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Commentary

Distribution of the Far-east Sardine and Russian Fishery in the Pacific waters and Okhotsk Sea during 1974–1993

A. Yu. ZHIGALIN[1] and V. A. BELAYEV[2]

Introduction

Significant cyclic fluctuations are peculiar to the Far-East sardine (*Sardinops melanostictus*) stock (Uda, 1952; Ito, 1961; Kuroda, 1991a). In this century two large peaks of the stock were well documented and confirmed by fishery statistics: the first from the end of 20's to the beginning of 40's, the second from the beginning of 70's to the present time. During the current century, the fishery was conducted with different intensity. Size of the catch was determined by stock abundance of the sardine, number and class of the boats, and fishing equipments in different periods. A maximum of about 1 million tons was observed in 1989. Basic part of the catch (50–80% in various years) was caught in the Pacific waters and in the Okhotsk Sea. Abundance of the sardine was catastrophically reduced after 1990. Total catch of the Pacific population has decreased to about one twentieth from the beginning of 1990's to the present time. The present peak of the sardine practically finishes, and the stock of the sardine is now in depressive condition.

In this paper, we summarize the results of the Russian sardine fishery in the Pacific waters and examine the relationship among stock abundance, distribution areas, migration and formation of fishing grounds of the Far-east sardine.

Materials

The biostatistical and fishing information assembled in fishing expedition and research cruises was used for analyses of the stock condition, biological conditions, and migrations of the Pacific sardine populations in the northwestern part of the Pacific Ocean during 1974–1993.

Catches, Fishing Efforts and Catch per Fishing Effort

Pacific sardine fishery by the Russian fishermen during 1974–1993 was conducted in 200-mile zone of Japan, South-Kuril region, the Okhotsk Sea, and the open ocean outside the economic zones of Russia and Japan (Fig. 1) mainly by purse seine net (97.9% of the total catch). Since the catch by trawl was only 2.2%, fishery of the sardine in the Pacific waters was represented by the purse seine fishery.

Russian sardine fishery in the Pacific waters began to develop from 1974 (3000 tons) (Belayev and Kenya, 1987), and its catch exceeded 100000 tons in 1976. After the temporary decrease in 1980 and 1981, the maximum catch more than 400000 tons was recorded in 1984–1989 with a peak of 570000 tons in 1988. However, the catch was sharply reduced during1990–1993, and the Russian fishery of the sardine in the Pacific waters was stopped in 1994.

Associated with the development of large-scale sardine fishery since 1977, numbers of the boat-days on the fishing exceeded 10000 per year, and the level was kept constant until 1989. The number of the boat-days spent on the fishing was sharply reduced after 1989. Total numbers of the hauls have a similar tendency with the number of the boat-day (Fig. 2).

From the beginning of the fishery, average catch per haul gradually increased and exceeded 30 tons per haul in 1983. It became more than 40 tons per haul from 1986, with the maximum 48.2 tons per haul in 1987. However, it has been reduced together with a decrease of the sardine stocks since 1991, and the catch per haul in 1993 has fallen down to a level of the beginning of 1980's. Catch per boat-days of the fishing was similar to the catch per haul.

Fishing season in a year changed together with changes in intensity of the fishery. Winter-spring was the most productive season in 1974–1975 because sardine dispersed to the large area in summer, meaning that fishery was ineffective. Similar situation can be seen in 1980–1981. During the period of high abundance of the sardine stocks (1977–1987), the Russian fishery was feasible almost whole year. After 1989, the fishery began only from April and completely stopped in August-October. Russian fishery of the sardine in the Okhotsk Sea was finished in 1991 and that in the Pacific Ocean in 1994 (Fig. 3).

Characteristics of the Russian purse seine fishery of the sardine are presented in Table 1. It is possible to conclude that favorable conditions for Russian fleets for the

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[1] Pacific Scientific Research Fisheries Center, 4 Shevchenko Alley, Vladivostok, 690600, Russia

[2] Pacific Scientific Research Fisheries Center, Vladivostok Branch. 9, Shevchenko Str., Khabarovsk, 680000, Russia

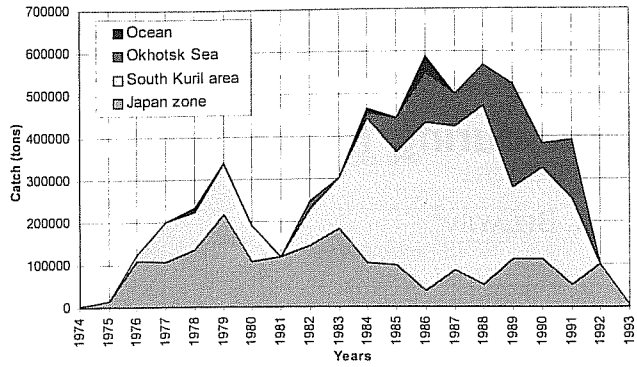

Figure 1. Russian catch of the sardine in the Pacific Ocean and the Okhotsk Sea.

