years trend of the fisheries fluctuation in relation to sea conditions. Jap. Soc. Sci. Fish., Bull., 23(7-8): 368-372.
124568

Uda, Michitaka. 1962. Cyclical fluctuation of the Pacific tuna fisheries in response to cold and warm water intrusions. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 415: 39.
156

Uda, Michitaka. 1970. Advances in fisheries oceanography of Japan from 1967 to 1969. Jap. Soc. Fish. Ocean., Advances Fish. Ocean., 3: 1-15.
368

Uda, Michitaka. 1973. Pulsative fluctuations of oceanic fronts in association with the tuna fishing grounds and fisheries. Tokai Univ., Jour Fac. Mar. Sci. Tech., 7: 245-266.
1256

Uda, Michitaka, and Makoto Ishino. 1958. Enrichment pattern resulting from eddy systems in relation to fishing grounds. Tokyo Univ. Fish., Jour., 44(1-2): 105-129.
156

Ueyanagi, Shoji. 1955. On the ripe ovary of the albacore, *Germo germo* (Lacepede), taken from the Indian Ocean. Jap. Soc. Sci. Fish., Bull., 20(12): 1050-1053.
1

Ueyanagi, Shoji. 1957. Spawning of the albacore in the western Pacific. Nankai Reg. Fish. Res. Lab., Rep., 6: 113-124.
1

Ueyanagi, Shoji (discussion leader). 1966a. Biology of tunas and bill fishes. Jap. Soc. Sci. Fish., Bull., 32(9): 739-755, 828.
12345

Ueyanagi, Shoji. 1966b. On the red pigmentation of larval tuna and its usefulness in species identification. Nankai Reg. Fish. Res. Lab., Rep., 24: 41-48.
12456

Ueyanagi, Shoji. 1967. On the spawning ground of tunas. Tuna Fishing, 60: 15-20.

Ueyanagi, Shoji. 1969a. The spawning of the southern bluefin tuna (*Thunnus maccoyii*) as indicated by the occurrence of its larvae. Far Seas Fish. Res. Lab., Bull., 1: 1-4.
3

Ueyanagi, Shoji. 1969b. Observations on the distribution of tuna larvae in the Indo-Pacific Ocean with emphasis on the delineation of the spawning areas of albacore, *Thunnus alalunga*. Far Seas Fish. Res. Lab., Bull., 2: 177-256.
123456

Ueyanagi, Shoji. 1978. Recent tuna culture research in Japan. Inter. Ocean Develop. Conf., 5(C1): 23-39 (preprint).
25

Ueyanagi, Shoji. 1980. Maguro (Tuna). Shirizu Umi (Sea Series), Rakuda Publishing Co., Tokyo: 55pp.
12345

Ueyanagi, Shoji, Keiichiro Mori, and Yasuo Nishikawa. 1969a. Research on distribution of larvae. Far Seas Fish. Res. Lab., S Series, 1: 12-17.
246

Ueyanagi, Shoji, Keiichiro Mori, and Yasuo Nishikawa. 1969b. Tuna spawning grounds and potential resources of pelagic fishes based on distribution of larvae. Far Seas Fish. Res. Lab., Tuna Fisheries Research Conference for Fiscal Year of 1968: 7pp.
123456

Ueyanagi, Shoji, Keiichiro Mori, Yasuo Nishikawa, and Akira Suda (editors). 1973. Report on experiments on the development of tuna culturing techniques (April, 1970-March, 1973). Far Seas Fish. Res. Lab., S Series, 8: 165pp.
256

Ueyanagi, Shoji, Yasuo Nishikawa, and Taira Matsuoka. 1974. Artificial fertilization and larval development of skipjack tuna, *Katsuwonus pelamis*. Far Seas Fish. Res. Lab., Bull., 10: 179-188.
6

Uno, Michio. 1936. *Germo germo* (Lacepede) in the waters east of Nozima Promontory, Tiba Prefecture (Preliminary Report I). Jap. Soc. Sci. Fish., Bull., 4(5): 307-309.
1

Usami, Shuzo. 1976. Classification, distribution and life history of *Scomber japonicus*. In Tomiyama, Tetuo, and Takashi Hibiya (supervision), Fisheries in Japan. Skipjack and Mackerel, Japan Marine Products Photo Materials Association, Tokyo: 151-156.
8

Usami, Shuzo, and Yuriko Matsushita. 1974. The movement of the Pacific subpopulation adult mackerel--characteristics of their movements, as viewed from tagging experiments during 1950-1968. Jap. Soc. Sci. Fish., Bull., 40(11): 1083-1097.
8

