clear records have been kept. The first entry of fish landings in annual statistical records, *Nôrin* (or *Nôshômu*) *Tokai* that is translated the Statistical Year Book in this report, compiled by the Government were those for 1894. The *iwashi* landings, mainly sardine, in Japan shows no substantical change during 1894 through 1904 (Table 24).

Table 25. Sardine catch in the Far East by region, 1904-57*
(Unit: 10,000 tons)

Year	Total	Japan	Korea	Coast range	Sakhalin	Year	Total	Japan	Korea	Coast range	Sakhalin
1905	12	12	—	—	—	1932	147	109	28	9	1
1906	12	12	—	—	—	1933	192	148	34	9	1
1907	13	13	—	—	—	1934	208	139	58	10	1
1908	11	11	—	—	—	1935	225	131	80	12	2
1909	12	12	—	—	—	1936	272	159	99	11	3
1910	13	13	—	—	—	1937	273	115	139	14	5
1911	13	13	—	—	—	1938	207	99	98	10	0+
1912	15	15	—	—	—	1939	232	100	121	11	0+
1913	17	17	—	—	—	1940	181	75	96	10	0+
1914	21	21	—	—	—	1941	152	87	63	2	0+
1915	23	23	—	—	—	1942	77	69	8	0+	0
1916	24	24	—	—	—	1943	46	46	0	0	0
1917	37	37	—	—	—	1944	25	25	0	0	0
1918	25	25	0+	—	—	1945	16	16	0	0	—
1919	26	26	0+	—	—	1946	24	24	—	0	—
1920	35	35	0+	—	—	1947	24	24	—	—	—
1921	29	29	0+	—	—	1948	25	25	—	—	—
1922	31	31	0+	—	—	1949	33	33	—	—	—
1923	41	41	0+	—	—	1950	38	38	—	—	—
1924	42	42	0+	—	0+	1951	48	48	—	—	—
1925	53	49	4	?	0+	1952	35	35	—	—	—
1926	52	43	9	?	0+	1953	40	40	—	—	—
1927	77	52	25	?	0+	1954	25	25	—	—	—
1928	82	57	25	?	0+	1955	21	21	—	—	—
1929	102	68	34	?	0+	1956	21	21	—	—	—
1930	108	69	30	8	1	1957	21	21	—	—	—
1931	142	95	38	9	0+						

0+: Catch less than 5,000 tons.
—: Presumably no substantial amount of commercial catch occurred in those regions for the year.

* From Statistical Yearbooks, MAF, 1907-59;
Statistical Records of the Government of Karafuto 1932-33 and 1942-43;
NAKAI 1949; and KURITA and TANAKA 1956.

A portion of the 1941 catch, which was landed in Ibaraki Prefecture, is based on reports from the field agencies of that prefecture, because the amount made entry in the Statistical Yearbook for that prefecture for the year appears erroneously large.

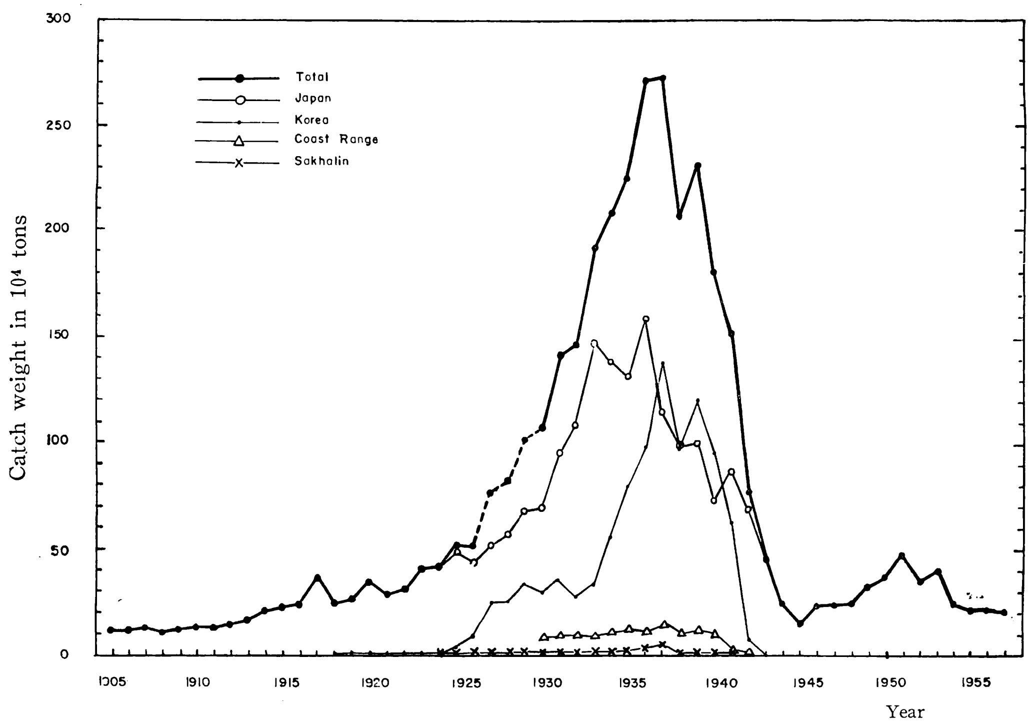

Fig. 31. Fluctuations in the sardine catch in the Far East by region, 1905–57*
* For sources of data, see footnote of Table 25.

For the years 1905 onwards, the data were considered more reliable than before. According to the satistics, the sardine landings in Japan increased gradually till 1925 and then rapidly for the following ten years. A peak of the catch at 1,590,000 tons in 1936 followed a sheer decline to the lowest level at 160,000 tons in 1945. A slight recovery effected by 1951 was followed by a decrease. The catch since then remained at a low level (Table 25, Fig. 31).

The most important gear in sardine fishery in Japan have been various types of round hauls. This group of fishery has provided about one half of the total sardine catch during 1932, 1942 and 1957. The catch by set nets has been on a steady decrease, from 27 to 3 percent during the 25 years. The significances of the beach and boat seines as well as drift gill net in the sardine fishery have fluctuated irregularly from period to period. Although the lift net did not catch as much sardine as the other major gear, the relative significance has increased in the recent years (Section 1–8). The number and tonnage of fishing boats of some gear for 1957 are also indicated in the same section.

Sardine fisheries in Korea and the Coast Range of the Soviet Union seem to have been initiated later than in Japan (Table 25, Fig. 31). According to IHARA *et al.* (1908, 1910), however, beach seines and some other gear were in use at that time on a small scale along the eastern coast of the Korean Peninsula to catch young sardine measuring less than 9 cm in body length. NAKAI (1939) inferred that even in that period large sized sardine might have been distributed in offshore areas beyond the fishing ground, although they were not available for fishermen operating only in the littoral waters. He (*loc. cit.*) gave as an evidence the mass mortality that took place along the coast of South Hamkyong, Korea, in October 1906 as well as a great number of large sized sardine observed at sea off Wonson, North Korea, in October of 1910. These fact led him to assert that migrating large sized sardine visited the areas adjacent to Korea at least in certain years, if not every season, prior to 1918. According to the catch statistics made available since then, the sardine catch off Korea reached to a peak of 1,390,000 tons in 1937. Production then decreased yearly until 1943 when the sardine was almost non-existent in Korean waters. Since then no catch from Korea is shown in statistical records. The major gear used in the fishery was the purse seine followed by the drift net, and a few set nets.

KAGANOVSKII (1931) reported sardine occurring in waters off the Coast Range, USSR, prior to 1923. Their migration was usually large in that year and gave the fishery an incentive to become an increasingly significant marine industries; the fishery has since developed at an astonishing rate. In the fishery, the most important gear was drift net with powered or non-powered boats. A few purse seines were also operated. As seen in the landing statistics, sardine in those waters appear to have followed the same fate as in Korea. The catch reached to a peak in 1937, then decreased and fell to zero around 1943 (Table 25, Fig. 31).

In the sea adjacent to Sakhalin, the years when sardine occurred and disappeared were almost the same as those in the Coast Range (Table 25, Fig. 31). According to BOGAEVSKII (1955), the sardine were occasionally caught by gear set at such

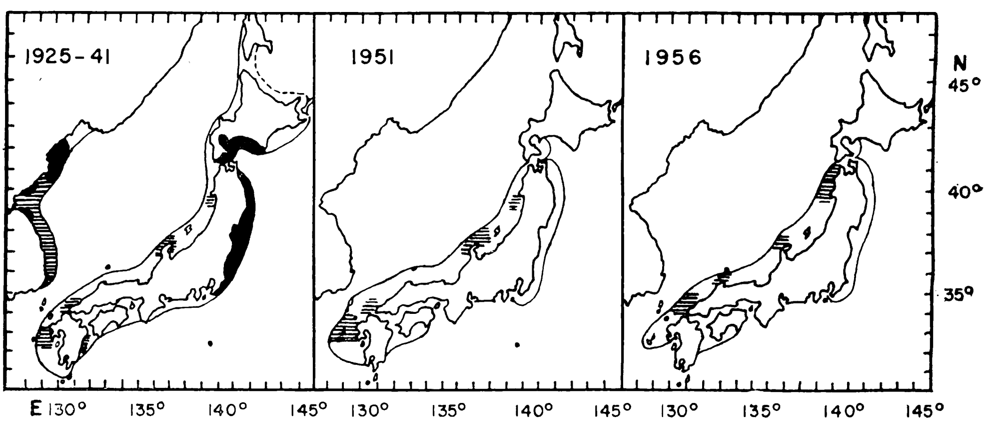

Fig. 32. Changes in locality of fishing grounds for the sardine in the Far East, 1925-41, 1951, and 1956 (after NAKAI 1960).

light moderate heavy

inshore areas as the southwestern coast of Sakhalin, Aniva Bay and the South Kuril Islands. During June through October 1954 the sardine catch taken mainly by set net in the northwestern area of Sakhalin was of some industrial significance, but remained at only 11.9 tons.

In summary, the sardine fishery in the Far East prospered during 1927 through 1942, the annual catch reaching a peak of about 2,000,000 to 2,700,000 tons from 1934 to 1939. The yearly catch since 1945 ranged at a low of 200,000 to 500,000 tons. Throughout the period, in which the catch was high, the major fishing grounds for sardine were located off the northeastern coast of Honshû, the Pacific side of Hokkaidô, and the waters adjacent to North Korea. In the years since 1945 the fish virtually disappeared from the northern regions inclusive of North Korea, and the major fishing ground for a time was the northwestern corner of the East China Sea centering around the Gotô Islands, now it is further north, in the coastal waters of the Japan Sea (Fig. 32).

