

# A NOTE ON THE BIOLOGY AND FISHERY OF THE JAPANESE ANCHOVY *ENGRAULIS JAPONICA* (HOULTUYN)

SIGEITI HAYASI<sup>1</sup>  
Tokai Regional Fisheries  
Research Laboratory  
Tokyo, Japan

## INTRODUCTION

One of the most prolific groups of fishes in the Japanese fisheries has been *iwasi* which comprises three clupeoid species including the sardine, *Sardinops melanosticta* (Temminck & Schlegel), round herring, *Etrumeus micropus* (Temminck & Schlegel), and anchovy. These three species have been caught by various types of fishing methods in almost all of the coastal waters around Japan, not only at stages after metamorphosis but also at postlarval stages under a commercial name of *sirasu*, in combination with a few related fishes (Hayasi 1961). The total catch of *iwasi* reached 1,130,000 metric tons, or 42 percent of the total fish landings in Japan during 1929 through 1938 (Nakai 1962b). Even though the catch of *iwasi*, including *sirasu*, has decreased since the 1940's, the landings in 1962 still measured 511,000 tons, comprising 12 percent of all the fishes landed by the Japanese fleet based at domestic ports (Statistics & Survey Division, MAF 1963).

The anchovy comprised only a few percent of the *iwasi* during the prosperous period (Nakai *et al.* 1955, Kurita and Tanaka 1956). The catch of this small fish has increased since the drastic decrease of the sardine in the early 1940's, comprising about nine percent of the total fish landings, or 67 percent of *iwasi* for the recent 5 years from 1958 through 1962 (Statistics & Survey Division, MAF 1959-63). Furthermore, the anchovy is regarded to be of great consequence in the biological production of the ocean as a major source of food for many important fishes.

In 1949, a nation-wide research program, the Cooperative *Iwasi* Resources Investigations (renamed the Cooperative Investigations on the Important Neritic-Pelagic Fisheries Resources in Japan in 1955), started with the primary aim of elucidating reasons for fluctuations in the sardine population. Consequently, biological information has been obtained so as to permit biologists to present opinions regarding regulation and prediction not only of the sardine but also of the anchovy as shown in the progress reports of the programs (Nakai *et al.* 1955, Murakami and Hayano 1955, Yokota and Asami 1956, Yamanaka and Ito 1957, Ishigaki *et al.* 1959, Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1961-63). The Conference of the Fisheries Agency, Japanese Government, for Fisheries Resources Investigations that was founded in 1962 will continue to publish the

progress of the investigations. In addition, several individual biologists have presented comprehensive papers on the Japanese anchovy, mainly in the prosperous fishing areas. Hayasi (1961), Asami (1962) and Takao (1964) discussed the investigations and management of the species and fisheries on the Pacific coasts of Honsyu, Sikoku and Kyusyu, and in the Seto Inland Sea, respectively. Kubo (1961) has given a review of works on the species under discussion.

In spite of a number of investigations, however, it is still difficult to assess and forecast the anchovy population. Such deficit is noticed not only in the anchovy study but in the fishery biology of various species (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan, 1961-63, Sato 1961, 1964). The present author has attempted to abstract the recent fishery investigations in Japan and introduce a new methodology through compiling this note that comprises (i) a brief description of fisheries, (ii) a remark on the cooperative investigation programs and (iii) biological information on the Japanese anchovy.

## A BRIEF DESCRIPTION OF FISHERIES

Hayasi (1961) outlined fluctuations in the amount of the anchovy catch and its regional distribution in Japan for 53 years between 1905 and 1957 as well as major fishing gear, fishing seasons and size composition of the catch on the basis of the catch statistics compiled by the Statistics & Survey Division, MAF, and information reported by workers who dealt with fisheries for *iwasi*. The following descriptions are mainly taken from this paper. Details of the history of development, construction and methods of operation of the fishing gear are summarized by Miyazaki (1960).

### *History of Landings*

Examinations of shell mounds, historical documents and literary works indicate that *iwasi*, including the anchovy, sardine and round herring, had been exploited by some kinds of nets, and that commercial fisheries have existed since the tenth century in various parts of Japan (Kishinouye 1908, 1911, Tagawa 1903, Fukuyo 1947, Yamaguchi 1947, Uda 1952, Yokota 1953, Nakai 1960, 1962b, Hayasi 1961). According to preliminary investigations of fisheries in Japan, the anchovy was one of the most abundant fishes around 1890 (Agriculture Bureau, MAC, 1891-93).

In 1894 the Statistics and Survey Division, MAF, commenced to publish a series of statistical year books

<sup>1</sup> Present address: Far Seas Fisheries Research Laboratory, Orido 1,000, Shimizu, Shizuoka-ken, Japan.

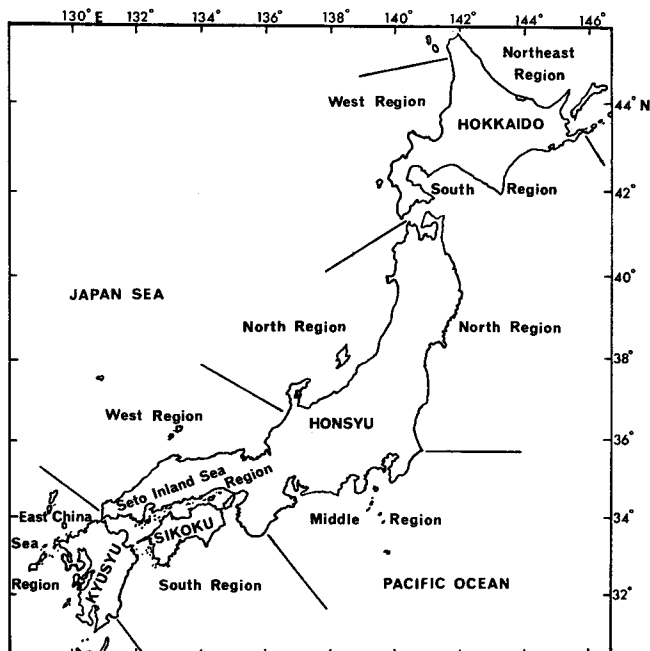


FIGURE 1. Division of the coast of Japan by Statistics and Survey Division, MAF. Division by Fisheries Agency is compared to that by Statistics and Survey Division as follows:

Fisheries Agency	Statistics and Survey Division
Hokkaido Region	North-East, South and West Regions of Hokkaido
Tohoku Region	North Pacific Region
Tokai Region	Middle Pacific Region
Nankai Region	South Pacific Region
Japan Sea Region	North and West Regions of Japan Sea
Seikai Region	East China Sea Region
Naikai Region	Seto Inland Sea Region

called *Nosyomu Tokai* (renamed *Norin Tokai* in 1925). Records of the anchovy catch, partly together with the sardine and round herring, have been given since 1905. On the basis of the catch statistics up to 1957, Hayasi (1961) summarized the fluctuations in amount of the anchovy catch as follows:

“The history of fluctuation in the anchovy catch (in Japan) are distinguished into four groups of years; early increase from 1905 to 1912, succeeding years of irregular fluctuation up to 1930, early part of the 1930’s of decrease, and following years of increase. The early increase might be caused by rapid development of fisheries. For the later three periods, it is noted that the anchovy catch has fluctuated reversely with the sardine catch. Investigation of published information indicates that the fluctuation in the anchovy catch has depended mainly on change in the population size rather than on change in species preference of fishermen, both of which might be largely due to the remarkable fluctuation in the sardine population. The geographic distribution\* of the anchovy catch has been consistent for the last half century. The Pacific waters have produced 60 percent

of the nation’s total. The landings in the Seto Inland Sea, coastal waters swept by the Tusima Current and seas surrounding Hokkaido have comprised 20, 15 and 5 percent of total, respectively.”

For the recent 5 years, up to 1962, total landings of anchovies and *sirasu*, mostly postlarval anchovy, showed no further increase (Figure 2). The major fishing grounds were still located in the Pacific waters and the Seto Inland Sea (Table 1).

TABLE 1  
REGIONAL CATCH OF ANCHOVY AND SIRASU IN JAPAN, 1962.  
UNIT: 1,000 METRIC TONS

	Anchovy	<i>Sirasu</i>
Total.....	349.5 (100.0 %)	26.3 (100.0 %)
Hokkaido.....	1.5 ( 0.4 )	-- ( -- )
Pacific.....		
{North.....	38.3 ( 11.0 )	2.7 ( 10.1 )
{Middle.....	107.1 ( 30.6 )	10.5 ( 39.8 )
{South.....	36.4 ( 10.4 )	4.6 ( 17.7 )
Japan Sea.....		
{North.....	2.3 ( 0.7 )	0.1 ( 0.2 )
{West.....	20.8 ( 6.0 )	0.3 ( 1.2 )
East China Sea.....	66.8 ( 19.1 )	1.2 ( 4.4 )
Seto Inland Sea.....	76.2 ( 21.8 )	7.0 ( 26.5 )

Data from Statistics & Survey Division, MAF (1963).

**Prospectus of Recent Fisheries**

According to Hayasi (1961), the major types of fishing are with two-boat purse seines that produce 60 percent of the total anchovy catch, and boat seines of several varieties that catch 20 percent of the anchovies and 75 percent of *sirasu*. Two-boat purse seines and boat seines are chiefly operated for anchovies at various stages of their life, but the fishermen engaging in these fisheries often change their objects depending on the stock sizes and prices of the species within their fishing grounds. These fisheries have been best developed on the Pacific coast off Honsyu and in the Seto Inland Sea, which comprise the major anchovy fishing grounds inclusive of the postlarval forms. In recent years these types of fisheries have continued to take the most important role in producing anchovies (Table 2).