Van Campen, Wilvan G. (translator). 1960. Japanese summer fishery for albacore (*Germo alalunga*). U.S. Fish Wild. Serv., Res. Rep., 52, 29pp.
1

Wade, Charles B. 1950a. Observations on the spawning of Philippine tuna. U.S. Fish Wild. Serv., Fish. Bull., 51(55): 409-423.
26

Wade, Charles B. 1950b. Juvenile forms of *Neothunnus macropterus*, *Katsuwonus pelamis* and *Euthynnus yaito* from Philippine seas. U.S. Fish Wild. Serv., Fish. Bull., 51(53): 395-404.
26

Wade, Charles B. 1951. Larvae of tuna and tuna-like fishes from Philippine waters. U.S. Fish Wild. Serv., Fish. Bull., 51(57): 445-485.
26

Waldron, Kenneth D. 1963. Synopsis of biological data on skipjack *Katsuwonus pelamis* (Linnaeus) 1758 (Pacific Ocean). FAO, Fish. Rep., 6(2): 695-748.
1246

Waldron, Kenneth D. 1964. Fish schools and bird flocks in the central Pacific Ocean, 1950-1961. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 464: 20pp.
26

Waldron, Kenneth D., and Joseph E. King. 1963. Food of skipjack in the central Pacific. FAO, Fish. Rep., 6(3): 1431-1457.
26

Walford, Lionel A. 1937. Marine Game Fishes of the Pacific Coast from Alaska to the Equator. Univ. Calif. Press, Berkeley: xxix, 205pp.
125678

Walters, Carl J. 1969. A generalized computer simulation model for fish population studies. Amer. Fish. Soc., Trans., 98(3): 505-512.

Walters, Vladimir. 1966. On the dynamics of filter-feeding by the wavyback skipjack (Euthynnus affinis). Bull. Mar. Sci. Gulf Carib., 16(2): 209-221.

Walters, Vladimir, and Harry L. Fierstine. 1964. Measurements of the swimming speeds of yellowfin tuna and wahoo. Nature, 202(4928): 208-209.
2

Wankowsky, J.W.J. 1980. Recent history and summarised statistics of the industrial fisheries for tuna and tuna-like species in the area of the Papua New Guinea Declared Fisheries Zone, 1970-1979. Papua New Guinea, Dept. Primary Indus., Res. Bull., 24: 82pp.

Warashina, Ikuo. 1969. Yaizu unizu uoichiba mizuagesen no kado jokyo kara mita showa 43 nen Indoyo, Taiheiyo no maguro gyokyo (Status of tuna stocks based on catch records of fishing boats landing on the Yaizu Fish Market). Tuna Fishing, New Series, 1: 12-24.

Warashina, Ikuo, and Koichi Hisada. 1970. Spawning activity and discoloration of meat and loss of weight in the southern bluefin tuna. Far Seas Fish. Res. Lab., Bull., 3: 147-165.
3

Warashina, Yukio, and Koichi Hisada. 1974. Preliminary evaluation of effect of the voluntary regulation on stock of southern bluefin tuna and the longline fishery. Far Seas Fish. Res. Lab., Bull., 10: 193-220.
3

Ward, James W. 1962. Helminth parasites of some marine animals, with special reference to those from the yellow-fin tuna, Thunnus albacares (Bonnaterre). Jour. Paras., 48(1): 155.
2

Wardle, C.S., and J.J. Videler. 1980. How do fish break the speed limit. Nature, 284(5755): 445-447.
26

Watanabe, Hisaya. 1958. On the difference of the stomach contents of the yellowfin and bigeye tunas from the western equatorial Pacific. Nankai Reg. Fish. Res. Lab., Rep., 7: 72-81.
24

Watanabe, Hisaya. 1960. Regional differences in food composition of the tunas and marlins from several oceanic areas. Nankai Reg. Fish. Res. Lab., Rep., 12: 75-84.
12456

Watanabe, Kazahuru. 1968. On the fishing conditions of the amberfish and the tunny caught by the summer set nets on the west coast of the Noto Peninsula in the Japan Sea. Japan Sea Reg. Fish. Res. Lab., Bull., 20: 23-34.
5

Watanabe, N. 1942. Measurement on the bodily density, body-temperature and swimming-velocity for "Katuo", *Euthynnus vagans* (Lesson). Jap. Soc. Sci. Fish., Bull., 11(4): 146-148 (translation by U.S. Nat. Mar. Fish. Serv., Honolulu).
6

Watanabe, Taisuke. 1970. Morphology and ecology of early stages of life in Japanese common mackerel, *Scomber japonicus* Houttuyn, with special reference to fluctuation of population. Tokai Reg. Fish. Res. Lab., Bull., 62: 283pp.
8