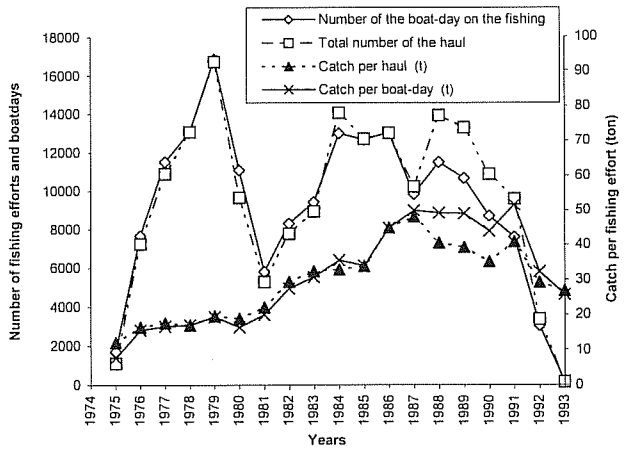

Figure 2. Number of fishing efforts and boat-days and catch per fishing efforts of the Russian sardine fishery.

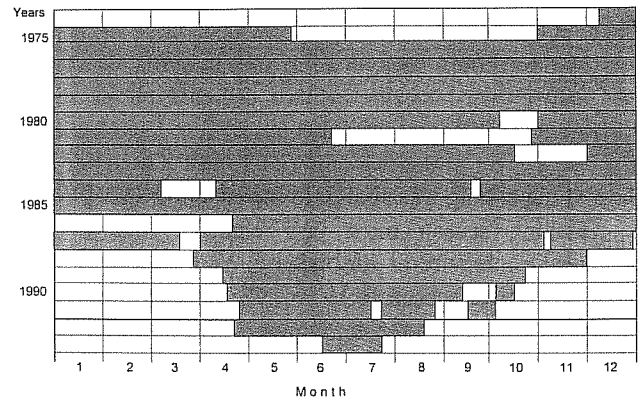

Figure 3. Annual change in the duration of Russian sardine fishery operation.

sardine fishery were continued until 1989, despite the reduction of the stock. After 1990, the parameters of the fishery intensity (catch per haul or boat-day) kept on comparatively high levels.

Table 1. Yearly changes of the sardine catches by the Russian fishery in the Pacific waters in 1974–1993.

Year	Number of the boat-day on the fishing	Total number of the haul	Catch per haul (t)	Catch per boat-day (t)	Catch by purse seine net (t)	Catch by trawl (t)	Total catch (t)
1974					2130.0	956.0	3086.0
1975	1735	1108	12.18	7.78	13491	0.0	13491.0
1976	7673	7250	16.56	15.65	120087	1700.0	121787.0
1977	11518	10905	17.66	16.72	192590	8750.0	201340.0
1978	13066	13063	17.13	17.13	223823.1	10001	233824.1
1979	16853	16704	19.63	19.46	327949.6	10856.6	338806.2
1980	11086	9659	18.99	16.55	183435.7	7231.2	190666.9
1981	5810	5278	22.04	20.02	116328.7	22081.1	138409.8
1982	8307	7783	29.33	27.48	228278.0	18608.0	247286.0
1983	9421	8927	32.44	30.74	289564.0	12048.7	301610.0
1984	12985	14040	32.93	35.61	462347.0	3486.6	464834.0
1985	12649	12696	33.88	34.01	430203.0	12041.0	442244.0
1986	13026	13006	44.86	44.79	583496.0	4764.0	588260.0
1987	9839	10226	48.02	49.91	491023.0	9504.2	500526.8
1988	11488	13911	40.57	49.13	564404.0	5361.0	569765.3
1989	10659	13277	39.33	48.99	522138.0	177.0	522315.0
1990	8699	10882	35.16	43.99	382642.0	0.0	382642.0
1991	7603	9590	40.92	51.61	392403.0	0.0	392403.0
1992	3065	3392	29.19	32.30	99014.0	0.0	99014.0
1993	174	167	26.81	25.73	4477.0	0.0	4477.0

Distribution and Migrations

The Far-east sardine is widely distributed in the northwestern warm waters of the Pacific Ocean near Japan and Kuril Islands. This species changes distribution, spawning grounds and population structure according to environmental changes and abundance of the stock. In the period of low stock, the sardine is divided into several separate populations with rather isolated spawning grounds. In the period of high stock, on the other hand, the sardine is characterized by existence of widely migrating super-populations.