Anchovies, including *sirasu*, are caught throughout the year in Japan as a whole. The amount of catch increases in the later half of a year with two peaks, one in the summer and the other in the winter. The fishing season is limited in the northern areas; *i.e.* in the autumn in the Hokkaido and North Pacific Regions, and in spring and autumn in the Japan Sea, while it lasts throughout the year in the central and southern areas of Japan. Fishing activities for both anchovies and *sirasu* move from the open coast to the bays and inlets during spring and summer, and then shift toward the open coast during autumn and winter (Asami 1958, Hayasi 1961).

The anchovy catch comprises various sized fish from postlarvae of 13 mm in total length to large individuals over 16 cm in body length. The fish over

\* Two systems are used to divide the coast of Japan, one by the Fisheries Agency and the other by the Statistics and Survey Division of Ministry of Agriculture and Forestry. They are identical to each other except for the names and subdivision of the regions (Figure 1).

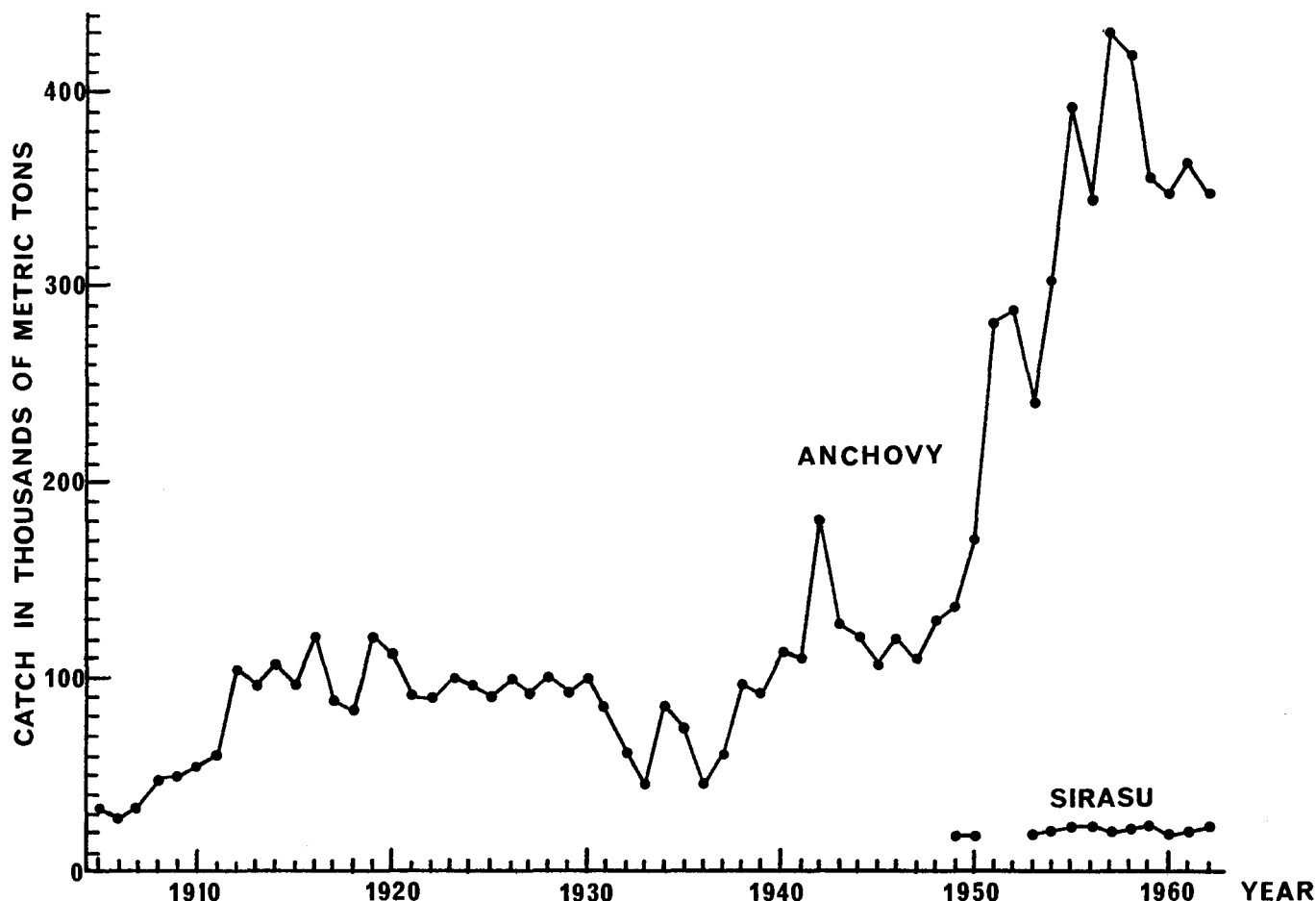


FIGURE 2. Annual landings of the anchovy (1905-62) and *sirasu* (1949, 1950 and 1953-62). Data for 1905-25 and for 1951-62 from Statistics and Survey Division, MAF (1906-26 and 1952-63), those for 1926-31 and for 1933-48 from Kurita and Tanaka (1956), those for 1932 from Statistics and Survey Division, MAF (1933) and Takayama and Sakai (1936), those for 1949 and 1950 from unpublished record taken by Tokai Regional Fisheries Research Laboratory. The figure for 1941 is corrected according to Nakai (1960).

TABLE 2  
ANCHOVY AND SIRASU CATCH BY METHOD OF FISHING IN  
JAPAN, 1962.  
UNIT: 1,000 METRIC TONS

	Anchovy	<i>Sirasu</i>
Total.....	349.5 (100.0 %)	26.3 (100.0 %)
{ Subtotal.....	203.2 (58.1)	0.1 (0.3)
{ Two-boat		
{   purse seine.....	157.8 (45.2)	0.0 (0.1)
{   Others.....	45.4 (13.0)	0.0 (0.1)
Lift nets.....	18.2 (5.2)	2.2 (8.2)
Set nets.....	9.6 (2.8)	0.0 (0.0)
{ Subtotal.....	102.8 (29.4)	21.5 (81.6)
{ Boat seine		
{   group.....		
{   { <i>Patti-ami</i> .....	54.2 (15.5)	6.4 (24.4)
{   { Boat seine.....	48.7 (13.9)	15.1 (57.3)
Beach seine.....	14.8 (4.2)	2.5 (9.7)
Other methods.....	1.7 (0.5)	0.0 (0.1)

Data from Statistics & Survey Division, MAF (1963).

14 cm in body length are scarce in the commercial catch. All the sizes appear in both Pacific and Japan Sea sides. Generally, the length composition data show three modes, (i) postlarvae around 25 mm mainly caught by boat seine, (ii) immature around 6-8 cm in body length by *patti-ami* and (iii) adults over 10 cm in body length by two-boat purse seines. It is also noted that the mean length is usually larger in the northern areas than in the southern areas (Yokota and Asami 1956, Yamanaka and Ito 1957, Hayasi 1961, Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1961-63, Asami 1962, Takao 1964).

#### A REMARK ON THE COOPERATIVE INVESTIGATIONS

The life history of the Japanese anchovy has not been investigated thoroughly enough to promote advance in the studies for forecasting and assessing the population up to the early 1950's. Since the cooperative investigations started in 1949, the biological information of the fish, including the amount and composition of the commercial catch, the number of eggs and larvae in the sea, and the environmental condi-

tions have been collected through systematic surveys, which almost all fisheries experimental stations of prefectural governments facing on the sea and the seven regional fisheries research laboratories have engaged in. Another investigation program was started in 1964 with the aim of forecasting fish stocks, inclusive of anchovy, as well as oceanographic conditions.

As far as the neritic-pelagic fishes are concerned, these two investigation programs are conducted as almost one project. The following description covers (i) social demands on the fishery research agencies, (ii) development of methodology and (iii) scale of the investigations.

At the start of the cooperative investigations, major efforts were laid upon the sardine, the decrease of which caused serious economic and social problems in Japan (Nakai *et al.* 1955). Since the middle 1950's, anchovies have exceeded sardines in amount of the commercial catch and more extensive information has been necessitated for predicting and regulating the anchovy stock to increase the economic productivity of fisheries, especially the two-boat purse seine and the boat seines on the Pacific waters along Honsyu, Sikoku and Kyusyu, and on the Seto Inland Sea.

At the initial stage of the cooperative investigations, the most urgent project was to collect information on the life history of the species in order to advance the study of population dynamics (Hayasi 1961). However, the biological information thus collected has led many fishery biologists to think that the numerical analysis of the fish populations shows only limited aspects of nature (for instance, Tanaka 1960, Hayasi 1961, Nakai (1962b)). An alternative methodology, in which a species is treated as a member of the community (Yokota and Asami 1956, Yokota *et al.* 1962), is regarded fruitless unless the elemental species are sufficiently understood. Recently, Sato (1961, 1964) proposed a methodology of fishery biology, through investigations of the king crab, *Paralithodes camtschaticus* (Tilesius), which necessitates the logical system of scientific conceptions. A more detailed explanation of his proposal is given in the following sections.

During April 1949 through March 1950 the cooperative investigations covered collection of catch statistics, surveys on the age and length composition and morphometric characters of the commercial catch, and the distribution and abundance of eggs and larvae as well as oceanographic conditions. The morphometric characters surveyed were body length, body weight, sex, gonad weight, diameter of ova, stomach contents, vertebral counts and scale rings. The eggs and larvae were collected by standardized nets (Nakai 1962a).

Engaged in the investigations during the first year were 47 prefectural fisheries experimental stations and 68 research boats of 34 prefectures, five regional fisheries research laboratories and four research vessels of the Fisheries Agency. Consequently, eggs and larvae were collected at 5,035 observatory stations (Nakai and Hattori 1962), and morphometric characters were determined for 14,202 anchovies taken at 82 landing ports (Nakai *et al.* 1955). Since 1951, more

efforts have been laid on the length composition survey in order to improve the accuracy of the estimates of population characteristics (Nakai *et al.* 1955). For the later years, almost the same amount of data have been collected annually. In addition, daily reports have been taken from some of purse seiners operating on major fishing grounds (Hirakawa 1955, Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1961-63). Since 1964, the boat survey has been conducted routinely, and the number of regular oceanographic stations has been increased as much as twice that in the preceding years.