Section 2-2. Shifts of spawning and nursery grounds

One of the most remarkable changes in ecology of the sardine is the shift in the geographical position of the spawning ground to a northern area as probably

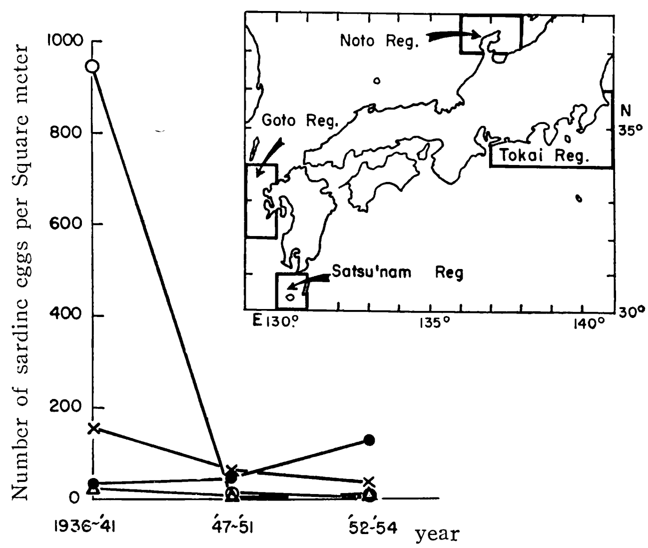

Fig. 33. Changes in the regional egg abundance of the sardine, 1936-41, 1947-51, 1952-54, with a map showing the spawning grounds* (after NAKAI 1960).

○ Satsunan Region × Gotô Region
● Noto Region △ Tôkai Region

* The number of eggs per squaremeter for the years 1936-41 is based on NAKAI (1952), the values for the other years have been estimated on the basis of the data from the Regional Fisheries Research Laboratories.

similar shift in the nursery ground of the adults. According to NAKAI (1949), Satsunan Area situated off the southern tip of Kyûshû received nearly 70 percent of the egg abundance during the prosperous period around 1940 (Fig. 33). Distribution range of the egg stock centering the Satsunan Area extended to the northwestern and northeastern coast of Kyûshû. The eggs were abundant in Enshû Nada and the waters adjacent to Bôsô Peninsula, Pacific side, and the northern waters around Noto Peninsula, Japan Sea (Fig. 34). The amount of eggs spawned in Satsunan Area has been on the decrease since sometime after 1943. Since 1945, the spawning centre has been moving to the northwestern waters off Kyûshû (NAKAI 1952) ; more recently the spawning sardine evidently proceed along the Japan Sea into the northern side of the Noto Peninsula ; and the amount of the eggs spawned further, north, off the western coast of Aomori Prefecture, is on the increase.

Since dispersion of the pelagic eggs and larvae from the spawning site is affected mainly by the currents, any changes in the location of spawning grounds may occur, depending upon the currents in the area, the distribution of the eggs ; hence also the location of nursery areas may be affected. According to NAKAI (1949), great quantities of sardine eggs and larvae that had been spawned in Satsunan Area in the prosperous days of the fishery were transported and spread along the Pacific coast of Japan by the Kuroshio Current which passed through the region. However, because of a chain of events, the sardine have not spawned in the Satsunan Area since 1946. These events are :

a. An anomaly in the Kuroshio Current became intensified since 1938 (Section 2-5). This anomaly caused the mass mortality of the larvae from the major spawning ground (Section 3-2).
b. The reduction of the population size caused by the decrease of recruitment improved the feeding condition of adults (Sections 1-7 and 2-3).
c. Under the improved feeding condition, the parent fish have not moved for the southern waters from their habitat in the Japan Sea during the early winter (Section 2-4).

Accordingly, the distribution area as well as the abundance of sardine larvae collected by plankton nets also indicated substantial changes. In the prosperous period around 1938, the larvae were most abundantly taken in the waters east of Kyûshû (south of Shikoku), to which the Kuroshio Current has proceeded from the Satsunan Area. In the recent adverse period, the larvae were found distributed in the similar pattern as of the eggs (Fig. 35). Consequently, the supply of the eggs and larvae to the Pacific area of Honshû was reduced to a very minimum or zero. The Pacific area of Honshû, although it always provided the sardine with a great expanse of highly productive nursery area, lost all the significance as a developing ground for young sardine after the decrease of the population. As additional circumstantial evidence to prove this point, NAKAI (1958) noted an abrupt disappear-

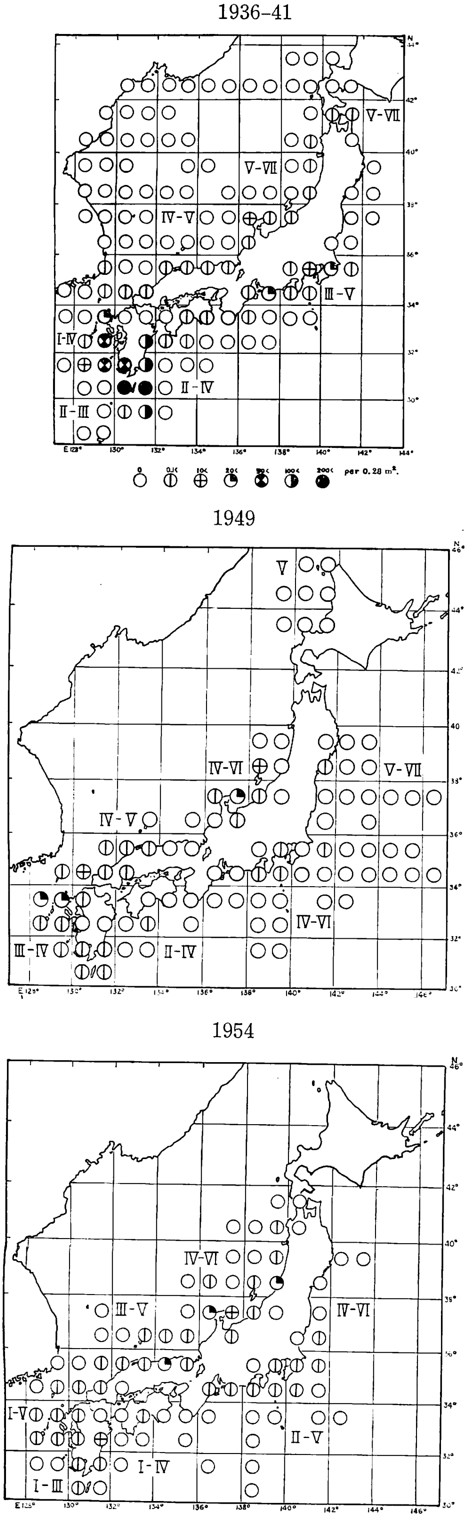

Fig. 34. Quantitative distribution of sardine eggs in the main spawning months by region, 1936-41, 1949 and 1954.

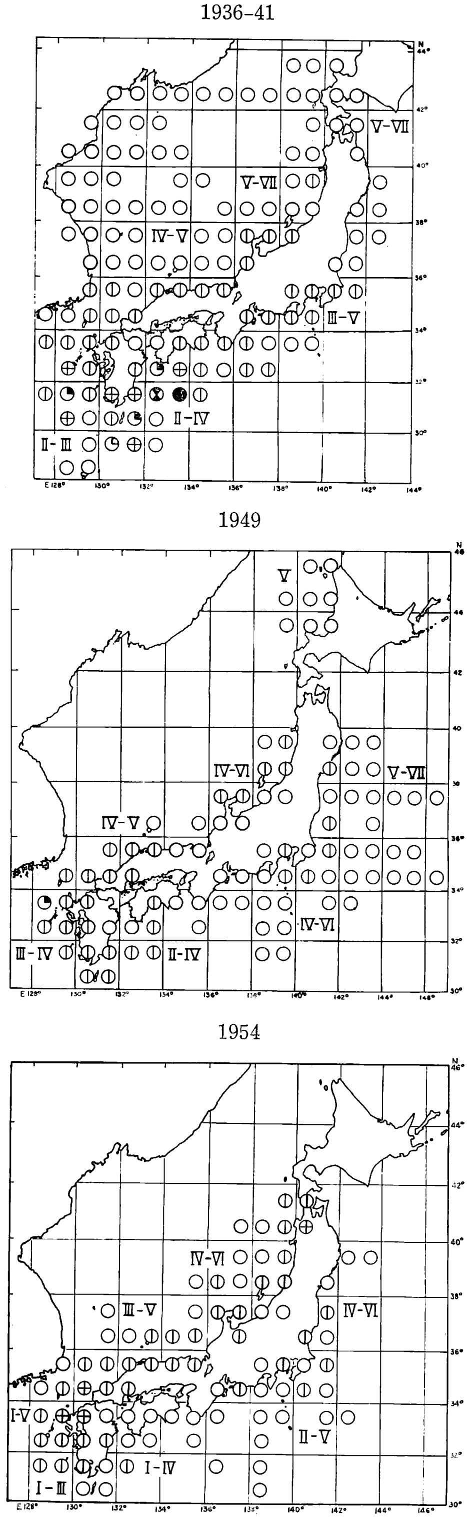

Fig. 35. Quantitative distribution of sardine larvae in the main spawning months by region, 1936-41, 1949 and 1954.

ance of young sardine, after 1946, from a beach seining ground adjacent to the Kii Peninsula by which the Kuroshio Current also passed.

Section 2-3. Variations of growth and age composition

Length composition: The sardine have their spawning waters as well as nursing grounds for their youngs in the littoral areas along certain parts of the Japanese Islands. The major distribution range of the young fish also does not extend very far from the coastal regions. In fact, the sardine are distributed in the sea adjacent to Japan during all their developmental stages. However, when the sardine population was large, the adult fish migrated extensively as far as Korea, Coast Range and Sakhalin, in which regions fishermen made very good catch (Section 2-1). This is a factor that has greatly complicated the age and size compositions of the sardine catch. In addition, a characteristic of Japanese sardine fisheries is that thousands of ports and beaches have received fish caught by countless varieties of gear. Therefore, it is more difficult to deduce an exact composition of the commercial sardine catch in Japan than in other areas. The composition of the catch is ill-defined for the years prior to 1949, when the Cooperative Investigations were not conducted on a country-wide scale.

In this report the sardine catch before 1949 was represented by that in the main productive regions, on the basis of works by AIKAWA and KONISHI (1940) and landing statistics by prefectural agencies. Body length of the catch in the Pacific waters off the northeastern part of Honshû and Hokkaidô ranged from 11 to 17 cm with a particular mode appearing between 12 and 15 cm. The catch landed on the Japan Sea coast of Honshû, though it remained at less than 12 percent of the annual total in the Far East, consisted mainly of older fish. The waters west of Kyûshû also produced the older fish from winter to spring. The body length composition of fish collected from those two regions during 1936 through 1938 ranged from 16 to 18 cm, with no appreciable variation depending on year (Table 26). Since the data were not derived from well-organized investigations, they would not bear close examination for such detailed feature as the annual variation of the composition. Nevertheless, it can be seen that the mode in every sample is distributed around a length class of 16-18 cm. It is, therefore, inferrable that no remarkable fluctuations had taken place in the size composition of old sardine prior to 1949, and that the samples roughly reflected the commercial catch. The change of mean body length of III-age fish caught in the Japan Sea including the Korean coast from 1938 to 1955 will be described later.