Watkinson, J.G., and R. Smith. 1972. New Zealand fisheries. New Zealand, Marine Department: 91pp (published in conjunction with Indo-Pacific Fisheries Council, 15th session).
1236

Webb, B.F. 1972. Report on a tuna polefishing and live bait venture, "Hoko Maru 15" February 8 to March 24, 1972. Section 1: General introduction; Section 2: Bait fishing. New Zealand, Minis. Agri. Fish., Fish. Tech. Rep., 112: 61pp.
16

Webb, B.F. 1974. Report on a tuna polefishing and livebait venture "Hoko Maru 15" 8 February to 21 March 1972. Section 3: Polefishing, hydrology, and tuna analysis. New Zealand, Minis. Agri. Fish., Fish. Tech. Rep., 106: 57pp.
136

van Weel, P.B. 1952. Observations on the chemoreception of tuna. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 91: 8-35.
2

Wetherall, Jerry A. (editor). 1979. Report of the third north Pacific albacore workshop Honolulu, Hawaii 13-14 September 1978. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., 25H: 11pp.
1

Wetherall, Jerry A., Fletcher V. Riggs, and Marian Y.Y. Yong. 1979. Assessment of south Pacific albacore stock. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep. H-79-6: 17pp.
1

Wetherall, Jerry A., and Marian Y.Y. Yong. 1975. A cohort analysis of the north Pacific albacore stock and an assessment of yield-per-recruit in the American and Japanese fisheries. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep. 16H.
1

Whitehead, S.S. 1931. Fishing methods for the bluefin tuna (*Thunnus thynnus*) and an analysis of the catches. Calif. Dept. Fish Game, Fish Bull., 33: 32pp.
5

Whitney, Richard R. 1969. Inferences on tuna behavior from data in fishermen's logbooks. Amer. Fish. Soc., Trans., 98(1): 77-93.
256

Wickham, Donald A., John W. Watson, Jr., and Larry H. Ogren. 1973. The efficacy of midwater artificial structures for attracting pelagic sport fish. Amer. Fish. Soc., Trans., 102(3): 563-572.

Wicklund, Robert I. 1968. Observations on the feeding behavior of the false albacore. Underwater Nat., 5(2): 30-31.

Wild, A., and T.J. Foreman. 1980. The relationship between otolith increments and time for yellowfin and skipjack tuna marked with tetracycline. Inter-Amer. Trop. Tuna Comm., Bull., 17(7): 507-560.
26

Williams, F. 1970. Sea surface temperature and the distribution and apparent abundance of skipjack (*Katsuwonus pelamis*) in the eastern Pacific Ocean, 1951-1968. Inter-Amer. Trop. Tuna Comm., Bull., 15(2): 229-281.
6

Williams, F. 1972. Consideration of three proposed models of the migration of young skipjack tuna (*Katsuwonus pelamis*) into the eastern Pacific Ocean. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 70(3): 741-762.
6

Williams, K.F. 1977. Sea surface temperature maps to assist tuna fisheries off New South Wales, Australia. FAO, Fish. Tech. Pap., 170: 38-55.
3

Williams, Kevin. 1980. Increased tuna tagging off Western Australia. Austral. Fish., 39(1): 11.
3

Williamson, Gordon R. 1970. Little tuna *Euthynnus affinis* in the Hong Kong area. Jap. Soc. Sci. Fish., Bull., 36(1): 9-18.

Yabe, Hiroshi. 1954. A study on spawning of skipjack in the Satsunan Sea area. Nippon Gakujitsu Shinko Kai, Suisan Gaku no Gaikan (Jap. Assoc. Advan. Sci., General View of the Fishery): 182-199 (translation by U.S. Nat. Mar. Fish. Serv., Honolulu).
6

Yabe, Hiroshi, and Shoji Ueyanagi. 1962. Contributions to the study of the early life history of the tunas. Nankai Reg. Fish. Res. Lab., Occas. Rep., 1: 57-72.
256

Yabe, Hiroshi, Shoji Ueyanagi, Shoji Kikawa, and Hisaya Watanabe. 1958. Young tunas found in the stomach contents. Nankai Reg. Fish. Res. Lab., Rep., 8: 31-48.
124

Yabe, Hiroshi, Shoji Ueyanagi, and Hiyasa Watanabe. 1966. Studies on the early life history of bluefin tuna *Thunnus thynnus* and on the larva of the southern bluefin tuna *T. maccoyii*. Nankai Reg. Fish. Res. Lab., Rep., 23: 95-129.
35