## BIOLOGICAL INFORMATION

It is axiomatic that fishery biologists working on any project attempt to approach not only the aspect of their interest but also the mechanisms regulating biological production of the organisms. For instance, a biologist researches the growth of the fish in order to determine how the species population changes in size, distribution or migratory route in the natural waters. Unless the position and role of any research project are *subjectively* determined, however, the investigations may not indicate the true nature of the organisms, because all the aspects are *unified* in the real life of organisms, which essentially changes from step to step during the course of ontogenesis. This makes it necessary to consider methods to systematize biological information on any species.

In the course of fishery biology, most phenomena are observed through the commercial fisheries. This fact means that one can see only compounds of three factors, fishes and environments in nature, and productive power of the human society. Accordingly, it is necessary to establish three systems of sciences corresponding to these factors. In the case of the anchovy investigations, the scientific systems are (i) biology, especially ecology, (ii) oceanography, and (iii) technology and economics. The biological features of the anchovy will be described *subjectively* with the use of *categories* particular to biology, which must be drawn on the bases of the following three features of organisms.

First, the living resources are retained and develop through their two major functions, individual maintenance and species maintenance, that are results of interactions between organisms. This fact shows that the *species* is the most comprehensive category in biology.

Second, the species has differentiated in the course of evolution. This fact makes the species and the subspecies two conceptions mutually defining one another (Darwin 1917). Eventually, it is concluded that a species population comprises subspecies that have both *universality* of the species and *peculiarity* of the subspecies. Systematic fractions of a species population, *e.g.* subpopulation defined by Marr (1957), must comprise the same nature. Therefore, the *systematic fraction* is to be considered as one of the major categories, being defined on the basis of the substantial knowledge of life of the species population.

Third, form and function of an individual essentially change depending upon the *developmental*

stages (or etap) from egg to adult, and upon the yearly cycle of life inclusive of spawning and shoaling cycles as suggested by Steven (1948). Even the same environmental factors may have different effects upon two individuals at different stages or cycles. From the above discussion it may be readily accepted that the systematic fractions must be distinguished by difference of occurrence of the developmental stages and the maturation phases.

For these reasons, the biological information must be systematized on the basis of developmental stages and yearly cycles for each species. The system obtained as such may provide hypotheses of the systematic structure and assessment of any fish populations. Accordingly the present section is divided into three parts: (i) biological notes of the fish at each developmental stage or maturation phase, (ii) systematic fractions, and (iii) assessment of the population.

The developmental stages and yearly cycle of life are to be defined through the whole body of knowledge, and will be modified if those categories are found to contradict observations made by succeeding investigations. At present, we can assume that the anchovy passes through the developmental stages defined by Hubbs (1943), and that two yearly cycles repeatedly appear every year at the adult stage. The developmental stages and yearly cycles adopted here are listed below. The substance of the stage or cycle was obtained by unifying existing knowledge on all aspects of the stage or phase in question.

Developmental stage	Yearly cycle of life
Egg-----	--
Larva (before absorption of yolk)-----	--
Postlarva (before completing metamorphosis)-----	--
Juvenile (before reaching adult form)-----	--
Immature (before sexual maturation)-----	--
Adult-----	Shoaling Spawning

### Geographical Distribution

The Japanese anchovy is actually widely distributed in the temperate zone of the Far East, extending from southern Sakhaline to Formosa, but the fisheries on this species have been concentrated in the waters around Japan and Korea (Hayasi 1961). Almost all the coastal waters surrounding Japan produce this species, except south of the Kuroshio Current (Matsubara 1955, Hayasi 1961). Most previous descriptions are given only in terms of the species.

**Egg and larval stages.** The spawning activities of anchovies have been determined through systematic plankton net collections conducted since 1949 (Nakai *et al.* 1955, Yokota and Asami 1956, Yamanaka and Ito 1957, Ex. Com., Conf., Invest. Neritic-Pelagic Fisher. Japan 1961-63). According to these studies, the species actually spawns over a wide extent of the waters between Hokkaido and Kyusyu, from the inlets to the high seas to a distance of around 1,000 nautical

miles from the coast. The spawning activities are distributed more abundantly over the middle and southern Pacific coast of Japan, and around the edge of continental shelf than in any other part of the sea. The spawning season lasts throughout a year in south of the middle Pacific and west Japan sea regions. The heaviest spawning activities occur during winter and early spring in the southern areas around Kyusyu and Sikoku, or in spring and in autumn in central Pacific waters such as between the Kii and Boso Peninsulas. Within an area the spawning proceeds with the passage of time from the outer coastal waters to the bays and inlets (Hayasi 1961; Asami 1958a, 1958b, 1962). The eggs are often transported by currents, and then the distribution pattern changes depending upon age of the eggs (Yokota 1953). The anchovy larvae have the same distribution as the eggs (Nakai *et al.* 1955, Yokota and Asami 1956, Yamanaka and Ito 1957).

**Postlarval and juvenile stages.** It is difficult to estimate, with the use of plankton nets, distribution and abundance of the postlarvae and juveniles that have gained enough swimming activity to avoid the nets. Some of the postlarval stocks are concentrated in the coastal waters, and are exploited by boat seines and other commercial fisheries operating within 5 miles from the coast and 20 m from the surface. The major fishing grounds for postlarval anchovies are located within the general areas comprising the spawning grounds. Representative fishing grounds are: The coast of Ensyu Nada and Hyuga Nada on the Pacific, and various parts of the Seto Inland Sea. Minor fishing grounds for postlarvae are found on the coast south of Kasima Nada on the Pacific and in Toyama Bay on the Japan Sea (Hayasi 1961). The postlarvae are abundantly distributed out of the fishing grounds (Nakai *et al.* 1962). Dense shoals are often found on *siome* in the waters off eastern coast of Honsyu (Odate 1957). The juveniles, less lucrative than the postlarvae, are caught just after the major fishing season for *sirasu* (Tanaka 1956).

**Immature stage.** Anchovies leave the nursery grounds by the time they reach the immature stage, and some are exploited by commercial fisheries mainly in the bays and inlets (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1961-63, Hayasi 1961, Asami 1962, Takao 1964).

**Adult stage.** The adult anchovy is exploited in all areas. Generally speaking, the ratio of the adults among the total anchovy catch is higher in the outer coastal waters than in the bays and inlets, and is higher in the northern area than in the south (Yamanaka and Ito 1957, Hayasi 1961).

a. **Shoaling cycle.** Almost all the anchovies caught in the areas south of middle Pacific region are in the shoaling cycle (Hayasi 1961, Usami and Sugiyama 1962).

b. **Spawning cycle.** The spawning areas are identical with the distribution areas of the spawning adults. The set nets in the northern areas catch the

“ripe” fish just before they discharge the ova or sperm in early summer (Usami and Sugiyama 1962).

**Abiotic Factors of the Habitat**

The anchovy is regarded to be an eurythermal and euryhaline species (Kubo 1961), because of the wide space-time extent of appearance of exploitable shoals and spawning. The fish are easily transported across the Kuroshio Current alive in live-cars of fishing vessels even though no report was obtained from isolated islands south of the current (Matsubara 1955, Hayasi 1961).

*Egg and larval stages.* The eggs are found in areas, where surface temperatures range between 11 and 29°C (Naki *et al.* 1955, Kubo 1961). Generally speaking, the surface temperature of the spawning grounds is high in the southern area and low in the northern area (Table 3).

TABLE 3

**SURFACE TEMPERATURE OF SOME SPAWNING GROUNDS OF JAPANESE ANCHOVY (AFTER YAMANAKA AND ITO 1957)**

Locality	Surface temperature (°C)	
	Range	Major spring season
Southern tip of Kyusyu.....	15-29	15-25
Hyuganada east coast of Kyushu.....	15-29	15-26
Bungo Suido, east coast of Kyusyu.....	15-29	15-29
Suho Nada, Seto Inland Sea.....	11-29	15-25
Ise Bay, Pacific coast of Honsyu.....	13-27	15-26
Boso, Pacific coast of Honsyu.....	14-27	16-19
Amakusa Nada, west coast of Kyushu.....	16-27	16-21
Wakasa Bay, Japan Sea.....	11-27	14-25
Isikari Bay, Hokkaido.....	14-23	14-18
Okhotsk coast of Hokkaido.....	11-15	--

Chlorinity in areas where the anchovy eggs are found range between 14.8 and 19.5 per mil, most frequently 18.4-19.3 per mil (Nakai *et al.* 1955, Kubo 1961). According to Nishikawa (1901), the eggs normally develop under a wide range of specific gravity between 1.012 and 1.033.

The eggs occur most abundantly in the sea area over the continental shelf and extending 10 miles more offshore (Nakai *et al.* 1955, Kubo 1961). Most of the eggs are distributed at a depth less than 30 m from the sea surface (Kubo 1961). Nishikawa (1901) recorded the eggs from the deeper layer between 45 and 83 m. The larvae may live at almost the same abiotic conditions with the eggs.

*Postlarval stage.* Postlarval anchovies are widely distributed from coast to offshore. Major fishing grounds are located in areas with sand or mud bottom, under influence of river water.

*Juvenile through adult stages.* Adults definitely select the open sea, while immature fish are distributed in bays and inlets as well as the open sea. The spawners may require abiotic conditions that differ from those of adults during the shoaling cycle.