Based on the recent investigations since 1949, it becomes clear that the young fish less than 13 cm in body length, especially the juveniles around 4 to 5 cm, have dominated among the commercial sardine catch in Japan, and that the large sized fish between 18 and 21 cm in body length have been more abundantly exploited than

Table 26. Body length composition of large sized sardine from the Japan Sea and East China Sea*, 1936-38 (after NAKAI 1960).

Period	January to August, 1936		February to April, 1937		January to June, 1938	
Area	Japan Sea coast and northern Kyûshû		Western Honshû and western Kyûshû		Japan Sea coast, northern and western Kyûshû	
Sampling port and number of samples	Fukaura 2 Kamo 1 Ryôzu 2 Usetsu 3 Hamada 1 Senzaki 4 Hirado 1 Total 14		Tsunojima 2 Karatsu 1 Hirado 1 Makurazaki 1 Total 5		Tsuchizaki 1, Ryôzu 3 Namerikawa 1, Tsuruga 4 Miyazu 1, Uratomi 1 Usetsu 1, Kanaiwa 1 Senzaki 2, Shigajima 2 Fukuyoshi 3, Makurazaki 3 Total 23	
Number of individuals	1, 528		1, 633		2, 068	
Body length interval (cm)	Composition (%)	Samples showing mode (number)	Composition (%)	Samples showing mode (number)	Composition (%)	Samples showing mode (number)
14. 1-15. 0	0. 9	0	0	0	0. 3	0
15. 1-16. 0	8. 0	1	1. 5	0	7. 5	0
16. 1-17. 0	24. 0	4	26. 7	1	38. 8	11
17. 1-18. 0	35. 0	8	36. 5	4	38. 4	12
18. 1-19. 0	22. 1	1	24. 9	0	11. 4	0
19. 1-20. 0	8. 8	0	7. 9	0	3. 0	0
20<	1. 2	0	2. 5	0	0. 4	0
Source of data	AIKAWA and KONISHI (1940)		NAKAI (1938a)		AIKAWA and KONISHI (1940)	

* Obtained from the samples used for the body length determination; the values may not always be applicable to the total catch of the year.

the medium sized fish between 14 and 18 cm (Table 27).

No statistical data accurate enough to obtain the length composition have been published on the catch from the Korean waters in the prosperous years of fishing. According to NAKAI (1938a), the fragmental samples collected during October 1936 through March 1937 mainly considered of the medium sized fish around 16-19 cm in body length. Although the samples are not sufficiently large in size, they may suggest the length composition of sardine catch in Korea at that period (Table 28).

Age composition: In estimating the age composition of catch, the scale reading has been widely adopted (Section 1-5). In the prosperous period, the Far Eastern sardine catch mainly consisted of I- and II-age fish landed on Hokkaidô and the northeastern part of Honshû, and III- and IV-age fish brought to the Korean ports. The catch of 0-age fish was of minor significance in most regions except the central and southern parts of the Pacific coast and the northeastern part of Kyûshû.

Tlble 27. Body length composition of the sardine catch in Japan by number of individuals as of 1956 (after NAKAI 1960).
(Unit: 1,000,000 fish)

Length class (cm)	Total	Japan Sea coast		Western coast of Kyûshû	Pacific coast		
		Northern part	Western part		Southern part	Middle part	Northern part
(Total)	17,879.6	485.8	13,725.0	3,203.0	92.6	58.7	314.4
3.0>	760.0	—	—	760.0	—	—	—
3.0—	62.0	—	15.6	46.4	—	—	—
3.5—	517.3	—	465.9	51.5	—	—	—
4.0—	2,563.2	—	2,551.9	11.3	—	—	—
4.5—	2,857.7	—	2,847.8	9.8	—	—	—
5.0—	2,253.7	—	2,234.5	19.2	—	—	—
5.5—	548.7	—	517.2	27.0	—	4.5	—
6.0—	718.2	—	701.2	16.1	—	0.9	—
6.5—	680.1	—	644.4	35.7	—	—	—
7.0—	613.7	—	552.8	60.9	—	—	0.1
7.5—	411.2	—	211.3	199.9	—	—	0.0
8.0—	610.8	0.1	258.5	352.1	—	—	0.0
8.5—	742.5	1.6	372.1	368.8	—	—	0.0
9.0—	388.0	6.1	194.2	175.8	—	—	11.9
9.5—	295.2	23.5	165.9	93.9	—	—	11.9
10.0—	354.9	21.3	263.0	61.0	—	—	9.6
10.5—	349.1	23.3	254.1	65.7	0.4	—	5.5
11.0—	411.9	33.7	227.6	136.1	2.9	0.0	11.6
11.5—	333.3	51.8	148.8	108.2	12.0	0.0	12.5
12.0—	272.6	46.8	107.7	84.1	19.1	—	14.9
12.5—	205.4	44.8	93.1	51.3	12.9	0.0	3.3
13.0—	105.0	10.7	36.1	36.8	15.1	0.0	6.3
13.5—	87.7	0.8	19.9	41.5	15.3	0.7	9.4
14.0—	74.5	5.3	3.2	32.6	6.6	1.4	25.5
14.5—	82.8	0.7	2.0	26.4	1.2	2.0	50.4
15.0—	80.7	1.6	10.8	21.8	0.2	2.6	43.6
15.5—	50.9	0.2	11.6	15.9	0.9	3.6	18.6
16.0—	42.2	0.5	15.8	11.6	1.3	5.5	7.5
16.5—	40.7	0.6	24.9	8.9	1.7	3.6	1.1
17.0—	46.5	1.6	31.8	6.0	1.2	4.8	1.2
17.5—	53.9	1.3	42.5	6.7	0.9	2.4	0.1
18.0—	108.2	7.2	75.7	20.9	0.4	2.6	1.3
18.5—	187.5	22.6	119.9	39.3	0.1	2.0	3.5
19.0—	258.7	43.1	152.1	51.9	0.1	2.5	9.0
19.5—	258.0	46.8	148.2	46.9	—	2.7	13.5
20.0—	211.4	36.9	103.9	50.1	0.1	5.5	14.9
20.5—	114.2	24.3	53.9	17.0	0.0	5.4	13.6
21.0—	65.8	13.5	22.4	18.5	0.1	3.9	7.5
21.5—	36.7	8.0	15.4	8.4	0.0	1.5	3.4
22.0—	16.5	4.1	5.0	5.2	—	0.6	1.6
22.5—	4.7	1.7	1.2	1.2	—	0.0	0.6
23.0—	2.8	1.0	0.9	0.6	—	—	0.3
23.5—	0.7	0.3	0.3	—	—	—	0.1
24.0—	0.1	0.0	—	—	—	—	0.0
24.5—	0.0	0.0	—	—	—	—	0.0

In the adverse period, the greater portion of catch landed at almost all the ports has been 0-age fish; and the II-age fish and older have been landed only in the spawning season at the ports northwest of Kyûshû and those on the Japan Sea (Table 29).

In the prosperous years the parent fish were mostly III-age group followed by IV-age group. Some time after 1945 the parent stock has come little by little to

Table 28. Body length composition of the sardine samples in Korea, October 1936–March 1937 (after NAKAI 1938a).
(Unit of the composition: percent)

Port	Chongjin		Chumungin		Bongouchin	Wokpo	Total
Data	30/10/'36	25/11/'36	14/11/'36	23/12/'36	5/1/'37	26/3/'37	
Gear	purse seine	purse seine	drifter	drifter & purse seine	drifter	drifter	
Number of indiv.	245	174	233	348	338	286	1,624
cm							
14.1–15.0	1.2	0.0	0.9	0.0	0.0	0.0	0.3
15.1–16.0	15.1	0.6	15.9	4.3	10.3	2.1	8.1
16.1–17.0	45.3	30.4	45.0	27.9	53.2	37.4	40.2
17.1–18.0	25.7	43.7	21.0	42.2	29.6	45.1	34.7
18.1–19.0	9.4	17.2	12.0	18.1	6.2	14.3	12.7
19.1–20.0	1.6	4.6	3.9	4.9	0.6	1.0	2.7
20<	1.6	3.5	1.3	2.6	0.0	0.0	1.4

Table 29. Annual catch and major age groups of sardine by region, 1925–38; 1951 and 1956 (after NAKAI 1960).
(Unit of catch: thousand tons)

Region	Average for 1925–38[1]		1951		1956	
	Catch	Major age group	Catch[2]	Major age[3] group	Catch[2]	Major age[3] group
Korea, Coast Range and Sakhalin	503	III, IV	0	—	0	—
Hokkaidô	(281)	I, II	4	0	4	0
Northern part of Pacific coast	(349)	I, II	19	0	11	0, III
Japan Sea coast of northern Honshû	(71)	III, IV	34	0, II–IV	26	0, II–IV
Japan Sea coast of western Honshû	(64)	III, IV	60	0–III	105	0–III
East China Sea off Kyûshû	(128)	0–IV	266	0–IV	53	0–IV
Central part of Pacific coast	(71)	0–II	15	0	4	0
Southern part of Pacific coast	(64)	0–IV	23	0	4	0
Inland Sea	(23)		8	?	0+	?
Total	1,563		429		207	

[1] Based on NAKAI (1949), the amount enclosed in parentheses includes the catch of anchovy (*Engraulis japonica*) and varies more or less depending on region and year. However, the total average of sardine only estimated from Table 24 is 1,530,000 tons against 1,563,000 tons indicated here including anchovy.

[2] Based on Statistical Yearbook, MAF (1952).

[3] Reported by the participating refional fisheries research laboratories.

consist of the younger fish (Fig. 36). The change of the age composition of the parent stock indicates that the sardine became to mature at a younger age in the recent adverse period than before.

Growth rate of large sized fish: The growth of sardine has shown remarkable change depending upon the population size. Changes in mean body length of III-age fish in the Japan Sea during 1938 through 1955 have been examined on the basis of data made available by NAKAI (1949), YAMANAKA and ITÔ (1957) and some other workers. According to the study, the body length was found to have increased year after year from 18.0 cm in 1940 to 20.6cm in 1944 (Fig. 37). The change in the growth rate observed in the later part of the period under study was not as remarkable as that in the earlier part. Changes in the growth rate also took place in other age groups.

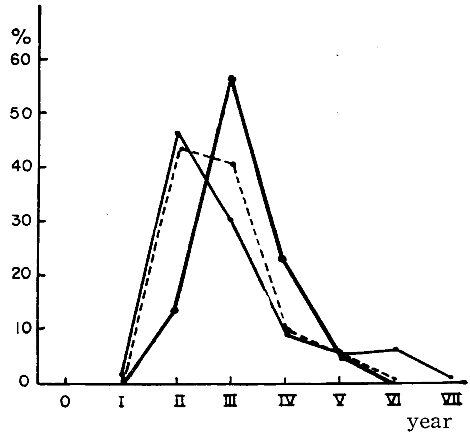

Fig. 36. Changes in age composition of the adult sardine taken from major spawning grounds, 1937-39 and 1951 (after NAKAI 1960).