With the recovering of the Pacific sardine populations, its feeding area began to expand. Although sardine had already reached near southern Kuril Islands before 1977, there has been marked concentration of the fishing grounds to the Okhotsk Sea since 1982 (Fig. 4).

The high abundance period was characterized by the presence of wide-migrating super-population of the sardine. Northward migrations for feeding are closely connected

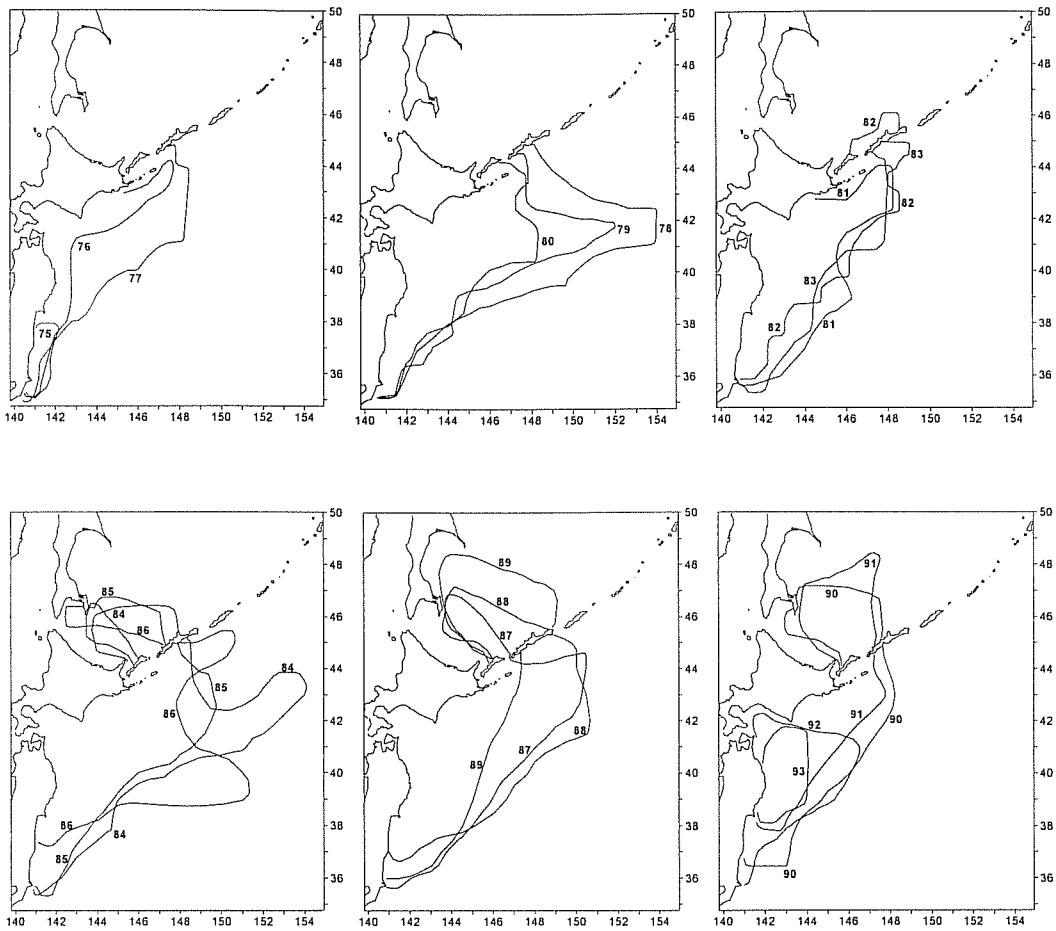

Figure 4. Boundaries of the maximal distribution of the fishing congestions of the sardine during 1976–1993.

with hydrological situations, such as the position, intensity and interaction of flows and branches of the Kuroshio and Oyashio. Sardine schools migrate northward together with warm flows of branches and eddies from the Kuroshio and aggregate near frontal zones. Sardines migrate offshore under influence of the strong cold Oyashio for feeding, and its coastal branch passes through cool waters adjacent to the coast of Honshu and Hokkaido Islands (Fig. 5). Northward movement of the sardine schools along the coast of Honshu and Hokkaido Islands occurs when flows of warm branches of the Kuroshio current are intensified, and the first branch of the Oyashio relatively retreats (Kenya, 1984). Frequently, sardines migrate on both ways as shown in Fig. 5.