Although not defining which developmental stage, Kubo (1961) outlined the relationships between the

anchovy, seemingly at the juvenile through adult stages, and abiotic factors as follows:

“The anchovy is an eurythermal species, because the fish are caught throughout a year in some particular fishing grounds. Yamanaka and Ito (1957) estimated that the temperature of habitat ranges from 8 to 30°C, through the field observation on catch and spawning. Suehiro (1936) determined the heat tolerance of the anchovy under rearing condition. According to his experiment, it was found that 11° and 31° are the lowest and highest survivable ranges of the anchovy taken from the waters of 22-23°C. Compared with the sardine experimented under the same time, it is found that optimum temperature is higher for the anchovy than for the sardine. In the same experiment, Suehiro (1936) determined that the anchovy died when the oxygen content of the water decreased to slightly less than 2 c.c./l. Distribution depth is found to differ by time of a day, size or age of fish, area, season and weather (Inoue and Ogura 1958).

Suehiro *et al.* (1957) reported that the anchovy are frightened by sounds of military cannons. Imamura and Takeuchi (1960) found that the anchovy are attracted by light of 30-40 lux. through rearing examination.”

**Relation With Systematically or Ecologically Related Fishes**

Hayasi (1961) summarized the distribution of fishes systematically related with the Japanese anchovy as follows:

“The fishes of the genus *Engraulis* are widely distributed throughout the temperate zones of the world except for the Atlantic coast of North America, where a closely related genus *Anchoa* occurs. Many of these two genera have supported fisheries at various significance within the area in which they occur.

In the temperate zone of the Far East, three other genera of Stolephorinae are known to occur in addition to the genus *Engraulis*, and some of them were fairly important for the local fisheries in Korea.”

It is well known that in Japan the sardine and the round herring have been ecologically and commercially related with the anchovy (Nakai *et al.* 1955, Yokota 1953, Ito 1961, Hayasi 1961). In addition, the mackerels, *Scomber japonicus* Houttuyn and *S. tapeinocephalus* Bleeker, and jack mackerel, *Trachurus japonicus* (Temminck & Schlegel), occupy almost the same habitat as the anchovy (Yokota *et al.* 1961).

*Postlarval stage.* Postlarval anchovy are often caught incidentally with postlarval sardine. The white fish, *Salangiethys microdon* Bleeker, and postlarval and juvenile sand lance, *Ammodytes personatus* Girard, are caught in more coastal area than the postlarval anchovy. Postlarvae of a systematically related fish, *Stolephorus zollingeri* Bleeker,<sup>2</sup> occur in the fish-

<sup>2</sup> A recent paper has reported: “Records of *Stolephorus zollingeri* from Japanese waters (Hayashi and Tadokoro 1962) are clearly based on another Hawaiian engraulid, *S. buccaneeri* Strasburg (Whitehead, P. J. P., M. Boesman, and A. C. Sheeler 1966. The types of Bleeker's Indo-Pacific elpoid and clupeoid fishes, *Zool. Verhand., Nat. Hist. Leiden*, (84): 159 pp).

ing grounds of sirasu, especially on the southern Pacific coast of Japan. These two species of Stolephorinae are distinguished from one another by meristic counts at a stage of 19 mm in total length (Hayasi and Tadokoro 1962).

*Juvenile stage.* Competition of the postlarval anchovy with those of the mackerels and jack mackerels affect the stock size of the anchovy in the south Pacific region (Yokota *et al.* 1961). The above rare species of Stolephorinae is easily distinguished from the anchovy by shape of head at a stage over 26 mm TL although these two species are caught incidentally (Hayasi and Tadokoro 1962).

*Juvenile through adult stages.* Anchovies compete with or are consumed by the fishes listed in the introductory part.

### Feeding

The investigation covers the form of digestive organs and the food species of the Japanese anchovy. These works are summarized as follows (Kubo 1961):

"The gill rakers are fine and numerous. The intestine length increases more rapidly than the body length with growth of fish. The copepods comprises major food of the fish throughout the life span. Size of food is linearly correlated with size of the fish."

*Postlarval stage.* Nakai *et al.* (1962) investigated feeding habit of the Japanese anchovy as well as sardine in the Pacific waters of Honsyu. The results are summarized as follows:

"Postlarvae of less than 5 mm TL just after absorbing yolk take mainly nauplii and eggs of copepoda. Only a few of them were found with protozoa, small mollusca and diatom in their digestive tracts. Postlarvae of 5-10 mm TL still mainly eat nauplii of copepods, but copepodid larvae increase in number from before. Generally, sizes of postlarvae and food organisms are correlated with each other. Number of postlarvae with food in the digestive tract occupy less than 20 percent on the average. They take the food most actively in the day time. The copepod eggs and larvae are more abundantly distributed in the coastal waters than in the offshore."

*Juvenile through adult stages.* Copepods comprises major food of the anchovy. Other food organisms are diatoms, and various types of small crustacea, larvae of mollusca, Chaetognatha and other small animals. The adults eat eggs and larvae of fishes including the anchovy (Nakai *et al.* 1955, Kubo 1961).

### Migration

No systematic knowledges have been obtained on migration of the anchovy. The following review covers fragmental information.

*Egg and larval stages.* It is shown that some amount of eggs are carried by the Kuroshio Current from southern Kyusyu to the Pacific coast along Honsyu (Hayasi 1961, Asami 1962).

*Postlarval stage.* Some postlarval anchovy assemble in the coastal waters (Yokota 1953, Tanaka 1956, Hayasi 1961).

*Juvenile through adult stages.* It is widely accepted that some of anchovy stocks enter into and leave from bays and inlets during spring through summer and during autumn, respectively (Kubo 1961). Most of sexually matured fish move from the coastal waters to the edge of continental shelves (Hayasi 1961).

### Schooling

The anchovy swim near the sea surface as schools throughout their life span.

*Egg and larval stages.* Since eggs and larvae are dispersed by currents after they are discharged, their geometrical distribution pattern changes depending upon age (Yokota 1953).

*Postlarval stage.* The postlarval anchovy actively forms schools so densely as to support commercial fisheries.

*Juvenile through adult stages.* In the live car, the anchovy tend to swim clockwise rather than counter-clockwise (Suehiro 1947). The fish can swim at a speed of 10-12 cm/sec. (Kimura 1934). Three swimming manners have been noticed in the fishing grounds (Inoue and Ogura 1958). As mentioned in abiotic factors, the species reacts sensitively against sound and light.

*Spawning cycle.* The anchovy discharge ova and sperm at a duration of time between sunset and midnight (Nakai *et al.* 1955, Yamanaka and Ito 1957, Kubo 1961).

### Reproduction and Recruitment

Two problems are left unsolved about fecundity of the anchovy: (1) How many times an individual spawns in a year, and (2) how many times a group of the fish having occurred at a spawning season in a spawning ground spawn in a year. In addition, it is not yet confirmed whether or not the anchovy in offshore, extending 1,000 nautical miles from the coast, are recruited to the fishing grounds.

*Larval and postlarval stages.* The minimal size of the anchovy caught by commercial fisheries is 13 mm in total length. Recruitment to the boat seine is completed during the postlarval stage of 23 mm in total length (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1961-63, Hayasi 1961).

*Juvenile and immature stages.* Juveniles of 3 cm in body length are taken by the fisheries that mainly exploit the immature anchovy. The fish are completely recruited at 7-8 cm to the stocks for these fisheries (Asami 1962, Hayasi and Kondo 1957, Hayasi 1961, 1962a). Immature fish over 6 cm in body length are taken by the large sized two-boat purse seines that mainly exploit the adult fish (Hayasi and Kondo 1957, 1959, Hayasi 1961, 1962a). Immature fish over 5 cm in body length are often distinguished by sex (Kubo 1961).

*Adult stage.* Examination of ovum frequency indicates that anchovies discharge their ova or sperm one or more times in a spawning season (Kubo 1961). Number of ova discharged by a female has been esti-

mated between 1,000 and 60,000 (Kubo 1961, Usami and Sugiyama 1962). The minimal size of matured fish was 5cm in body length, but the biological minimal size differs depending upon season and locality (Kubo 1961).

### Growth and Life Span

Age determination was regarded one of the most important projects since the population dynamics was the major methodology of the investigations. The embryonic growth rate was investigated in order to determine the abundance of egg and larval stocks.

**Egg stage.** The eggs hatch out about 30 hours after fertilization at a temperature between 20° and 25°C (Nishikawa 1901, Uchida *et al.* 1958), or about 48 hours at 18°C (Kaymiya 1916).

**Larval stage.** The anchovy larvae just after hatching out range between 3.2 and 3.6 mm TL (Kamiya 1916, Uchida *et al.* 1958).

**Postlarval stage.** It is estimated through examination of meristic characters and abiotic factors that the postlarvae between 25 and 40 mm TL are 1 to 2 months old on the average (Hayasi and Suzuki 1957, Hayasi 1961).

**Juvenile through adult stages.** There are a number of works on the growth rate of the anchovy after the postlarval stage. Technically, these works were advanced through three steps: (1) analysis of length composition, (2) analyses of length composition and vertebral counts, and (3) analyses of length composition, vertebral counts and scale rings. Estimates of the growth rate of the fish differ depending upon workers. Examination of these investigations lead Hayasi and Kondo (1957) and Hyasi (1961, 1962b) to the following conclusions.

- “1. One may estimate the season of hatching of the fish in the first year of life through analyses of length frequency and vertebral counts.
2. The age of fish can be determined by scale readings since most fish form the scale annuli once a year during late autumn through early spring. To determine the age of a few fish, however, the date of catch, length and vertebral counts as well as the scale readings must be considered.
3. The anchovy grow 5-11 cm and 11-14 cm in body length by the end of the first and second years of life, respectively. Most fish leave the fishing ground by the summer of the third year when they attain 12-15 cm. As only a few fish were found to exceed 16 cm, the life span of the species is concluded to be two years.”

The following formulae approximate the growth of fish taken on the Pacific coast of Honsyu (Hayasi and Kondo 1957).