—●— Feb. 1937 and 1939; southern Kyûshû.
—●— Jan.-Mar., 1951; Kyûshû.
--●-- Jan.-June, 1951; Japan Sea.

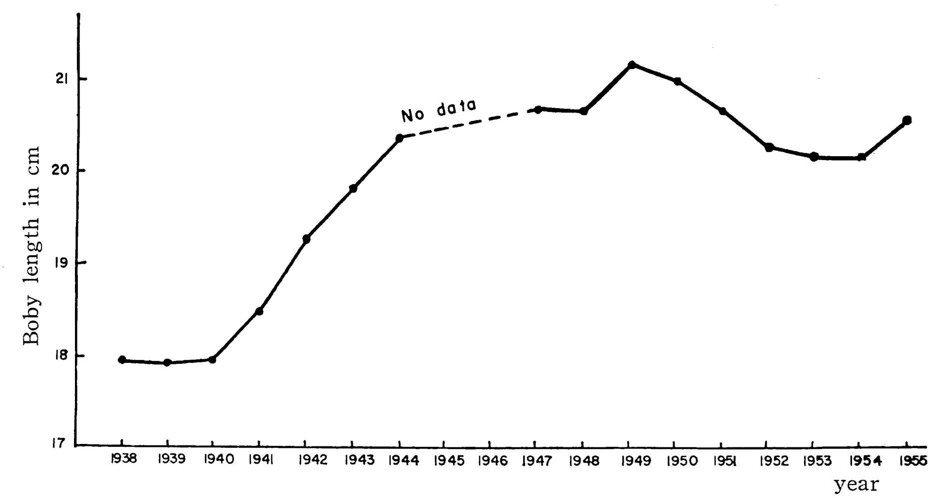

Fig. 37. Fluctuation in mean body length of III-age sardine from the Japan Sea, 1938-55 (after NAKAI 1960).

As to the yearly mean body weight of large sized sardine caught by drift net off the Japan Sea coast of Honshû during 1922-49 except 1928-35, there are found two peaks, a small one (110 g) for 1925 and a large one (141 g) for 1946, with the lowest level (71-78 g) for the years 1936-39 (Fig. 38). A relative increase in the

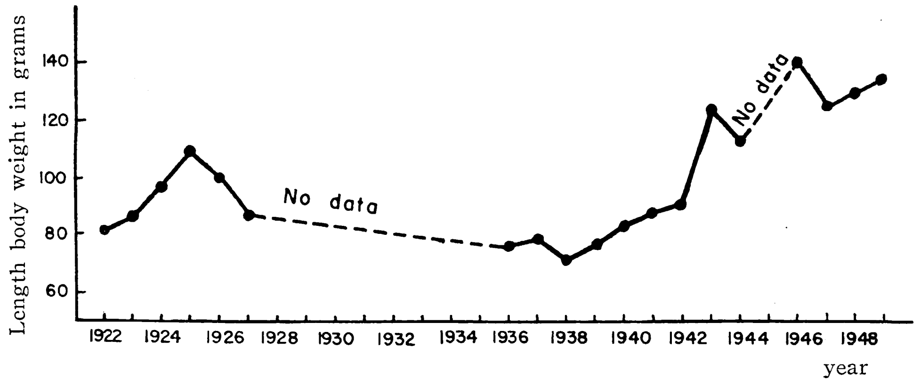

Fig. 38. Fluctuation in mean body weight of the adult sardine caught by drift nets in the Japan Sea, 1922-49 (after NAKAI 1960).

amount of food, resulting from depletion of the population, may logically be inferred as the cause of this aspect of the fluctuation (Sections 1-5 and 1-6).

Section 2-4. Changes in migratory route

Presumed migratory routes of the sardine during the prosperous period were presented by KAGANOVSKII (1931) and also by AIKAWA and KONISHI (1940). Here is given a more probable pattern of the migratory routes in that period on the bases of four evidences. The evidences are:

a. that the major catch in the Pacific waters consisted of I- and II-age fish, while III-age fish or older dominated in the Japan Sea (Section 2-3).
b. that the major spawning ground was located in the Satsunan Area, from which the Kuroshio Current has proceeded to the northeastern coast of Honshû, the most prosperous fishing ground of the young sardine, bringing a number of eggs and larvae (Section 2-2),
c. the general acceptance on the progression of fishing season in the major fishing grounds,
d. the correlation between the annual catches from two different regions—Hokkaidô and North Korea.

Detailed description of the last evidence is summarized below. Off Hokkaidô the main fishing ground of sardine was limited in those days to an area along the Pacific coast; the number and efficiency of set nets, which were the major gear, varied little. In view of this limited variation in the gear, it seems reasonable to accept the sardine catch in that area as an index of the stock size. Body length data reported by AIKAWA and KONISHI (1940) and other workers indicate that II-age fish were an important group of the stock, although the information is not highly reliable.

The best index of sardine stock in the Korean waters is given by the catch from non-powered drifters operated on major ground off North Hamkyong (Kankyô Hokudô), because the most important fishery, purse seiners, showed remarkable yearly increase in number and efficiency of boats. Moreover, information on the fishing season and on the location of the fishing ground of the drifters supports the view that the catch per boat in this fishery is more indicative of the stock than the catch of purse seiners. In this period, III-age fish were the major age group caught there.

The annual catches from these two regions fluctuated similarly with each other between 1928 and 1941, insofar as all the changes took place one year earlier in Hokkaidô, producing II-age fish, than in Korea, producing III-age fish (Fig. 39). This is particularly true for the period 1928-34, for which the correlation coefficient between those catches reaches to 0.95. For the later half of the period, 1935-40, the

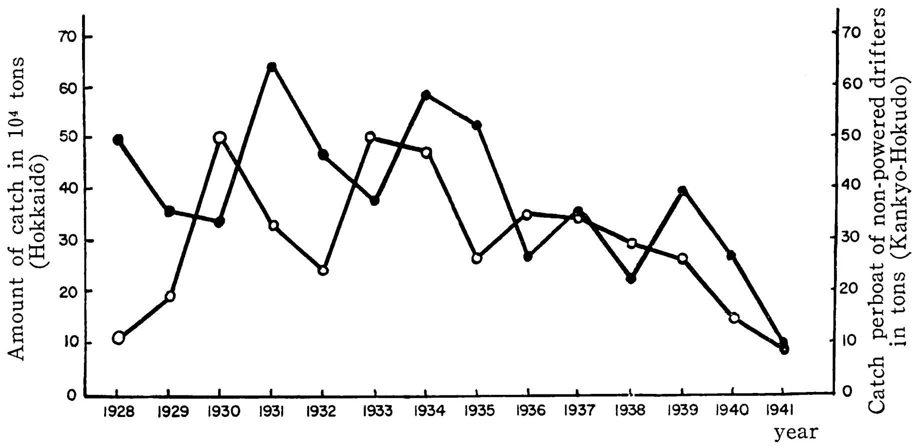

Fig. 39. Fluctuations in the sardine catch from Hokkaidô and the catch per boat-season of non-powered drifters from North Hamkyong, Korea, 1928-41* (after NAKAI 1960).

—○— Sardine catch in Hokkaiô;
—●— Catch per boat of non-powered drifters in North Hamkyong, Korea.

* The catch in Hokkaidô is based on the Statistical Year Books, MAF, and the catch in North Hamkyon is based on information from the Fisheries Section, the Regional Government of Kankyô-Hokudô (North Hamkyong).

correlation coefficient decreases to 0.69, and all the catches reduced below the regression line for the early years (Fig. 40). However, when the drift net catch in Korea is plotted logarithmically, the catches in the two regions seem to be in a linear relation. In regard of this change of the relationship between catches in the two regions, it is highly probable that the boats engaged in purse seining in the Korean waters increased in number and in fishing efficiency, and that the purse seiners came into serious competition with the drifters. It is, however, obvious that both the sardine catch off Hokkaidô and the catch by drifters per boat-season in

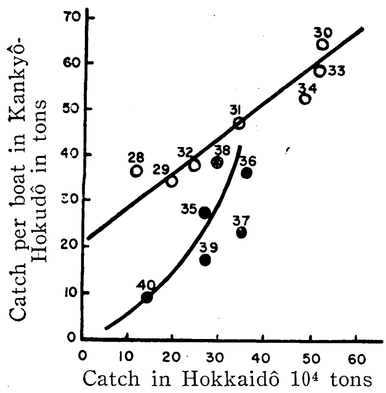

Fig. 40. Relationship between sardine catch in Hokkaidô one year before and the catch per boat-season of non-powered drifters in North Hamkyong, Korea one year later, 1928-41 (after NAKAI 1960).

○ 1928-34; ● 1935-41.

The numerals denote the year relevant to the catch in Hokkaidô.

Korea had markedly irregular fluctuations from year to year, and that a high correlation existed between fluctuations occurring in the former and those occurring in the latter one year later. These facts seem to support the validity of the suggested migratory route across the Japan Sea.

All this information indicates that the sardine, in the prosperous period, were mainly spawned in the Satsunan Area. Major portion of the eggs and larvae were drifted to the Pacific waters along Honshû by the Kuroshio Current. The fish spent the first through third years of life off the Pacific coast of Honshû and Hokkaidô. In autumn and early winter of the third year, II-age fish moved to the Satsunan Area passing through the Tsugaru Straits and across the Japan Sea. Since then, the older fish moved up to the north in the warmer months and down to the south in the colder months within the Japan Sea (Fig. 41 and 42). However, in the recent adverse period, the fish, especially I-age or the older, have not shown appreciable migration extending over wide range (Fig. 41).

Here it should be taken into account that the drawing of the migratory routes has been simplified with sacrifice of local details, in order to show the general features of the major routes. This is particularly the case for the migratory routes of II- and III-age fish that travelled across the Japan Sea from the Pacific side of

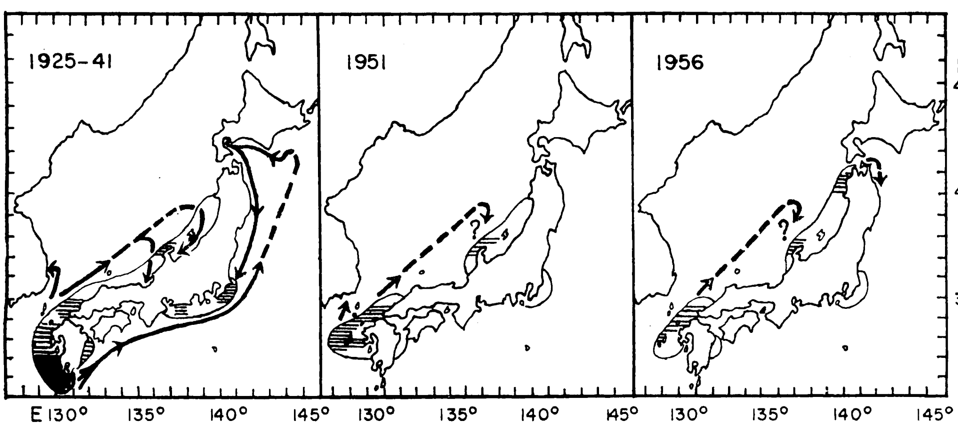

Fig. 41. Spawning grounds of the sardine and migratory routes of 0-age fish, 1925-41, 1951 and 1956 (after NAKAI 1960).