The wide distribution of sardine schools in the offshore regions was characteristic in 1978–1979 and 1984–1988 years (Fig. 4). During this period, together with intensive development of the coastal branch of the Oyashio and second offshore branch of the Kuroshio plenty of immature sardines were wintering in open ocean, and migrated to the north along the offshore way. After 1987, productivity of the sardine has sharply decreased, and total biomass began to fall quickly. In this connection, schools of immature fish have not been recorded in open ocean in winter and spring after 1988. Distribution area of the sardine congestions began to be reduced in the longitudinal direction of its southern part. Especially, the sharp reduction has taken place together with decrease after 1991. In 1992–1993, fishing grounds of the sardine did not form outside the Japan's 200-mile zone during the period of northern migration.

In large cyclonical eddies and zones of mixture of cold and warm waters, the sardine keeps the most favorable conditions for feeding. During the examined period, the fishery grounds in summer were rather stable, and it is probably related to high-productivity zone toward the east and southeast from the Southern Kuril Islands up to 150°E. In the feeding period, (since 1982) the fishing was in the South Kuril region. In the Okhotsk Sea the fishing was operated usually only in the coastal zone of the Kuril Islands. As the sardine expanded by further penetration into the Okhotsk Sea, where temperature gradients were usually small in summer, schools were widely dispersed and the fishery be-

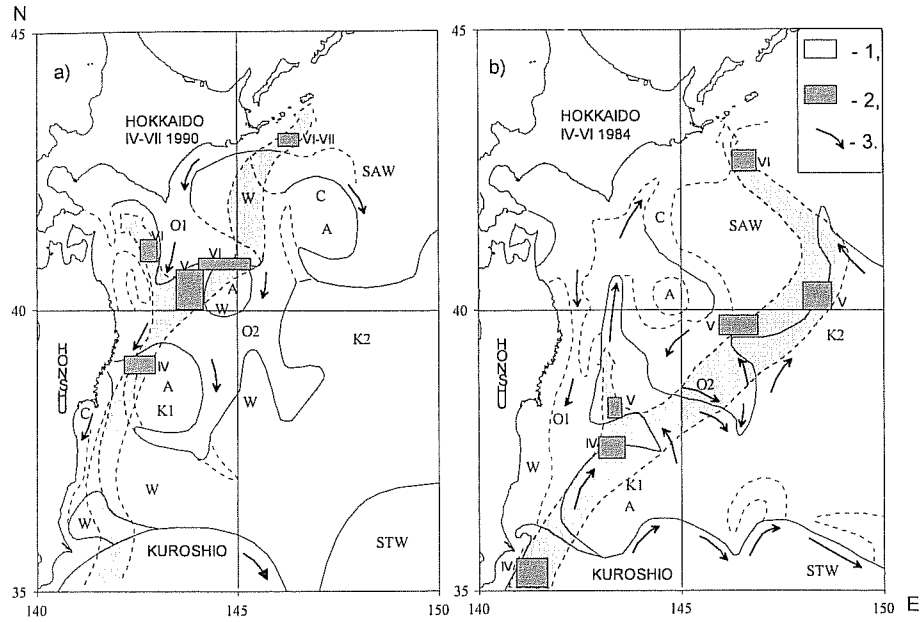

Figure 5. Sardine migrations in different years in the Kuroshio-Oyashio region: a) along the 1st branch of the Kuroshio (1990), b) along the 1st and 2nd branches of the Kuroshio (1984).
1, ways of migration; 2, region of fishery; 3, direction of currents; K1, K2, branches of the Kuroshio ; O1, O2, branches of the Oyashio; A, anticyclonical eddies; SAW, subarctic water; STW, subtropical water; W, warm areas; C, cold areas.

came impossible. The special conditions have developed in 1990–1991, when the greatest penetration of the sardine into the Okhotsk Sea was recorded, and the main fishery was operated in open waters of its southern part.