Fish spawned in spring;

$$14.82(1 - 0.9153e^{-0.0142t}) \text{ cm,}$$

Fish spawned in autumn;

$$15.23(1 - 0.9442e^{-0.084t}) \text{ cm,}$$

where,  $t$  is age in term of month.

Yokota and Furukawa (1952) and many other workers adopted the exponential curve for approximating the growth of the anchovy, and Yasumura *et al.* (1956), the logistic curve (Kubo 1961).

The immature and adult fish show different seasonal changes of their condition coefficients from one another (Hayasi and Kondo 1962a).

### Mortality

The anchovy are consumed not only by commercial fisheries but also by various animals with large stocks such as the mackerels, skip jack, tunas, yellow tail, and squids. However, no attempt succeeded to estimate reliable mortality rates of the anchovy in the exploited phase. Investigation of plankton samples showed tremendously high mortality at the beginning of postlarval stage (Nakai *et al.* 1955, Yokota *et al.* 1961).

**Egg stage.** The mortality rate of the eggs was estimated as about 30 percent from fertilization to hatching out. The eggs are taken by many animals including the adult anchovy. *Noctiluca* also eat the anchovy eggs (Nakai *et al.* 1955, Enomoto 1956, Hattori 1962).

**Larval and postlarval stages.** About 10,000-20,000 tons of postlarval anchovy are commercially landed mainly by boat seiners. The larval and postlarval anchovy comprise one of the most common food organisms of various marine animals (Yokota *et al.* 1961). The mortality rate just after yolk absorption is quite high, and then the mortality rate from fertilization to larval stage of 5 mm TL reaches about 99 percent (Nakai *et al.* 1955). Known causes of the high mortality from larval to postlarval stages include starvation and predation (Nakai *et al.* 1962, Yokota *et al.* 1961). Monthly mortality coefficients were calculated to be about three for the postlarvae exploited in a major fishing ground along the Pacific coast of Honsyu (Tanaka 1960).

**Juvenile through adult stages.** More than 300,000 tons of anchovy have been landed every recent year. The fish are also eaten by various species (Yokota *et al.* 1961). The annual survival rate was calculated as 0.26 (Yoshihara 1962). Monthly mortality coefficients were calculated as 0.115 by the fishing and 0.136 by the natural causes for the local group in the southern Pacific waters (Asami 1962).

### Morphometric Variation

A number of works on the vertebral counts of the anchovy were conducted for discriminating the fish having occurred in different seasons of a year in different places, as reviewed by Asami and Hanaoka (1957), Asami (1958), Hayasi and Kondo (1957), Hayasi and Suzuki (1957, 1959), Hayasi (1961, 1962a), Kubo (1961) and Takao (1964). Eventually, it was concluded that the systematic fractions of the anchovy population are not distinguished by one or a few morphological characters (Hayasi 1961).

**Egg stage.** Asami (1953) showed seasonal variation in size and shape of the anchovy eggs taken from the eastern coast of Kyusyu.



*Postlarval stage.* Comprehensive notes are given on variations of the vertebral counts of the anchovy at postlarval through adult stages by Kubo (1961) and Hayasi (1961, 1962a). Major features in variations of vertebral, and dorsal and anal fin ray counts of the postlarval anchovy are summarized as follows (Hayasi 1961):

1. The adult numbers of vertebrae (43-47), and dorsal and anal fin rays (13-17 and 15-20, respectively) are fixed by the time the fish reaches 19 mm TL.
2. On the basis of meristic variation, the fish spawned in the early half of the year can be segregated from those spawned in the later half.
3. The meristic characters differ depending upon the hatching place, but usually the actual differences are too small to make the meristic variation practically useful in segregating local groups.

Kubo (1961) showed that many workers indicated that the mean vertebral counts are reversely correlated with temperature at hatching place (Figure 3).

The postlarvae taken in the coastal waters have larger body depth than those taken offshore (Nakai *et al.* 1962).

*Juvenile through adult stages.* Through a number of investigations, it has been found that the vertebral counts differ depending upon size of fish at the juvenile through immature stages but not at the adult. The locality of habitat is not as significant a source of the vertebral variation as size of fish or season of sampling (Kubo 1961, Hayasi 1961).

#### **Systematic Fractions of Population**

The wide space-time extent of spawning and short life span imply that the anchovy population comprises fractions at various steps of differentiation. Hayasi (1961) defined two of such steps as follows:

**Local group:** A local group is a fraction of a population regarded to consist of fish inhabiting a general locality, such as the Pacific waters along Honsyu. A local group includes several space-time groups.

**Space-time group:** A space-time group consists of fish that are spawned in a particular area during a particular season of the year. Because the spawning activities continue to some extent spatially and seasonally, if the amount is disregarded, a space-time group is referred to a group of fish spawned to such an extent as in the western Pacific area of Honsyu during spring months.

The systematic fractions segregate most completely at the spawning phase. Examination of the distributions of eggs as well as several characters of commercial catch indicates major local groups chiefly propagating in four different localities: (1) between Hyuga Nada and Tosa Bay and (2) Kii Peninsula and Boso Peninsula in the Pacific waters, and (3) between western Kyusyu and western Honsyu and (4) Wakasa Bay and Toyama Bay in the Japan Sea. The stocks in the Seto Inland Sea comprise immigrants from Hyuga Nada and Tosa Bay as well as the indigenous group. In addition to these major groups, there are

a number of minor local groups that may intermingle with each other and with the major groups. The eggs and larvae of the group inhabiting the southern Pacific region, major spawning area of which extends between Hyuga Nada and Tosa Bay, are transported, especially in the early spring, to the middle Pacific region, in which large egg stocks are observed in the waters between Kii Peninsula and Boso Peninsula (Hayasi 1961, Asami 1962, Takao 1964).

For each of the local groups, several space-time groups are segregated. In the middle Pacific region, the spawning activity reaches to the highest peak during March through June, and the second peak appears sometime in autumn. The landings of *sirasu* are the most numerous in spring and early summer, and the second peak of catch appears in autumn. Thus, there are two major time groups, spring and autumn groups. In the waters, the anchovy are observed at four developmental stages; eggs by the spawning surveys, and postlarvae, immatures and adults of two age groups by the commercial fisheries. Examination of the growth, morphological characters, stock sizes, and seasons of their appearance indicate the following features of life history of the local group inhabiting the waters under discussion (Hayasi 1961, 1962b).

Most of the anchovies in the Pacific waters along Honsyu occur in the waters between Kii Peninsula and Boso Peninsula. The eggs are chiefly produced by the fish in their second year of life (I-age). The mortality rates at postlarval through adult stages did not remarkably change for most of about ten year classes up to 1960. A portion of them moves into the coastal area at postlarval, immature and adult stages except the spawning cycles. A few eggs and larvae may drift to the high sea along the Kuroshio current. Most fish may die within two and half years after birth.

The spring group mainly occurs in the outer coastal waters, and intermingles with eggs and larvae that immigrated from the southern waters in spring. After juvenile stage, many of the fish spawned in spring enter into the bays during the warmer months of the first year of life. The autumn groups occur not only in the outer waters but in bays. They also appear in the coastal waters in their first autumn, but their stock size is smaller than that of the spring groups. These two time-groups are discriminated by body length, meristic characters and distribution at the stages just before sexual maturation, and then intermingle with each other (Hayasi 1961, 1962b).

The anchovy inhabiting the southern Pacific region are closely related with those in the Seto Inland Sea (Asami 1958 a, b, c, 1962, Takao 1964). The major spawning season shifts from the outer coastal waters to the bays and inland sea during spring and summer, and then reversely during autumn and winter. The major fishing grounds of each space-time group are located in the waters near the spawning grounds. Most fish leave the fishing grounds by one and half years after birth. The fish having occurred in the spring are liable to move toward the middle Pacific region at the egg and larval stages, but most of the other groups stay within the region under discussion.

### Assessment of Population

Even though many estimates have been made of the characteristics inherent to the population dynamics (Yokota 1953, Yokota and Asami 1956, Hayasi and Kondo 1957, Hatanaka 1960, Tanaka 1960, Hayasi 1961, Yoshihara 1962, Asami 1962, Beverton 1963), it has been concluded that the anchovy is one of the most typical organisms indicating limitations of the present system of the population dynamics (Tanaka 1960, Hayasi 1961). The most comprehensively accepted opinion on the effects of fisheries upon the stock is that the fisheries may not seriously damage the anchovy stocks, because of the short life span and vigorous reproduction of that species, even if increase of amount of fishing efforts often causes decrease of the catch per unit effort (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1962). Techniques of forecasting the anchovy stock size have succeeded in limited areas, where the life history of the fish is understood (Ex. Com., Conf. Invest. Neritic-Pelagic Fisher. Japan 1963).

Hayasi (1961) summarized a general belief among fishery biologists engaging in the Cooperative Investigations on effect of fisheries upon the anchovy population as follows:

“One of the most important biological features of the Japanese anchovy is the short life span, practically about two years in duration. Another important feature is the wide-temporal and areal extent of the spawning activities.

Deduced on the basis of these features are the following two general conclusions on fluctuation in the size and distribution of the population. Firstly, the environmental change in the early stage of life of a space-time group may not exert any serious effect on the amount of recruitment for the year, because the population consists of a number of such groups. The wide-extended spawning indicates that the species can propagate under various environmental conditions. Secondly, the natural mortality rate is regarded to be high because the anchovy, being small in size, represents the major prey of diverse fishes, and because the life span of two years is much shorter than that of other neritic-pelagic species such as the sardine, many of which live for five or more years (Nakai and Hayasi 1962). Therefore, changes of the mortality rate by natural causes, especially those based on predation and competition, may play more important roles than the changes of the fishing intensity in determining the population size of the anchovy. The consistent regional distribution of catch suggests that the well-developed fisheries in the Pacific waters and the Seto Inland Sea have not seriously depleted the stocks therein.”