The arrows denote the migratory routes of 0-age fish.

□ light ▤ moderrte ■ heavy

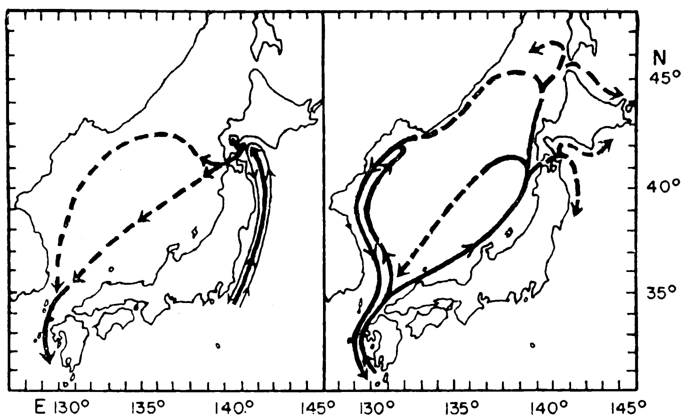

Fig. 42. Migratory routes of I-age and older fish in the prosperous period, 1925-41 (after NAKAI 1960).

In the left panel, the light lines show the migratory routes of I-age fish, the heavy line, those of II-age. In the right panel the arrows denote the routes of III-age and older fish.

Hokkaidô to Korea and Coast Range in the prosperous period. It is needless to say that there were various local groups of the species.

In describing these changes in migratory habits and distribution ranges, NAKAI (1949) ascribed the cause to curtailment of feeding migration range as a result of depletion of the population. In addition, he (1951) pointed out that intensification of fishing operations in the waters west of Kyûshû since around 1946 could be expected to have had a detrimental effect upon the migratory habits of the fish—particularly if, as is thought, the spawning stock passed through the area on their southward journey each winter.

Section 2-5. Anomaly of environmental conditions

Except incidences that claimed an exceedingly heavy toll of large sized sardine on the north Korean coast in October 1923 (NAKAI 1939, 1955), and of medium sized sardine on the Pacific coast of Hokkaidô in November 1933 (KURAGAMI and KAWANA 1934), phenomena attributed to such environmental anomalies as water temperature and current may not have been adequately reported and explained. The environmental changes seemed to be also responsible for unusual migration of the large sized sardine that brought about changes in fishing localities and occurrences of season off the eastern coast of Korea throughout the 1936 season (NAKAI 1949, 1955). Of those phenomena, the first two took place during the period when the sardine population was apparently on the increase. In the last case, the influence of the abnormal environment would have been effective enough to change temporarily the migratory route and season of sardine exploited then and there, but could not have caused an observable mortality of the sardine population.

Generally speaking, the mortality rate of organisms is the highest at the early stage of life. Basing on the biological investigations for 1949-51, it was estimated that the young sardine would have the survival rate of only 0.10 percent during the early stage from the egg to the postlarva of 15 mm in total length (Section 1-4). In fact, the fish at such an early stage are physiologically the least resistible against the environmental changes.

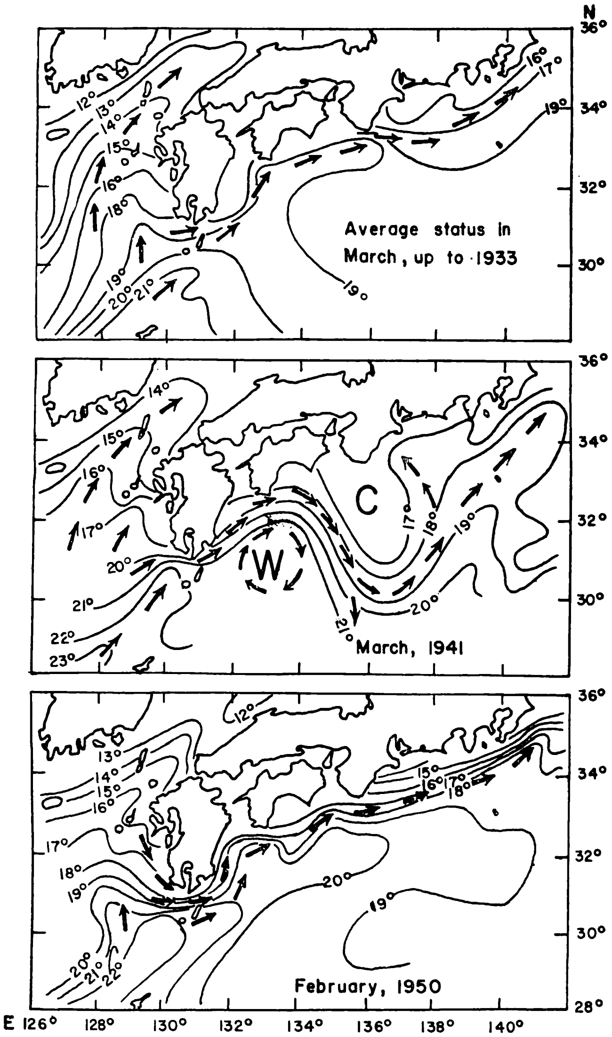

Fig. 43. Distribution of the surface temperatures and the direction of the Kuroshio Current in the western part of Japan in winter, 1933, 1941 and 1950 (after NAKAI 1962a).

C: cold water mass;
W: warm water mass of descending clockwise gyre;
Arrows: the direction of the Kuroshio Current inferred from distributions of temperature and salinity.

Therefore, it is certain that their survival rate is strongly governed by the environmental conditions. This may be warrant necessity for paying special attention to the environmental conditions in the area extending from the main spawning ground ever located in Satsunan Area to the off-shore of Shikoku and its vicinity where the postlarval sardine were abundantly distributed. In a series of reports, UDA (1940, 1949, 1951, 1952) has attracted attention to the following phenomena. At an area south of Shio-no-misaki on the Kii Peninsula, a cold water body that had made a symptomatic appearance sometime around 1934 became most prevalent during 1938-45, developing to such a scale as to block out the Kuroshio Current and to divert it from the normal direction. At the same time the Current showed noticeable meandering, while there formed clockwise gyre in the warm offshore waters south of the main axis of the Current. The existence of the cold water mass was confirmed through the surveys conducted during

February and March in 1940 and 1941, the months being the time for the sardine to spawn in the Satsunan Area (NAKAI 1949).

Until about 1945 the hydrographical anomaly seemed to have existed, but it virtually disappeared from the area when observations were carried out in 1947. During the following several years, the Kuroshio Current was flowing through the area almost as normally as it was in the prosperous period (Fig. 43).

Attributing the primary cause of depletion of the sardine population to the prevalence of the cold water mass off the Kii Peninsula and the anomalous flow of the Kuroshio Current, NAKAI (1949) maintains that the recovery of the population size has been delayed, despite the removal of the primary cause, because the spawning ground has not come back to such a locality that larval sardine can be supplied to the Pacific coast.

Chapter 3. Consideration of the fluctuations in the catch and the population

This chapter is devoted to present discussion on causes of the remarkable fluctuations in the sardine catch during the three periods:

(1) a ten-year period from 1924 to 1933 of the sharp increase,
(2) the following period of the 1940's of the drastic decrease,
and (3) the post war period of the adversity.

Section 3-1. Causes of increase during 1924 through 1933

For the period 1924-33, the increase of sardine catch in the Far East was as remarkable as the decrease that occurred later (Fig. 31). According to YOKOTA (1957), who maintains that the sardine population in those years began to show a tendency to increase, the increase of catch was attributable partly to that tendency of the population and partly to a rapid development of fishery. However, no data proving his point has been presented, and no systematic investigations of the sardine population were carried out in those days.

NAKAI (1943, 1949) inferred that the change in size of the individual fish reflected changes of the population size (Section 2-3). In the case that the trend observed in the annual means of body weight was what had actually taken place in the stock, the changes of body weight may suggest that the stock of the large sized sardine increased substantially after about 1925. Furthermore, the sardine catch was made in Korea, Coast Range and Sakhalin almost in the same period as that in which the body weight of large sized fish in the Japan Sea was on the decrease (Fig. 38). The simultaneity of the changes in regional catch and body weight seem to give further support to the above inference.

Although the data on the amount of fishing efforts during 1924-33 are not very satisfactory, the official satistical records (Statistical Year Books) on the number of purse seine boats* may be used as an index of changes in the fishing effort. No steady trend is apparent in changes in the size of boats during the period under consideration, but the number of boats increased until 1930 and then remained more or less constant for the rest of the period (Fig. 44). On the other hand, mechanization of the boats progressed after the introduction of internal combustion engines to Japan in the 1910's untill 1928. In all probability, the fishing efficiency

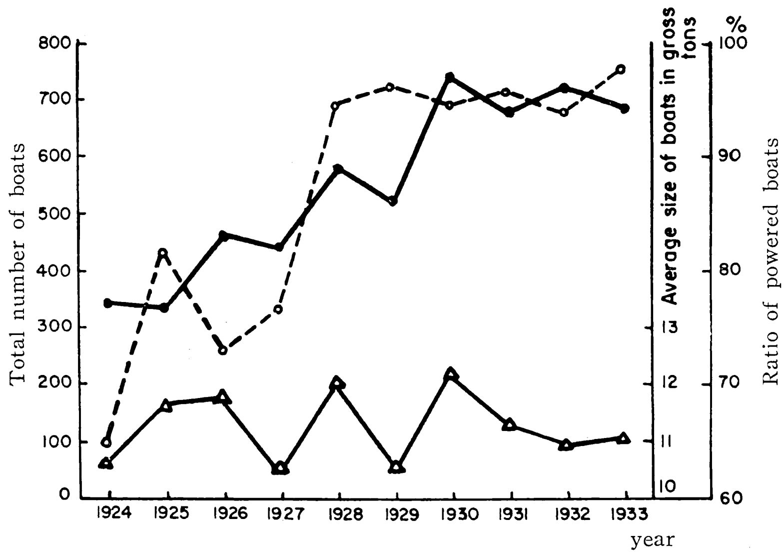

Fig. 44. Fluctuations in the amount of effort of "offshore" purse seines in Japan, 1924-33 (after NAKAI 1960).
—●— Total number of boats; --○-- Ratio of powered boats;
—△— Average size of boats in gross tons.

increased during that time. During 1928-33, however, the percentage of powered boats remained nearly constant (Fig. 44). Judging from these data, the change in fishing efforts, though it has possibly influenced the sardine catch to some extent during the years 1924-30 as suggested by YOKOTA (1957) does not seem to have had substantial effects on the increase of catch. Of course, technological developments in fishing gear, and in methods and means of selecting fishing grounds, would have been supported by incentive factors such as increasing demand for fish meal and fish oil.