Yabe, Hiroshi, Yoichi Yabuta, and Shoji Ueyanagi. 1963. Comparative distribution of eggs, larvae, and adults in relation to biotic and abiotic environmental factors. FAO, Fish. Rep., 6(3): 979-1009.
1234567

Yabuta, Yoichi, Noburo Anraku, and Mori Yukinawa. 1958. Studies on the yellowfin tuna-III. Annual variations of the size compositions and the hooked-rates of yellowfin tuna distributing in equatorial Pacific. Nankai Reg. Fish. Res. Lab., Rep., 7: 88-104.
2

Yabuta, Yoichi, and Mori Yukinawa. 1957. Age and growth of yellowfin tuna (*Neothunnus macropterus*) in Japanese waters by size freguencies. Nankai Reg. Fish. Res. Lab., Rep., 5: 127-133.
125

Yabuta, Yoichi, and Mori Yukinawa. 1959. Growth and age of yellowfin tuna (*Neothunnus macropterus*) in the equatorial Pacific. Study of length frequency distribution-I. Nankai Reg Fish. Res. Lab., Rep., 11: 77-87.
2

Yabuta, Yoichi, and Mori Yukinawa. 1963. Growth and age of albacore. Nankai Reg. Fish. Res. Lab., Rep., 17: 111-120.
1

Yabuta, Yoichi, Mori Yukinawa, and Yukio Warashina. 1960. Growth and age of yellowfin tuna-II. Age determination (scale method). Nankai Reg. Fish. Res. Lab., Rep., 12: 63-74.
2

Yamanaka, Hajime. 1958. Studies on the bluefin tuna-I. The modes of the weight compositions of the catch. Nankai Reg. Fish. Res. Lab., Rep., 9: 125-135.
5

Yamanaka, Hajime, Yoshio Kurohiji, and Jiro Morita. 1966. General results of the investigation in the south western Pacific Ocean by the fish finder. Nankai Reg. Fish. Res. Lab., Rep., 24: 115-127.
26

Yamanaka, Hajime, Jiro Morita, and Noburo Anraku. 1969. Relation between the distribution of tunas and water types of the north and south Pacific Ocean. Far Seas Fish. Res. Lab., Bull., 2: 257-273.
12345

Yamanaka, Hajime, et al. 1963. Synopsis of biological data on kuromaguro Thunnus orientalis (Temminck and Schlegel) 1842 (Pacific Ocean). FAO, Fish. Rep., 6(2): 180-217.
5

Yamanaka, Ichiro. 1978. Oceanography in tuna research. Cons. Perm. Int. Explor. Mer, Rapp. Proces-Verb., 173: 203-211.
12345

Yang, Rong-Tszong. 1971. Population study of yellowfin tuna in the waters adjacent to Taiwan. Acta. Ocean. Taiwanica, 1: 137-155.

Yang, Rong-Tszong. 1975. Skipjack tuna fisheries in the waters around Taiwan. Fish. Soc. Taiwan, Jour., 4(1): 93-110 (translation by Language Services Division, F43, U.S. Nat. Mar. Fish. Serv.: 26pp).
6

Yang, Rong-Tszong. 1979. Taiwan's tuna longline fishery in the Indo-Pacific area, 1967-1978. Acta. Ocean. Taiwanica, 10: 211-232.
124

Yang, Rong-Tszong, Yukio Nose, and Yoshio Hiyama. 1969. A comparative study on the age and growth of yellowfin tunas from the Pacific and Atlantic Oceans. Far Seas Fish. Res. Lab., Bull., 2: 1-21.
2

Yasutake, Hiroshi, Genjirou Nishi, and Keiichiro Mori. 1973. Artificial fertilization and rearing of bigeye tuna (Thunnus obesus) on board, with morphological observations on embryonic through to early post-larval stage. Far Seas Fish. Res. Lab., Bull., 8: 71-78.
4

Yokota, Takio, Masahiro Toriyama, Fukuko Kanai, and Seizi Nomura. 1961. Studies on the feeding habit of fishes. Nankai Reg. Fish. Res. Lab., Rep., 14: 1-234.
124568

Yorita, H. 1976. On the bluefin tuna of the Japan Sea coast of Hokkaido. Hokkaido Fish. Exper. Sta., Month. Rep., 33: 2-11.
5

York, A. G. 1972. Acoustic detection and attraction of tuna in New Zealand waters. FAO, Indo-Pacif. Fish. Coun., Proc., 15(3): 470-480.
126

York, Don. 1979. Catching and handling methods. New Zealand, Minis. Agri. Fish., Catch '79, 6(9): 7-9.
3

Yoshida, Howard O. 1965. New Pacific records of juvenile albacore, *Thunnus alalunga* (Bonnaterre) from stomach contents. Pacif. Sci., 19(4): 442-450.
1

Yoshida, Howard O. 1966a. Skipjack tuna spawning in the Marquesas Islands and Tuamotu Archipelago. U.S. Fish Wild. Serv., Fish. Bull., 65(2): 479-488.
6

Yoshida, Howard O. 1966b. Tuna fishing vessels, gear, and techniques in the Pacific Ocean. In Manar, Thomas A. (editor), Hawaii, Governor's Conf. Cent Pacif. Fish. Resources, Proc.: 67-89.