In the Pacific waters along Honsyu, it is possible to estimate sizes of large stocks at five developmental stages; (1) eggs in offshore, (2) postlarvae on the fishing grounds of *sirasu* fisheries on the outer coast, (3) immatures in the fishing grounds in the bays, (4) adults at the end of their first year of life and (5) adults at the early half of their third year of life on the fishing grounds along the Boso Peninsula and north. The egg stock must be proportionate with

the stock of parents, mainly I-age fish. Hayasi (1961, 1962b) compared the stock sizes at these five stages of the same year classes under a hypotheses that fluctuations in these stock sizes must be correlated if the following conditions are satisfied: (1) these stocks are actually related in the course of ontogeny, (2) the older three stocks are not overexploited, (3) the accessibility and vulnerability of the stocks do not remarkably vary between year classes, and (4) the estimates of abundances are reliable. Actually high correlation coefficients, ranging between 0.90 and 0.98, were found for most of 8 to 10 year-classes between the four stocks except the immatures in the bays.

Taking the correlations between stock sizes as well as information on spawning, migration, age and duration of life span, it has been concluded that no fishing activity exerts any serious damage on the anchovy stocks in the major fishing grounds. The correlations between *sirasu* catch and either one of the older stages reveal that the fishing did not reduce the youngest stock severely. The fisheries in the bays exploited only a portion of the immature stock. The two-boat purse seiners aiming at the adults did not exploit 0-age fish so seriously as to affect the stock sizes of I- and II-age fish. The exploitation of II-age fish did not affect size of the major local group because the oldest anchovy may die within the year, and may not much contribute to the reproduction (Hayasi 1961, 1962b).

The level of stock sizes during 1950 through 1959 was assessed on the basis of the reproduction curve proposed by Ricker (1954). In constructing the curve for the Japanese anchovy, the abundance of eggs in any two successive years was used because this measure is free from such a bias as inherent to the catch statistics, and because the spawners are mainly I-age fish. The egg abundance spawned by two successive generations are not well correlated with each other, except those reproducing in 1950 through 1952, which produced less than  $500 \times 10^{12}$  eggs. Therefore, it can be stated that the classes spawning since 1953 were large enough to supply a large amount of landings (Hayasi 1961, 1962b).

On the basis of the correlations, formulae are given for predicting the catches of 0 and II age adults in several months or two years prior to the fishing seasons. Application of the formulae to the catch for past data showed that the predicted amount agreed with the actual catch for 8 or 9 years out of 10 (Hayasi and Kondo 1962). With the use of those formulae and catch statistics, the landings have been predicted as about 26,000 tons for 0-age adults during October through December of 1961, and about 50,000 tons for the II-age adults in the early half of that year. The actual landings of 0- and II-age adults in those periods were 23,000 tons and 47,000 tons, respectively (Hayasi 1962b). This procedure was not applied for the following seasons because of occurrence of the remarkable anomaly of the environmental conditions (Nakai *et al.* 1964). Thus, the prediction based on the correlations between catches at different stages are applicable only in the case when the migratory route of fish, type of fishery, and environmental conditions

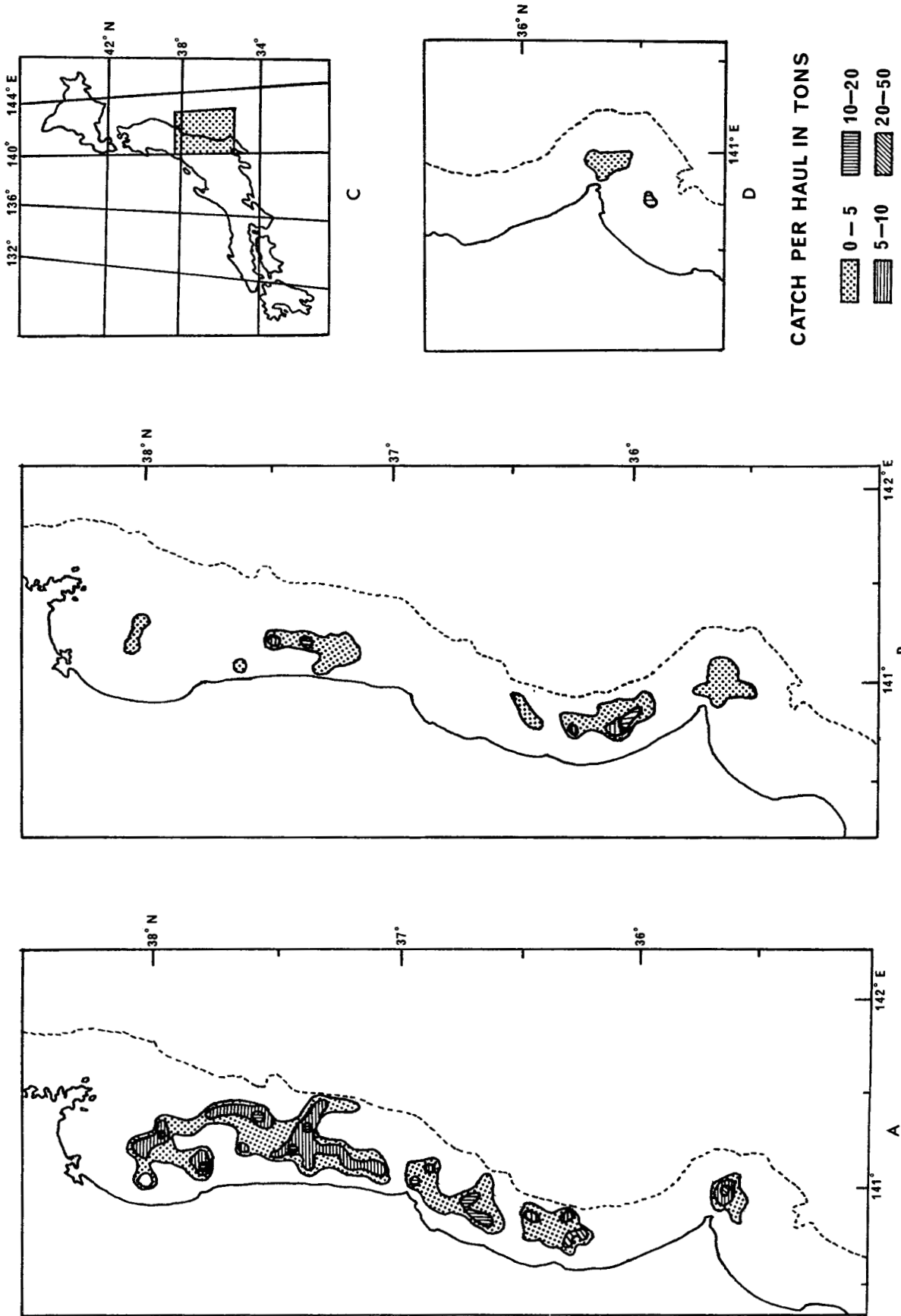


FIGURE 3. Difference of density distribution of the adult sardine at three yearly cycles of life in 1963-64 season. A. Early southward migratory cycle; B. later southward migratory cycle; C. general locality of the fishing grounds in question; and D. spawning cycle. The density is expressed by average catch per haul by purse seiners.

are nearly constant for a length of time. (Hayasi and Kondo 1962b, Hayasi 1962b).

Asami (1962) estimated the monthly mortality coefficients of the anchovy in the eastern waters along Kyusyu and Sikoku as 0.115 by fishing and 0.136 by natural causes. He also estimated the dispersion coefficients that extended between -1.090 and +2.910, being much larger than the mortality coefficients in the absolute value.

Abundance of food organisms, competitors, and predators are found to contribute obviously in determining the stock size of the anchovy (Yokota *et al.* 1961, Nakai *et al.* 1962). It was found that the analytical study was impractical for the anchovy stocks but the estimated rates of decrease and growth of the postlarvae and immatures in the western Pacific waters along Honsyu suggested the possibility to increase the amount of catch (Tanaka 1960).

In spite of a number of scientific works upon the anchovy, the present system of knowledges has not provided any objective way for development of techniques to predict the fish population as a living resource. In other words, the biological information is not unified as an *idea* since the fishery biology has treated the phenomena only superficially, even if many refined techniques have been adopted.

In order to consider biological mechanisms underlying fluctuation in the catch, it is necessary to start from the simple fact that the fish appear in a particular place in a particular season of the year. This fact must be due to the biological rules that the fish assemble in a particular way at a particular developmental stage or yearly cycle of life, or, in other words, that the fish behave independently from, as well as dependently to, the environmental conditions. The mode of assembly must be the most fundamental biological project of the investigations in order to understand where, when and how, and why, the fish appear.

Up to now, three ways were adopted for expressing the mode of assembly of fish: (1) map of distribution, (2) map of migratory route, and (3) map of catch. The maps of distribution and migratory route indicate the biological rules, but are deficient in that they show only an aspect of life. Therefore, these maps, despite their biological basis, are not applicable for indicating the most reasonable way of fishing. The map of catch does not indicate any biological rule, because the natural and social factors are not distinguished there. In this regard, we must re-evaluate and criticize the technique proposed by Vinogradov (1945), who started from the work by Greene (1913). Vinogradov (*loc. cit.*) presents maps indicating the density distribution of the king crab for each of the yearly cycle of life. Indeed his maps would present moments to approach the biological rules governing the assembly of the species, since the mode of assembly must differ depending upon the yearly cycle of life that comprises particular physiological requirements. Unfortunately, his method did not exhibit any further advance, however. The most fundamental reason for the deficit is that the yearly cycle of life was not con-

sidered as a series of categories comprising life of species, systematic fraction and developmental stage.