Nevertheless, from such biological evidences as changes in body weight and length, and the trend in fishing effort, the increase of population size is regarded as the major cause of the augmentation of the catch during 1924 through 1933.

* The number of purse seine boats quoted is that which was entered in the Statistical Year Books under the item of "fishing fleet operated in the offshore". But the term "offshore" was not defined.

Section 3-2. Causes of depletion in the 1940's

Review of previous works: During 1940-45 the sardine catch in the Far East reduced at such degree as the annual landings in Japan decreased by nearly one-third yearly. Since the Japanese fishing industry was largely dependent on the sardine fishery, the resultant economic depression was particularly critical. In 1943 the Japanese Government urgently requested scientific researches into the cause of the reduction. The findings submitted did not necessarily seem ready acceptance. NAKAI (1949) prepared a brief account of the researches including his own view on the major causes of reduction in catch; these are summarized below in somewhat generalized categories along with those more recently advanced.

a. Theories attributing the reduction not to change in population, but to change in the distribution caused by environmental changes:
   i. KIMURA (1943) pointed out the abnormal dispersion of the littoral water in certain areas around the Japanese Islands, and suggested divergence of the migratory route into the offshore area as the cause;
   ii. TAUTI (1943) took notes of prevalence of the cold current flowing southwardly and recession of the warm current running northwardly, and inferred that the sardine stocks might have moved away from their usual habitat to the south;
   iii. RUMYANTZEV (1947) suggested that the sardine made a mass migration into the sea off Vancouver because of environmental change in the sea adjacent to Japan on the basis of the fact that in 1942 nature claimed a mass mortality of the sardine which appeared to be incapable of migrating from that part of Canada to the south;
b. Theories attributing the reduction of the population size to overfishing:
   i. AIKAWA (1943) noticed a similarity between reduction in the sardine catch and that in catches of other fishes, the latter apparently caused by overfishing. From the abovementioned analogy he felt that the former was also ascribable to the overfishing;
   ii. On the basis of change in the mean vertebral counts and decreasing regional catches, YOKOTA (1957) suggested the cause was the diminution of recruitment brought about by increased fishing intensity.
c. Theories linking the reduction of the population size to environmental changes:
   i. TAUTI (1945) believed that in the sea off Kôchi and Miyazaki Prefectures the Kuroshio Current returned to the previous direction flowing eastward. Thus, the eastward returning of the Current caused scarcity of food for the young sardine in the coastal areas, and in turn resulted a decrease in size as well as in availability of the sardine stocks in the coastal regions. He (1942) computed a conditional fishing rate of 17 percent and conditional

natural mortality rate of 22 percent on the basis of data including tagging experiments and age composition of the sardine catch in Japan and in Korea in 1938. Using TAUTI's formulae and additional data from the tagging experiments, NAKAI (1949) calculated the fishing rate for the sardine population in that year at 9 percent and the natural mortality rate at 29 percent;

ii. Basing on the correlations between the regional catches and on the tagging experiments, KUBO and HAYASHI (1949) attributed the decline of sardine catch to depletion of the podulation size, which was independent of fishing effect;

iii. KURITA (1957) examined the decrease in sardine catch during the 1940's, on the basis of annual landings and postulated rates of exploitation. The study shows that the relation between population size and natural increase does not approximate a sigmoid curve. In particular the natural increase including recruitment and growth in the years 1941-43 was so abnormally low that fishing restriction, even if enforced, could have had little effect. In the light of those findings, KURITA (*loc. cit.*) considers scanty recruitment during 1938-40 to have been mainly responsible for the reduction of catch in the 1940's;

iv. In proposing another view, NAKAI (1943, 1948, 1949 and 1962a) observed that the sardine catch in the Far East during the prosperous period mainly consisted of I- to IV-age fish, and argued that, if sardine fishery had been carried out for some years at an excessively heavy rate with nearby constant effort, prosperous catch would not have been continued more than four years, although they did so during 1933-36, with the peak catch in 1936; during this period fishing effort changed but little. The facts do not seem to support an assertion that fishing in those days was so heavy as to have seriously impaired the sardine population. Instead, one may regard both an abrupt decrease in number of eggs and an increase in growth rate as clear evidence of natural depletion of the population. NAKAI (*loc. cit.*) assumes that the fundamental cause for depleting the population was an anomally in the Kuroshio area as discussed below.

Discussion and conclusions: The distribution of eggs and larvae, which has indicated that of the parents, disproved the mass movement of the sardine population (Section 2-2). In addition, the change of growth suggests the actual fluctuation in the population size (Section 2-3). As mentioned by NAKAI (1943, 1948, 1949) as well as by KURITA (1957), analyses of the catch statistics did not indicate that the fisheries exploited the sardine to intensively to decrease the parent stocks to a level too low to retain the population size. Thus, no evidence is available to prove that great numbers of sardine left their normal habitat for an offshore area during the 1940's, nor has there been any confirmation that overfishing could deplete the population. The following description comprises reasons to regard the environmental changes as the major causes of the depletion of the sardine population in the period under study.

In an area south of the Kii Peninsula a cold water mass brought about by upwelling gained a marked ascendancy during the years 1938-45 (Section 2-5). This anomaly of the Kuroshio Current was combined with data from the net collections of eggs and larvae extending over the cold water area and Satsunan Area. In other words, it is possible to assume that the particular anomaly of the Kuroshio Current, having caused mass mortality of the sardine at their early stages, constituted the fundamental cause of the depletion of the sardine population.

To explain how the survival rate of the young fish was critically lowered, the present author cites circumstantial evidence that sardine eggs and larvae were found on the west of the cold water at a high density, while almost none occurred on the east of the area moreover, off the northeastern coast of Honshû and Hokkaidô where no spawning had taken place, the catch, mainly I- and II-age fish, started to decline earlier than that in any other locality. As to the mechanism that lowered the survival rate of the sardine at the early stages of life, it is claimed that probably the young fish encountered

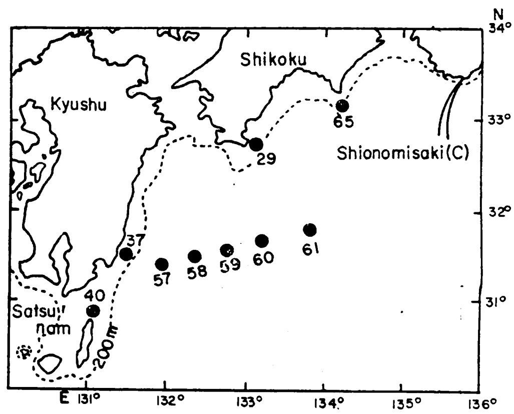

Fig. 45. Stations occupied in February–March 1941, for collecting postlarval sardine used in this study (after NAKAI 1960).

Table 30. Data relevant to sardine eggs and larvae collected in the Pacific waters off Kyûshû and Shikoku, 1941. (after NAKAI 1960).

Station	Date (1941)	Hour	Depth (m)	Depth of collection (m)	Number of individuals collected			Range of total length of postlarvae (mm)	Postlarvea determined	
					Eggs	Pre-larvae	Post-larvae		Number of individuals	Mean total length (mm)
29	Feb. 17	1230	101	0-101	3	6	4	4. 8-5. 9	1	4. 8
37	„ 21	1423	82	0-82	57	6	6	4. 9-6. 3	2	5. 0
40	„ 22	1316	132	0-132	109	37	8	4. 9-5. 9	4	5. 0
57	Mar. 1	1814	150<	0-150	1	98	34	4. 8-5. 9	16	4. 9
58	„ „	2053	„	„	0	129	40	4. 6-6. 1	11	4. 8
59	„ „	2332	„	„	0	458	76	4. 3-6. 9	20	4. 9
60	„ 2	0203	„	„	0	1	474	4. 3-5. 9	20	5. 0
61	„ „	0549	„	„	0	1	75	5. 0-8. 0	20	5. 1
65	„ 3	0421	101	0-101	0	1	9	4. 7-6. 1	7	5. 1

Table 31. Size class of the alimentary canal of the postlarval sardine. shown in Fig. 46 (after NAKAI 1960).

Class	Minimum	Small	Medium	Large
Mean diameter (mm)	0.059–0.068	0.068–0.098	0.098–0.120	0.120–

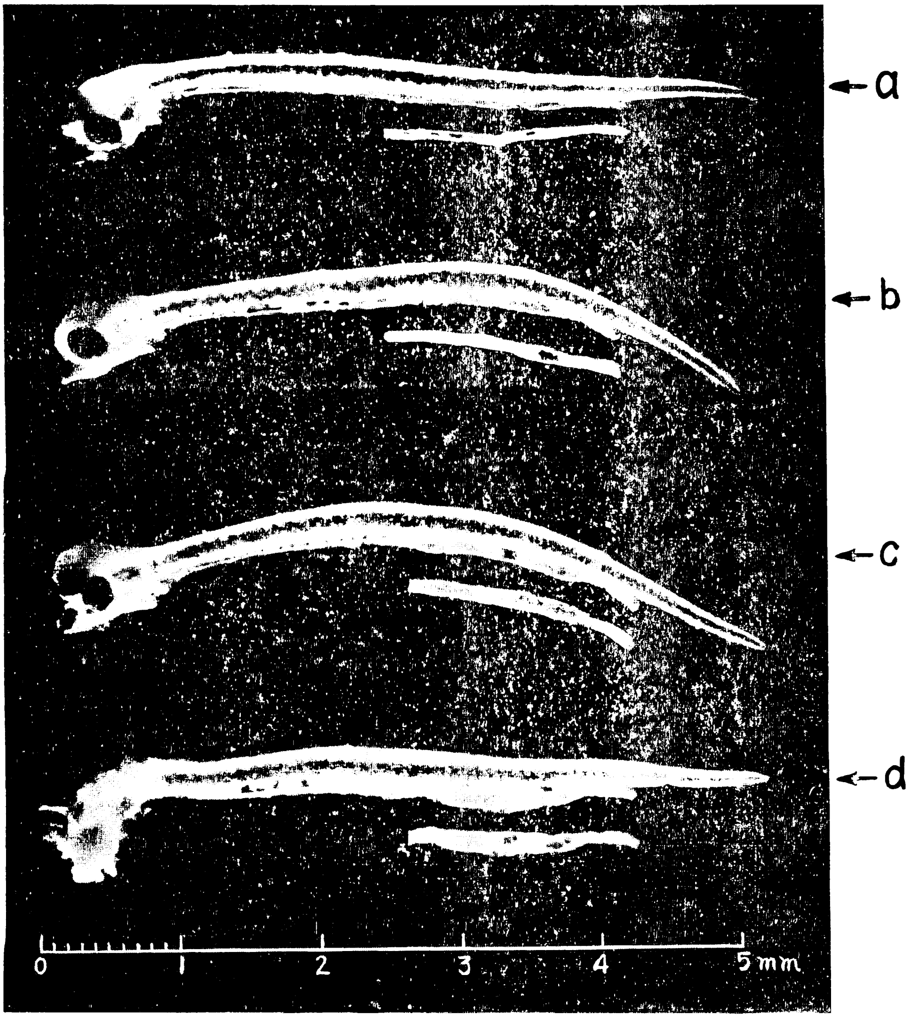

Fig. 46. Variation in alimentary canal size of postlarval sardine (after NAKAI 1960).