In September–October, together with gradual cooling of waters in the Okhotsk Sea and near the Kuril Islands, the sardine begins to migrate to south. In 1984–1991 the densest concentrations of the sardine were formed in the southern part of the Okhotsk Sea near the east coast of the Sakhalin Island, where highest annual catches per fishing effort were recorded. During southern migrations, sardine schools moved in rather cold subarctic waters, adhering to the frontal zones of flows. The most part of southward migrants passed along coast, in waters of the coastal branch of the Oyashio. During the last several years since 1989, under the sharp decrease of the sardine abundance, its congestions were diminished during the period of southern migration. In these years, migration routes were in direct affinity from the coast near the boundaries of the territorial waters of Japan, where sardine schools were inaccessible for the Russian fishery. In this connection the fishing intensity was sharply fell, and the fishery stopped in August–September.

Since 1992, the fishing congestions of the sardine did not expand to outside the boundaries of the 200-mile zone of Japan. In the last several years only small schools of the young sardine occurred in the Russian fishing zone and open ocean. These schools had no commercial importance and were only caught by the research vessels.

Age and Size Structure of the Catches

Although the stock generally consisted of three age groups (1–3), age structure of the sardine population is variable. In the years of dominant year-classes (1980, 1981, 1984), the stock consisted of 4 age groups, as zero age group entered to the fishery. The zero age group had been maintained constant in the catches until 1987 (Table 2).

Body length (FL) distribution of the catches showed bimodal character after appearance of dominant 1980–1981 year-classes until 1983–1984 (Fig. 6). Density of the stock increased after appearances of these generations, and this has changed the biological characteristics of the sardine population: rates of growth have much decreased; body weights of same-size specimens have decreased; duration of life has increased; age of the first maturity has delayed; failure of the spawning become to be notable, feeding area has sharply extended (Zhigalin and Malcev, 1992).

During 1984 to 1988, age and size structure of the catches was stable. After 1989, there were not enough modal groups with the length 15–17 cm (age 1 and 2) in size structure of the catches, and after 1991 modal group 16–19 cm (age 2 and 3) disappeared.

Namely in 1989–1992, the 1986–1987 years-classes dominated in the catches, and occupied more than 90% in 1991 and 1992 age structures of the catches. In the subse-

Table 2. Age composition of commercial catches of the sardine.

Year	Age composition of the catches (%)				
	0+	1+	2+	3+	4+<
1975	2.4	36.5	43.3	16.0	1.8
1976	8.1	57.2	25.6	8.2	6.8
1977	3.0	30.1	37.6	26.1	3.2
1978	5.9	35.7	32.0	23.9	2.5
1979	2.4	32.8	40.9	21.4	2.5
1980	19.1	28.4	30.7	18.0	2.8
1981	25.7	44.4	13.8	14.2	1.9
1982	9.4	50.5	19.7	18.1	2.3
1983	5.9	39.8	28.6	19.2	6.5
1984	14.1	18.1	22.6	33.2	11.9
1985	1.4	19.5	40.8	28.4	10.0
1986	0.0	12.2	21.4	30.4	35.9
1987	0.3	23.4	35.2	35.6	5.5
1988	0.0	28.1	44.6	22.4	4.9
1989	0.0	0.0	62.0	33.0	5.0
1990	0.0	0.0	51.0	37.0	12.0
1991	0.0	0.4	18.7	40.1	40.8
1992	0.0	0.3	2.2	1.9	95.6
1993	4.4	85.3	1.0	1.0	8.3

quent years (1993–97), the sardine stock was supported only at the expense of the occurrence of separate year-classes, such as those in 1992 and 1996 with average recruitment.

The sharp reduction in the reproduction level was related to lots of reasons. Overflow from spawning grounds owing to high number of the parent's stock, expansion of spawning grounds toward the offshore regions, and significant reduction of survival rate during early stages of the development. Sharp reduction of the abundance of the zero age group was found in 1988 in the Subarctic front zone (Table 3), together with reduction in the reproduction level of the Pacific populations of the sardine. This tendency continued to 1992. In the last several years, the number of the zero age group in 1993 was increased. However, these data were obtained from near eastern coast of Honshu Island in November on the way of the wintering migration. The most yielding in recent years was made by the 1992 year-class. Obviously, these year-classes were lower than high-yielding levels. We could see some increase in number of the zero age group also in the Subarctic front zone in 1995.