Yoshida, Howard O. 1968. Early life history and spawning of the albacore, *Thunnus alalunga*, in Hawaiian waters. U.S. Fish Wild. Serv., Fish. Bull., 67(2): 205-211.
1

Yoshida, Howard O. 1971a. Distribution, apparent abundance, and length composition of juvenile albacore, *Thunnus alalunga*, in the south Pacific Ocean. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(4): 821-827.
1

Yoshida, Howard O. 1971b. The early life history of skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 69(3): 545-554.
6

Yoshida, Howard O. 1975. The American Samoa longline fishery, 1966-71. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 73(4): 747-765.
12

Yoshida, Howard O. 1979a. Synopsis of biological data on tunas of the genus *Euthynnus*. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS Circ., 429: 57pp.
267

Yoshida, Howard O. 1979b. Compilation of published estimates of tuna life history and population dynamics parameters. U.S. Nat. Mar. Fish. Serv., Southwest Fish. Center, Admin. Rep., H-79-8: 15pp.
12345

Yoshida, Howard O., and Tamio Otsu. 1963. Synopsis of biological data on albacore, *Thunnus germo* (Lacepede), 1800 (Pacific and Indian Oceans). FAO, Fish. Rep., 6(2): 274-318.
1

Yoshida, Howard O., Richard N. Uchida, and Tamio Otsu. 1977. The Pacific tuna pole-and-line and live-bait fisheries. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS Circ., 408: 36-51.
126

Yuen, Heeny S.H. 1955. Maturity and fecundity of bigeye tuna in the Pacific. U.S. Fish Wild. Serv., Spec. Sci. Rep. Fish., 150: 30pp.
4

Yuen, Heeny S.H. 1959. Variability of skipjack response to live bait. U.S. Fish Wild. Serv., Fish. Bull., 60(162): 147-160.
6

Yuen, Heeny S.H. 1963. Schooling behavior within aggregations composed of yellowfin and skipjack tuna. FAO, Fish. Rep., 6(3): 1419-1429.
26

Yuen, Heeny S.H. 1966. Swimming speeds of yellowfin and skipjack tuna. Amer. Fish. Soc., Trans., 95(2): 203-209.
26

Yuen, Heeny S.H. 1970. Behavior of skipjack tuna, *Katsuwonus pelamis*, as determined by tracking with ultrasonic devices. Fish. Res. Bd. Canada, Jour., 27(11): 2071-2079.
6

Yuen, Heeny S.H. 1977. Desired characteristics of a bait for skipjack tuna, *Katsuwonus pelamis*. U.S. Nat. Mar. Fish. Serv., NOAA Tech. Rep. NMFS Circ., 408: 52-54.
6

Yuen, Heeny S.H. 1979. A night handline fishery for tunas in Hawaii. Mar. Fish. Rev., 41(8): 7-14.
124

Yuen, Heeny S.H., and Fred C. June. 1957. Yellowfin tuna spawning in the central equatorial Pacific. U.S. Fish Wild. Serv., Fish. Bull., 57(112): 251-264.
2

Yukinawa, Mori. 1970. Age and growth of southern bluefin tuna *Thunnus maccoyii* (Castelnau) by use of scale. Far Seas Fish. Res. Lab., Bull., 3: 229-257.
3

Yukinawa, Mori, and Yoichi Yabuta. 1963. Age and growth of bigeye tuna, *Parathunnus mebachi* (Kishinouye). Nankai Reg. Fish. Res. Lab., Rep., 19: 103-118.
4

Yukinawa, Mori, and Yoichi Yabuta. 1967. Age and growth of bluefin tuna, *Thunnus thynnus* (Linnaeus), in the north Pacific Ocean. Nankai Reg. Fish. Res. Lab., Rep., 25: 1-18.
5

de Zylva, E.R.A. 1974. Trolling for albacore (*Thunnus alalunga* Bonnaterre) off the west coast of Auckland. Indo-Pacif. Fish. Coun., Proc., 15(3): 452-460.
1