Size class	a	b	c	d
Date of collection	March 1941	March 1941	March 1941	March 1951
St. Number	60	57	57	111

Note a posterior part of the alimentary canal removed and shown below each specimen.

See Figs. 45 and 49 for the positions of the stations.

Size classes, a, b, c, and d, correspond to minimum, small, medium and large in Figs. 47 and 48, and Table 31, respectively.

physiological difficulties caused by an abrupt change in water temperature and by the shortage of food supply in the Kuroshio Area. In regard of this point, consideration is given to the feeding condition of sardine larvae collected in the area under discussion.

The materials used for this purpose are postlarvae taken by the *marunaka*-type plankton nets during February to March 1941 at the stations off Shikoku (Table 30, Fig. 45). The total length of the materials ranged from 4.5 to 5.2 mm. The postlarvae were arranged into four groups in increasing order of the diametre of the alimentary canal (Table 31, Fig. 46). The result revealed that individuals having a thick alimentary canal occurred oftener in the sea around the continental shelf than in the other areas. Further eastward from Satsunan Area, the larvae had thinner alimentary canal (Figs. 47 and 48).

An important question yet to be solved is whether the size of the alimentary canal of fish really represents a physiological condition

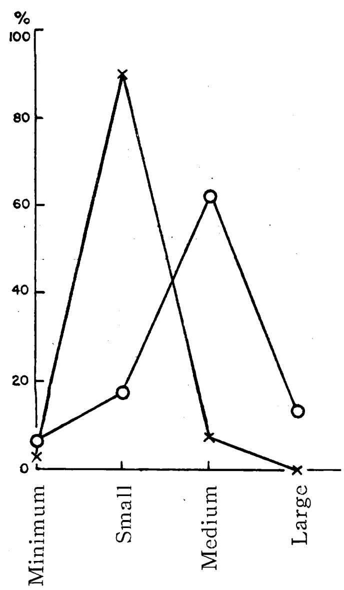

Fig. 47. Size composition of alimentary canal of postlarval sardine by area, 1941 (after NAKAI 1960).

○ Continental shelf and its vicinity (Sts. 29, 37, 40, 57, 65);
× Offshore (Sts. 58–61)

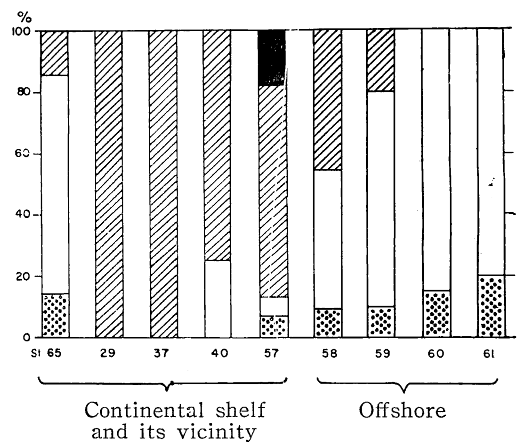

Fig. 48. Size composition of alimentary canal of postlarval sardine by station, 1941 (after NAKAI 1960).

Large, Medium, Small, Minimum

affecting survival or merely shows the relative amount of food taken. Even if the latter is the case, the data seem at least to show the density of food for the larvae distributed in the area. Therefore, it may be admissible to judge the survival conditions of the larvae from indications of their alimentary canal.

Before doing this, however, the relation between feeding activity and collecting hours must be examined to ensure that the materials are free from the bias that can be introduced by the collecting only at special times. The examination has been carried out by use of other materials which had total length similar to that of the materials in question and concerning which there were relatively satisfactory data relating to the hours of collection, the materials having been collected during an extensive survey in 1954 (Fig. 49).

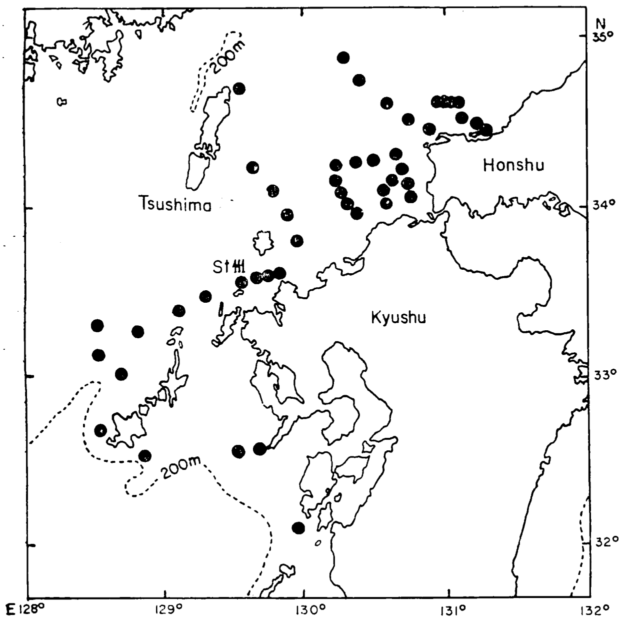

Fig. 49. Stations for collecting postlarval sardine (4.5-5.1 mm in total length) in the western waters off Kyûshû, February-March 1954 (after NAKAI 1960).

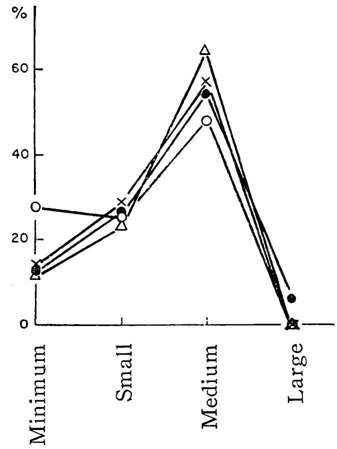

Fig. 50. Size composition of alimentary canal of postlarval sardine from the western waters off Kyûshû by hours of the day, 1954 (after NAKAI 1960).

× Caught during 0-6 hr.
○ " 6-12
● " 12-18
△ " 18-0

When these materials were arranged into classes of collecting hours, little or no significant relation was observed between the mean diametre of the alimentary canal and the collecting hours (Fig. 50). The examination supports the inference that the food density for the postlarvae was lower in offshore areas than the continental shelf and in inshore areas becoming increasingly scarce with the eastward progress of the Kuroshio Current from Satsunan Area (Figs. 47 and 48). UDA (1940, 1951) inferred that a clockwise gyre on the southern side of the main axis of the current off Shikoku was a descending water body. Thermoisometric distributions observed by NAKAI (1949) in the sea during February and March 1941, also suggested the existence of the descending warm water gyre in that general locality. Those oceanographic conditions enabled NAKAI (*loc. cit.*) to infer that the sardine larvae transported along the Kuroshio Current from Satsunan Area must have been accumulated in that warm water area. In fact, the amounts of sardine eggs and larvae as well as the geographic distribution of the total length of larvae support his inference.

On the other hand, according to HONJÔ *et al.* (1957), nauplius forms of copepods, a major item in the alimentary canal contents of postlarval sardine measuring less than 15 mm in total length, are distributed usually at a very low density in the warm offshore waters adjacent to Japan. It is conceivable that a scarcity of food organisms in the warm water mass off Shikoku caused reduction of the alimentary canal of the sardine larvae accumulated in the area. No observation has been made as to physiological phenomena that might have followed contraction of the alimentary canal. Nevertheless, it is no doubt that this contraction indicates evironmental conditions that induced, at least, scarcity of food and that were detrimental to the growth and existence of postlarval sardine. When great quantities of postlarval sardine are subjected to such an adverse environmental condition throughout the early developmental stage one season after another, it is possible that the survival rate of the young fish and recruitment to population might decrease.

From these evidences, it is concluded that the depletion of the sardine population in the Far Eastern waters during the 1940's was caused primarily by the change of abiotic environmental factor, *i. e.* anomaly of the Kuroshio Current that contributed to making a secondary causes, biological one, affects size of the major portion of the recruitment for the years in question.

Section 3-3. Causes of the recent decrease

Information available for recent years suggests that the sardine fishery would have been conducted on a substantial scale in few areas of the Far East, other than in the waters adjacent to the Japanese Islands (Section 2-1). Thus, the nationwide investigations since 1949 have covered almost the entire range of the fishing grounds of this species.

Fluctuaiton in the catch by age group: Regional Fisheries Research Laboratories have reported the age composition of the commercial sardine landings on the almost entire coast of Japan for the years since 1949 (Fig. 51). It can be seen that the catch of 0-age fish fluctuated from one year to another, with abundance in every odd year until the 1954 class appeared. For the rest of the period, the catch of 0-age fish has generally been on the decrease, with the fluctuation becoming less regular. The decrease in the catch of that particular age group seems to be attributed chiefly to failure in fishing and to a resultant decrease in fishing intensity in the neighbourhood of the Gotô Islands northwest of Kyûshû where the fish used to be caught in great quantity.

The catch of I-age fish has also declined since the 1954 year class appeared, but no steady trend is obvious for the catch of II- and III-age fish that formed the major parent stock after 1945. Nevertheless, it may be noted that the 1949 and 1953 classes, which had both been caught abundantly at 0-age, were again dominant when they were three years old. Although apparent survival rates of the 1953 and older year classes do not seem to have changed appreciably from year to year, II-age fish