In order to understand way of life, therefore, it is necessary to express the mode of assembly through drawing maps of major aspects in the life for each of these categories. This series of maps, called fishing map, must give the moment to approach the mode of assembly of the fish. As an example of the fishing map, here is shown density distribution of the adult sardine in a fishing ground on the Pacific waters along Honsyu (Figure 3). The maps indicate differences in the mode of assembly based upon the yearly cycle of life, not only in geographical position but also in density (Hayasi 1965, Kubo and Hayasi 1964, Tokai Reg. Fish. Res. Lab., 1964). Thus works on the individual aspects must start from the fishing maps that may essentially express the mode of assembly on the basis of the substantial knowledge upon the life of species.

The annual change in the mode of assembly thus expressed will improve recognized *substance* of the life of species. Namely, the fishing maps drawn for any particular yearly cycle of life may deform from year to year. The yearly deformation in the mode of assembly have been caused by inadequate classification of the maturation phase, or yearly changes of the environmental conditions or of the fishery activities. Therefore, the classification of the yearly cycle is to be inspected at first. It should be noted that the inspection of the yearly cycle of life covers the inspection of the related categories which mutually define themselves. Discovery of any inadequate classification means advance of the investigations of the life of species. If no misclassification is discovered, the deformation will be attributed to the yearly change of environments, and then of the fishing activity. Repeating the procedure, it is possible to examine the three factors underlying the phenomena. Further consideration on the existence of fish indicates such series of conceptions as community, species population, systematic fraction, migratory group, shoal and individual. Actually the latter conceptions are more fundamental, while the biologist usually commences his study under the former conceptions such as community or species population. It is necessary to treat the conceptions from community to shoal in order to assess the species population itself, however. Similar systems of conceptions are required for the studies on environments and productive power of human beings. We may be able to consider real relationships between fishes, environments and productive power through examinations of the three systems but not by direct comparison of phenomena based on the individual aspects.

## REFERENCES

- \* Titles of Japanese publications without English summary are given in italics with the English translations given for preparing the present paper in parentheses.
- Agriculture Bureau, Dept. Agr. Com. 1891-93. "Preliminary report upon the fisheries of Japan", 4 vols.
- Asami, T. 1953. "Studies on the spawned eggs of anchovy, *Engraulis japonicus* T. et S." *Contr. Nankai Reg. Fish. Res. Lab.*, (1), *Contr.* 19, 7 pp.

- Asami, T. 1958 a. "On the patterns of development and growth of Japanese anchovy along the coast of Nankai and Naikai Regions of Japan". *Rept. Nankai Reg. Fish. Res. Lab.*, (7), 1-18.
- Asami, T. 1958 b. "On the condition of dispersal and clustering of fish eggs in the sea—I". *Ibid.*, (7), 19-29.
- Asami, T. 1958 c. "Ibid. II". *Ibid.*, (9), 92-102.
- Asami, T. 1962. "Studies on the Japanese anchovy, *Engraulis japonica* (Houttuyn), along the coast of Nankai Region of Japan". *Ibid.*, (16), 1-55.
- Asami, T. and M. Hanaoka 1957. "On the variation of vertebral number of *iwashi*, with special reference to its possibility of being a clue for testing difference of races or of environmental conditions during their development". *Ibid.*, (5), 59-73.
- Beverton, R. J. H. 1963. "Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing". *Rep. Proc. Verb. Reu., Cons. Perm. Inter. Exp. Mer.*, 154, 44-67.
- Darwin, C. 1917. "On the origin of species by means of natural selection" (Japanese edition translated by R. Yasugi and published in 1963 by Iwanami Syoten, Tokyo).
- Enomoto, Y. 1956. "On the occurrence and the food of *Noctiluca scintillans* (Macartney) in the waters adjacent to the west coast of Kyushu, with special reference to the possibility of the damage caused to the fish eggs by that plankton". *Bull. Japan Soc. Sci. Fisher.*, 22 (2), 82-88, 1 pl.
- Executive Committee of Conference for the Investigations of the Important Neritic-Pelagic Fisheries Resources of Japan, 1961-63. "Progress report of the cooperative investigations on the important neritic-pelagic fisheries resources in Japan, 1956-61".
- Fukuyo, T. 1947. "*Tyosi iwasi gyogyoki* (History of *iwasi* fisheries at Tyosi)." 151 pp. Published by author. Tyosi.
- Greene, C. W. 1913. "The storage of fat in the muscular tissue of the king salmon and its resorption during the fast of the spawning migration". *Bull. U.S. Bur. Fisher.*, 33, 69-138, 11 pls.
- Hatanaka, M. and M. Takahashi, 1960. "Studies on the amounts of the anchovy consumed by the mackerel". *Tohoku Jour. Agr. Res.*, 11 (1), 83-100.
- Hattori, S. 1962. "Predatory activity of *Noctiluca* on anchovy eggs". *Bull. Tokai Reg. Fish. Res. Lab.*, (9), 211-220.
- Hayasi, S. 1961. "Fishery biology of the Japanese anchovy, *Engraulis japonica* (Houttuyn)". *Ibid.*, (31), 145-268.
- Hayasi, S. 1962. a. "Growth of the Japanese anchovy—II. Vertebral counts of mature and immature fish". *Ibid.*, (9), 193-209.
- Hayasi, S. 1962. b. "Recent advance in population dynamics of the Japanese anchovy, *Engraulis japonica* (Houttuyn)". IPFC 10th Proc. Sect. II, 105-113.
- Hayasi, S. 1965. "*Honsyu togan no maki-ami gyozyo ni raiyusuru oba-maiwasi no bunpuyosiki to raiyuryo yosoku* (mode of distribution and forecast of stock size of the large sized sardine immigrating the purse seine fishing ground on the east coast of Honsyu)". *Rept. Conf. Fisher. Res'ces. Invest.*, (2) :26-33.
- Hayasi, S. and K. Kondo 1957. "Growth of the Japanese anchovy—IV. Age determination with the use of scales". *Bull. Tokai Reg. Fish. Res. Lab.*, (17), 31-64.
- Hayasi, S. and K. Kondo 1959. "Two-boat purse seine fishery and the age composition of the anchovy catch in the area extending between Kujukuri-Hama and Kashima-Nada, 1953 through 1956". *Ibid.*, (26), 21-41.
- Hayasi, S. and K. Kondo 1962 a. "Growth of the Japanese anchovy—I. Seasonal fluctuation in condition coefficient". *Ibid.*, (9), 179-192.
- Hayasi, S. and K. Kondo 1962 b. "Age composition and prediction of the anchovy catch in the waters along Kujukuri-Hama and Kashima-Nada, eastern Pacific coast of Honshu. *Bull. Japan. Soc. Sci. Fisher.*, 28 (8), 784-787.
- Hayasi, S. and H. Suzuki 1957. "Growth of the Japanese anchovy—III. Vertebral counts of postlarvae". *Bull. Tokai Reg. Fish. Res. Lab.*, (15), 21-28.
- Hayasi, S. and H. Suzuki 1959. "On the counting of the vertebral segments of the postlarval anchovy". *Ibid.*, (26), 43-50.
- Hayasi, S. and A. Tadokoro 1962. "Catch of the *taiwan-ainoko* in the anchovy fishing area around Japan". *Bull. Japan. Soc. Sci. Fisher.*, 28 (1), 30-33.
- Hirakawa, M. 1955. "Studies on the sardine resources and the structure of the sardine fisheries in the sea of western Kyusyu basing on the survey of the sardine model-boats". *Bull. Seikai Reg. Fish. Res. Lab.*, (7), 1-92.
- Hubbs, C. L. 1943. "Terminology of early stages of fishes". *Copeia*, 1943 (4), 260.
- Ishigaki, T., K. Kaga, Y. Kitano and O. Sano 1959. "Progress report of the cooperative coastal important resources investigations, 1955". 186 pp. Hokkaido Regional Fisheries Research Laboratory. Yoiti.
- Imamura, Y. and S. Takeuchi 1960. "Study on the disposition of fish toward light. no. 5. The strength of illumination comfortable to *Engraulis japonicus*". *Jour. Tokyo Univ. Fisher.*, 46 (1, 2), 133-148.
- Inoue, M. and M. Ogura 1958 a. "The swimming-water-depth for anchovy shoals in Tokyo Bay". *Bull. Japan. Soc. Sci. Fisher.*, 24 (5), 311-316.
- Inoue, M. and M. Ogura 1958 b. "The characteristic behaviors of anchovy shoals called rippling and jumping in Tokyo Bay". *Ibid.*, 24 (5), 317-321.
- Ito, S. 1961. "Fishery biology of the sardine, *Sardinops melanosticta* (T. & S.), in the waters around Japan". *Bull. Japan Sea Reg. Fish. Res. Lab.*, (9), 227 pp.
- Kamiya, T. 1916. "The pelagic eggs and larvae of fishes in the Tateyama Bay". *Rept. Imp. Fish. Inst. Tokyo*, 11 (5), 1-92.
- Kimura, K. 1934. "On the manner of swimming sardines in a confined space". *Bull. Japan, Soc. Sci. Fisher.*, 3 (2), 85-92.
- Kishinouye, K. 1908. "Notes on the natural history of the sardine (*Clupea melanosticta* Schlegel)". *Jour. Fisher. Bur.*, 14 (3), 71-105.
- Kishinouye, K. 1911. "Prehistoric fishing in Japan". *Jour. Coll. Agr. Tokyo Imp. Univ.*, 2 (7), 327-382.
- Kubo, I. 1961. "*Suisan Sigen Kakuron* (Summary of fishery biology, particular to living resources in Japan)". 396 pp. Koseisyu-Koseikaku. Tokyo.
- Kubo, I. and S. Hayasi 1964. "*Engan gyozyo niokeru gyokyo to kaijyo tonu kanren no bunseki-yoho* (Analysis of relationships between catch and oceanographic conditions in the neritic fishing grounds-preliminary report), 9 pp. 2 figs. (mimeo). Tokyo University of Fisheries, Tokyo.
- Kurita, S. and C. Tanaka 1956. "Estimation of annual catches of sardine and anchovy in Japan, 1926-50—Using the amounts of processed *iwashi* products". *Bull. Japan. Soc. Sci. Fisher.*, 22 (6), 337-347.
- Marr, J. C. 1957. "Contributions to the study of subpopulations of fishes". *U. S. Fish and Wildlife Serv., Spec. Sci. Rept.*, (208), 1-6.
- Matsubara, K. 1955. "Fish morphology and hierarchy". 11+1605 pp. Isizaki Syoten. Tokyo.
- Miyazaki, C. 1960. "*Engan kinkai gyogyo* (Coastal and neritic fisheries in Japan)". 370 pp. Koseisyu-Koseikaku. Tokyo.
- Murakami, S. and T. Hayano 1955. "Progress report of the cooperative *iwashi* resources investigations, 1952". 86 pp. Seikai Regional Fisheries Research Laboratory. Nagasaki.
- Nakai, Z. 1960. "Changes in the populations and catch of the Far East sardine area". *Proc. World Sci. Meet. Biol. Sardines & Related Species*, 3, 807-853.
- Nakai, Z. 1962 a. "Apparatus for collecting macroplankton in the spawning surveys of *iwashi* (sardine, anchovy, and round herring) and others". *Bull. Tokai Reg. Fish. Res. Lab.*, (9), 221-236, 10 pls.
- Nakai, Z. 1962 b. "Studies relevant to mechanisms underlying the fluctuation in the catch of the Japanese sardine, *Sardinops melanosticta* (Temminck & Schlegel)". *Japan. Jour. Ichth.*, 9 (1-6), 1-115.
- Nakai, Z. and S. Hayasi 1962. "On the age composition of the Japanese sardine catch, 1949 through 1951—With an attempt of population analysis". *Bull. Tokai Reg. Fish. Res. Lab.*, (9), 61-84.