Stock Abundance

As was already specified above, recovery of the sardine stock began since 1972 (Kenya and Sokolovskaya, 1977; Kondo, 1980). According to the estimate by the virtual population's method using mathematical models, available

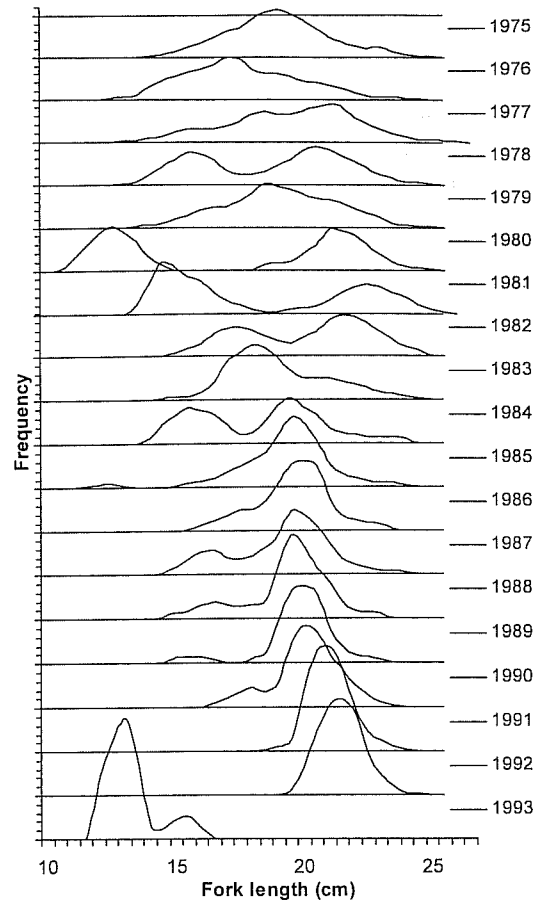

Figure 6. Yearly changes of body size (in fork length) composition of the Russian sardine catches during 1975–1993.

Table 3. Abundance of the zero age group of the sardine collected in the Subarctic front zone by mid-water trawl net.

Year	Abundance	Year	Abundance
1985	$14.84 * 10^{10}$	1991	$0.99 * 10^{7}$
1986	$2.03 * 10^{10}$	1992	no data
1987	$2.83 * 10^{10}$	1993	$3.51 * 10^{8}$
1988	$0.64 * 10^{7}$	1994	no data
1989	$1.22 * 10^{7}$	1995	$3.38 * 10^{7}$
1990	$0.45 * 10^{7}$	1996	no data

stock of the sardine in the Pacific waters consisted 9.5 million tons in 1975. The increase of stocks proceeded until 1982, i.e. up to the moment of the strong 1980–1981 year-classes. Then, the stock abundance gradually reduced (Belayev and Kenya, 1987; Belayev *et al.*, 1991). Available stock of middle yielded 1983–1987 year-classes was kept at a level of more than 12 million tons. As the result of the low reproduction level in 1988–1991, only low yielding year-classes occurred, and accordingly the recruitment was poor. After disappearance of the stock of rather highly

yielding 1986–1987 year-classes supporting the fishery for a long time, biomass of the sardine was sharply reduced. In the last several years, sardine stock was supported by separate middle yielding 1992 and 1996 year-classes.

The recruitment failures were caused mainly by low survival in the early life stages because egg production was high (Watanabe *et al.*, 1995; 1996). Many authors investigated the influence of long-term and global changes in oceanographic conditions on stock fluctuations of the Far east sardine (Wada *et al.*, 1995). Kuroda (1991b) and Naganuma (1992) reported that higher temperature in the spawning grounds and adjacent nursery grounds allowed good survival conditions in early life stages. Tomosada (1988) also found that the period of large catch of the sardine corresponded to that of warm temperature in spawning and nursery grounds and cool temperature in feeding grounds. Wada (1998) analyzed reproduction processes of the sardine and pointed out that period of increasing sardine stock was characterized by low average sea surface temperature (SST) in the Kuroshio Extension, main nursery grounds of the sardine during high abundance period, but that since 1988 average level of SST rose abruptly in this area corresponding to sharp decline in recruitment.

In the nearest years, the sardine stock will probably fluctuate responding to the occurrence of separate yielding year-classes. Although recovery of the sardine stock looks improbable in nearest time, it may proceed toward the same direction of the processes as occurring in the Pacific population.

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