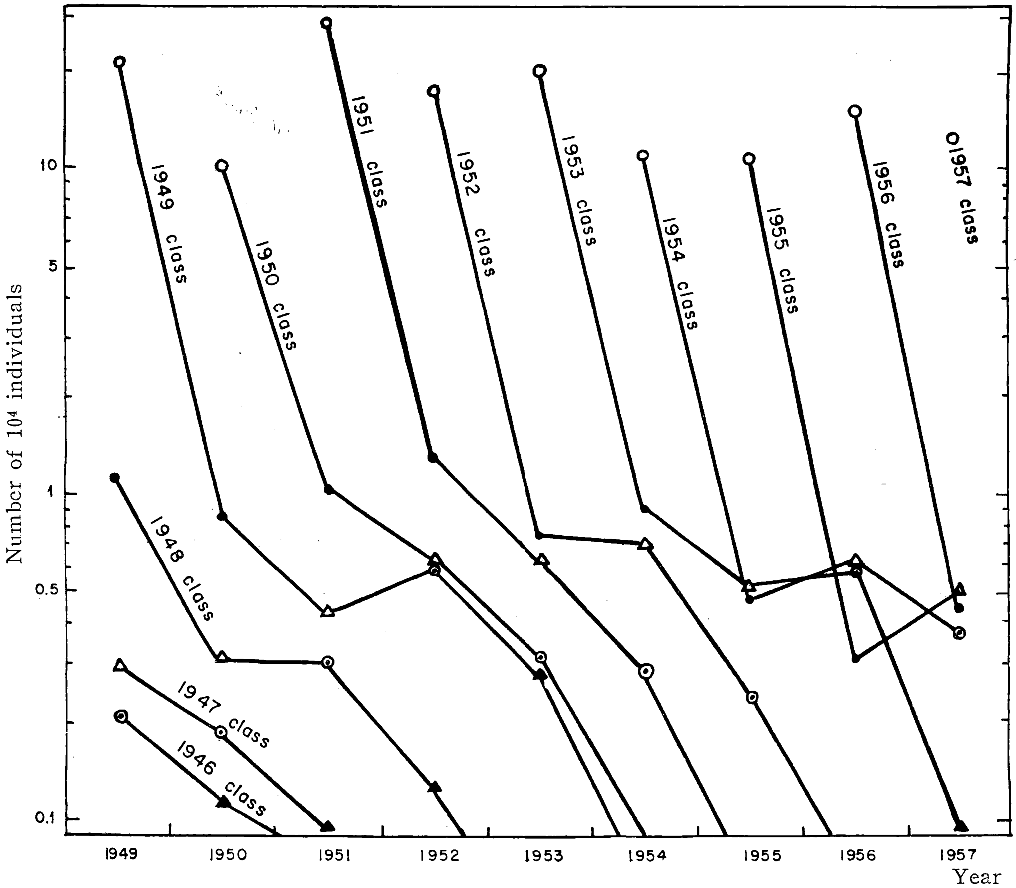

Fig. 51. Age composition of the sardine catch in Japan, 1949–57 (after NAKAI 1960). Based on data estimated by the Regional Fisheries Research Laboratories.
○ O-age; ● I-age; △ II-age; ⊙ III-age; ▲ IV-age.

of the 1954 and 1955 classes were caught more copiously than one year before. This fact, while indicating changes of the survival rates of these year classes, may not be necessarily interpreted as meaning that changes occurred in the age composition of the population. Instead, the phenomena have most probably derived from changes in fishing circumstances, because in the sea west of Kyûshû, which used to offer a major fishing ground for sardine boats, the operation has been in failure since about 1955 with marked decrease in the catch of I-age fish.

The age group caught most abundantly during the last ten years in Japan has been the 0-age fish, constituted more than 60 percent of the average sardine catch in weight. The catches in number of 0- and I-age fish from the same year class seem to be positively correlated with each other (Fig. 52). In recent year, however, the effect of thinning has become heavier on one of the age groups in one place than on another fished elsewhere, because of some changes in circumstances such as fishing locality, gear and effort. On the basis of these evidences it may be assumed that there has been little or no correlation; in any event, no negative correlation between these age groups has ever been known. As far as the present data are concerned, therefore, it is hardly conceivable that fishing for 0-age group has had a detrimental effect on the stock of I-age group. Few 0-age fish have been caught in the Japan Sea off northern Honshû, despite it having lately become an important spawning ground.

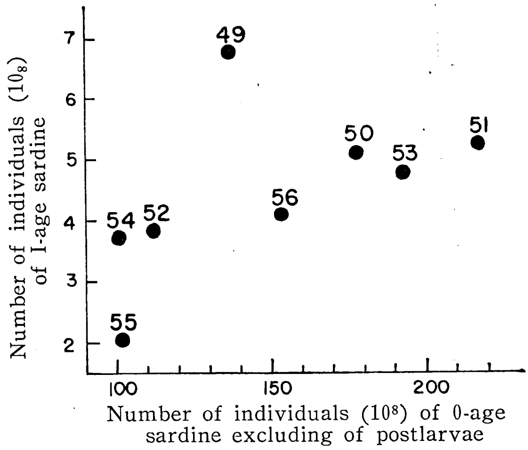

Fig. 52. Relationship between catch of 0-age fish and that of I-age fish, 1949–56 year classes in Japan Sea and East China Sea (after NAKAI 1960).

Numerals denote the year classes.

It seems improbable, therefore, that the fishery aiming at 0-age fish has put too heavy a pressure upon the sardine population. Nevertheless, YOKOTA (1957) and YOKOTA and ASAMI (1956) are apprehensive about this pressure, and full vigilance must be maintained possible effect on the population.

The negative correlation between catches of I- and II-age fish is noticeable in regard of the numbers caught (Fig. 53). It is almost impossible to assert that the decrease in the catch of I-age fish has resulted in an increase of the stock of older fish, because in recent years fishing intensity apparently has not been as heavy on

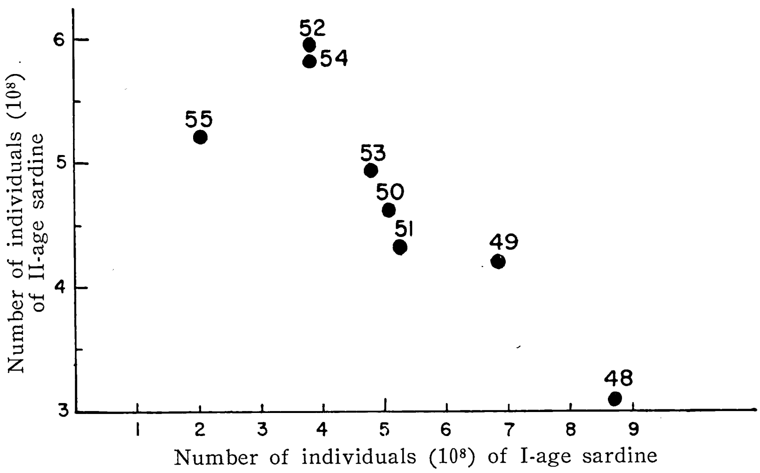

Fig. 53. Relationship between catch of I-age fish and that of II-age fish, 1948–55 year classes in Japan Sea and East China Sea (after NAKAI 1960).

Numerals denote the year classes.

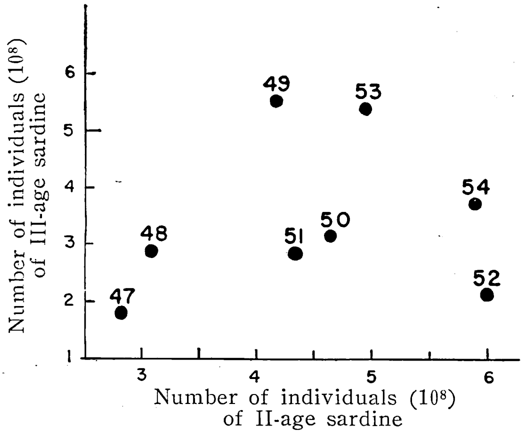

Fig. 54. Relationship between catch of II-age fish and that of III-age fish, 1947-54 year classes in Japan Sea and East China Sea (after NAKAI 1960).

Numerals denote the year classes.

I-age fish as on II-age fish. The data at hand reveal no correlation between the catches of II- and III-age fish (Fig. 54).

Analysis of the parent stock: Since the commencement of the investigations in 1949, it has been intended to use the total number of eggs estimated on the basis of the net collections for estimating the size of parent stock that is to be compared with the adult catch in order to analyse the total mortality rate of the stock. The method is thought applicable for analysing the fluctuation in the stock sizes of migratory fishes, inclusive of the Japanese sardine, exploited under remarkably complicated circumstances (Section 1-8). In the following, the first approach to the analysis of fluctuation in the population during 1949-51 will be discussed as far as the present limit of study allows. Although it is true that neither the catch statistics and the egg abundance perfectly fit for deliberation on the stock sizes, these data seem to be still reliable for macroscopic study of the population dynamics because either of them showed no remarkable discrepancy from year to year during the current period.

First of all, what is needed for estimating the standing number of adults from the egg abundance is an average number of normally developing eggs produced by a female. However, the number of eggs found in the ovary has not been satisfactorily determined for the sardine. Even if the number of ova in a female were secured, efforts much greater than for spawning surveys would be required in enumerating eggs actually fertilized by a pair of adults. Of course, an experimental proof must be provided for the fecundity (Section 1-6).

Here the discussion is concerned with a method how to compute the average number of fertilized eggs per female under simplified conditions during the current years, 1949-51, when the size of the sardine population is thought nearly leveled off.

Suppose that the environment of adults remains as same as throughout their life and that the survival rates be available to every stage of the life. Putting N_{Ay} as the number of adults at the beginning of y-th year, then the number of progeny at the start of $y+i$-th year should be:

$$PN_{Ay}nS_eS_0\prod_{a=1}^{i-1}S_a\,,$$

where, P: ratio of females to all the adults,
n: number of eggs produced by a female,
S_e and S_0: survival rates at the early stage and at the successive stage in 0-age, respectively,
and S_a: annual survival rates at I-age and older stages.

If N_{Ay} and S_a are constant, being N_A and S_A, respectively, and the parent stock consists of II- to IV-age fish (Section 2-3), the relationship between the number of spawning adults and the average number of eggs per female is expressed by:

$$N_A=PN_AnS_eS_0S_A^{2-1}+PN_AnS_eS_0S_A^{3-1}+PN_AnS_eS_0S_A^{4-1},$$

where the first, second and third terms denote number of II-, III- and IV-age fish, respectively. Solving the equation with n,

$$n=\left\{PS_eS_0S_A\left(\frac{1-S_A^3}{1-S_A}\right)\right\}^{-1}.$$

On the assumption that the postlarvae when immigrating first into fishing grounds attain to 15 mm in total length, S_e, S_0 and S_A are assumed to be 0.0010, 0.03 and 0.46, respectively. As the sex ratio is approximately one, P is regarded to be $\frac{1}{2}$ (NAKAI *et al.* 1955). Substituting these values into the above equation, the average number of eggs spawned by one female sardine is about 100,000. The number of spawned eggs thus estimated, even though not highly reliable, falls within the range of 30,000 to 100,000 that has been estimated on the previous occasions as the number of ova to be spawned (Section 1-6). Such a coincidence between the values would not necessarily attest the reliability, because there may be many adults capable of spawning twice or more times a year, and because it is not certain as to how many eggs from one female may develop to the stage collectable by the plankton nets. Anyhow, let us compute the number of adults in the sea using the above value, 100×10^3 eggs, as well as that based on the study of fecundity, 40×10^3 eggs.

The parent stock size is obtained by

$$N_A=N_e/nP,$$

where N_e is total egg abundance. Ratio of the adult catch to the stock in the sea, E, is defined as the fishing rate or the rate of exploitation for the stock. If fishing and natural mortalities take place each in a proportion constant over a given length of time, the conditional natural mortality rate of adults, m_A, is estimated as;

$$m_A=1-exp\cdot\left\{Z_A\left(\frac{E}{1-S_A}-1\right)\right\},$$

where Z_A is the instantaneous mortality coefficient of the adult stock. It should be noted that the fishing season for adult sardine generally tends to cover an early half of the year. Referring to a similar case, RICKER (1948) recommended that "... it is best to arrange...the mean time of fishing at the middle of the (statistical)