- Nakai, Z. and S. Hattori 1962. "Quantitative distribution of eggs and larvae of the Japanese sardine by year, 1949 through 1951". *Ibid.*, (9), 23-60.
- Nakai, Z., S. Hattori, K. Honjo, T. Watanabe, T. Kidachi, T. Okutani, H. Suzuki, S. Hayasi, M. Hayashi, K. Kondo and S. Usami 1964. "Preliminary report on marine biological anomalies on the Pacific coast of Japan in early months of 1963, with reference to oceanographic conditions". *Ibid.*, (38), 57-75.
- Nakai, Z., K. Honjo, T. Kidachi, H. Suzuki, T. Yokota, T. Tsujita, E. Ozasa, Y. Shojima and S. Nishimura 1962.\* "Iwasirui kokisigyo no syokuzi to kanyuryo tonu kankei (Relationships between food organisms and size of recruitment of iwasi)". *Suisan Sigen ni kansuru kyodo kenkyu suisin kaigi hokokusyo, Syowa 36 nendo*, 102-121. Norin Suisan Gizyutu Kaigi. Tokyo.
- Nakai, Z., S. Usami, S. Hattori, K. Honjo and S. Hayasi, 1955. "Progress report of the cooperative iwashi resources investigations, 1949-51". 116 pp. Tokai Regional Fisheries Research Laboratory. Tokyo.
- Nishikawa, T. 1901.\* "Hisiko tyosa hokoku (A study on the anchovy)". *Jour. Fish. Bur.*, 10(1), 1-16, 1 pl.
- Odate, S. 1957. "Studies on the larval fish of the Japanese anchovy, *Engraulis japonica* (Houttuyn), in the northeastern sea area of Japan". *Bull. Tohoku Reg. Fish. Res. Lab.*, (9), 111-128.
- Odum, E. P. 1953. "Fundamentals of Ecology (Japanese edition translated by research group for ecology of the Kyoto University, and published by Asakura Syoten, Tokyo, in 1956).
- Ricker, W. E. 1954. "Stock and recruitment". *Jour. Fisher. Res. Bd. Canada*, 11 (5), 559-623.
- Sato, S. 1961.\* "Suisan sigen kenkyu no riron to zissen ni okeru syomondai (Problems inherent to theories and performance in the fishery biology)". *Suisan Kagaku*, 9 (2, 3), 1-28.
- Sato, S. 1964.\* "Sakana no seikatu—syutai to kankyo to no kankei—no Kenkyu nituite (Problems of investigations on the way of life of the fish—relationships between the subject and the environments)". *Bull. Japan. Soc. Fisher. Oceanogr.*, (5), 80-102.
- Statistics and Survey Division, Ministry of Agriculture and Forestry (or Ministry of Agriculture and Commerce), 1906-63.\* Norin (or *Nosyomu*) *Tokei* (Statistical Year Book), 1905-62.
- Steven, G. A. 1948. "Contributions to the mackerel, *Scomber scombrus* L.III. Mackerel migrations in the English Channel and Celtic Sea". *Jour. Mar. Biol. ASS. U. K.*, 27, 517-539.
- Suehiro, Y. 1936. "On the various causes of mortality of sardines". *Jour. Imp. Fisher. Exp. Sta.*, (7), 51-90.
- Suehiro, Y. 1947.\* "Gyorui seirigaku no zissai (Practical text book on fish physiology)". 184 pp. Takeuti Syobo. Tokyo.
- Suehiro, Y., S. Yoshino and Y. Tsukamoto 1957.\* "Hosei ni taisuru gyogun no seitai ni tsuite (Effect of the cannon sound upon behavior of fishes)". 55 pp. Tiba Prefecture. Tiba.
- Tagawa, I. 1903. "Sardine fishery in the Prefecture of Kanagawa". *Jour. Imp. Fisher. Bur.*, 12 (2), 7-56.
- Takao, K. 1964.\* "Seto Naikai no katakati-iwasi, *Engraulis japonica* (Houttuyn), no seitai ni tuite (Ecological study on the Japanese anchovy, *Engraulis japonica* (Houttuyn), in the Seto Inland Sea." *Naikai Reg. Fish. Res. Lab., Publ. Ser. C.*, (2), 1-50.
- Tanaka, S. 1956. "Body length distribution of the Japanese anchovy, *Engraulis japonica* (Houttuyn), in Ise Bay, Mikawa Bay and Enshu Nada—I. Body length in 1951 and 1952." *Bull. Tokai Reg. Fish. Res. Lab.*, (13), 35-50.
- Tanaka, S. 1960. "Studies on the dynamics and the management of fish populations". *Ibid.*, (28), 1-200.
- Tokai Regional Fisheries Research Laboratory 1964. "Quarterly forecast on distribution and abundance of the important neritic-pelagic fishes in Tokai Region". Nos. 1 & 2. (mimeo.).
- Uchida, K., S. Imai, S. Mito, S. Fujita, M. Ueno, Y. Shojima, T. Senta, M. Tabuku and Y. Dotu 1958. "Studies on the eggs, larvae and juvenile of Japanese fishes, Ser. I". 89 pp. 86 pls. Kyushu University, Hukuoka.
- Uda, M. 1952. "On the relations between the variations of the important fisheries conditions and the oceanographic conditions in the adjacent waters of Japan". *Jour. Tokyo. Univ. Fisher.*, 38 (3), 363-389.
- Usami, S. and H. Sugiyama 1962. "Fecundity of the Japanese anchovy, *Engraulis japonica* (Houttuyn)—I. Process of maturation and number of ova discharged in a season based on ovum diameter frequency of the anchovy in Mutsu Bay". *Bull. Tokai Reg. Fish. Res. Lab.*, (34), 19-37.
- Vinogradov, L. G. 1945. "Yearly cycle of life and migration of the crab in the northern part of the western Kamchatka shelf". *Proc. TINRO*. 19. (Japanese edition translated by Nakaba and published by the Hokuyo Sigen Kenkyu Kyogikai, Tokyo, on no. 38, pp. 1-70, of the *Soren Hokuyo Gyogyo Kankei Bunkensyu*).
- Yamaguti, K. 1947. "Nihon gyogyosi (History of Japanese fisheries)". 349 pp. Seikatusya. Tokyo.
- Yamanaka, I. and S. Ito 1957. "Progress report of the cooperative iwashi resources investigations, 1954". 177 pp. Japan Sea Regional Fisheries Research Laboratory, Niigata.
- Yasumura, T., T. Utunomiya, Y. Otuka, and K. Maekawa 1956.\* "Yamagutiken Setonaikai ni okeru iwasi ami gyogyo to katakati—iwasi ni kansuru tyosa kenkyu (Investigations on the iwasi fisheries and the anchovy in the Seto Inland Sea off the Yamaguti Prefecture)". *Jour. Yamaguti Pref. Naikai Fisher. Exp. St.*, 8 (2), 1-42.
- Yokota, T. 1953. "Studies on the sardines in Hyuga—Nada and Bungo Strait". *Rept. Nankai Reg. Fish. Res. Lab.*, (2), 1-251.
- Yokota, T. and T. Asami. 1956.\* "Iwasi sigen kyodo kenkyu keika hokoku, Syowa 28 nen (Progress report of the cooperative iwashi resources investigations, 1953)". 117 pp. Nankai Regional Fisheries Research Laboratory, Koti.
- Yokota, T. and I. Furukawa 1952. "Studies on the stocks of the clupeoid fishes in Hyuganada—III. Note on the variation of the number of vertebrae and monthly growth rate of Japanese anchovy, *Engraulis japonicus* Temminck et Schlegel". *Bull. Japan. Soc. Sci. Fisher.*, 17 (7, 8), 60-64.
- Yokota, T., M. Toriyama, F. Kanai and S. Nomura 1961. "Studies on the feeding habit of fishes". *Rept. Nankai Reg. Fish. Res. Lab.*, (14), 234 pp.
- Yoshihara, T. 1962.\* "Suisan sigen no dotai ni kansuru suriteki kenkyu (Mathematical studies on dynamics of fishery resources)". *Jour. Tokyo Univ. Fisher., Spec. Ed.*, 5 (1), 1-103.