year, with times of little fishing distributed...at the beginning and at the end". As such an arrangement has not been done, actually the fishing rate would be lower, and the natural mortality rate, higher than the values estimated through the above method. The unconditional fishing rate, f, is assumed to be equal for all the age classes,

$$f=1-\frac{S_A}{1-m_A}.$$

This method was applied for the data taken during 1949 through 1955 (Table 32). The reliability of such a view depends, however, on the accuracy of the data used, and a close scrutiny must be made of these data from various viewpoints. Here the author is concerned with the estimated egg abundance. The catch of large sized sardine per unit effort of round hauls has been calculated as an index of the stock size migrating into the Seikai Region, an important grounds of spawning and fishing for the sardine (MURAKAMI and MAKO 1956).

Although the period during which the data were collected was rather short, the data may be helpful in examining the validity of the assumption of a relation between the catch per unit of effort and the egg abundance in the region. The results indicate that a relatively high correlation between these two measures makes it permissible to use the estimated egg abundance as an index of the stock size of parents, as far as the period and area under survey are concerned (Fig. 55).

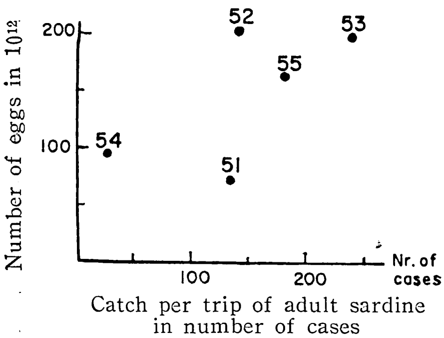

Fig. 55. Relationship between catch per boat-day of purse seines and total egg abundance spawned in the western waters off Kyûshû, 1951-55 (after NAKAI 1960).

Numerals denote the year of spawning and fishing.

1 case=ca. 15 kg.

The mortality rates have been computed on the basis of the data including the catch of II-age and older fish estimated for the years 1949-55. The values thus obtained suggest that thinning by the fishery has not been excessively heavy despite the survival rate having decreased since 1954 (Table 32). Inasmuch as the stock of large sized sardine is concerned, the conclusion so far obtained is in agreement with a finding that the amounts of effort is not correlated with the instantaneous mortality coefficients (YAMANAKA and ITÔ 1957).

However, the thinning is not the only effect of fishery upon the fish population. For instance, NAKAI (1951) assumed that the fishing activity disturbed the southward migration of the spawning sardine in the waters off northwestern coast of Kyâshû. On the other hand, there are data revealing a high mortality rate, over 99 percent, during the early stages of the life (Section 1-4). For this reason, it is readily inferred that a slight fluctuation in the mortality rate at these stages of life will

Table 32. Mortality rates of the large sized sardine in Japan, 1949-55 (after NAKAI 1960).

			1949	1950	1951	1952	1953	1954	1955*	
									a	b
Data used as bases of computation		Survival rate of II- to V-age fish	0.50	0.54	0.53	0.54	0.52	0.40	0.38	
		Instantaneous total mortality coefficient	0.69	0.62	0.63	0.62	0.65	0.92	0.97	
		Catch of II-age fish and older (10^6)	576	648	966	1,415	1,165	1,165	852	
		Total number of eggs spawned (10^{12})	198	235	198	300	438	297	282	385
Values estimated under an assumption that the effective number of eggs spawned per female is either one of these:	40,000	Size of parent stock (10^6 individuals)	9,900	11,750	9,900	15,000	21,900	14,850	14,100	19,250
		Rate of exploitation	0.058	0.055	0.098	0.094	0.058	0.078	0.060	0.044
		Unconditional natural motality rate	0.442	0.405	0.372	0.366	0.422	0.522	0.560	0.576
		Instantaneous fishing mortality coefficient	0.080	0.074	0.132	0.127	0.079	0.120	0.094	0.069
		Instantaneous natural mortality coefficient	0.610	0.546	0.498	0.493	0.571	0.800	0.876	0.901
		Conditional fishing rate	0.08	0.07	0.13	0.13	0.08	0.11	0.09	0.07
		Conditional natural mortality rate	0.46	0.42	0.39	0.38	0.44	0.55	0.58	0.59
	100,000	Size of parent stock, (10^6 individuals)	3,960	4,700	3,960	6,000	8,760	5,940	5,640	7,700
		Rate of exploitation	0.146	0.138	0.244	0.236	0.145	0.197	0.151	0.110
		Unconditional natural mortality rate	0.354	0.322	0.226	0.224	0.335	0.403	0.469	0.510
		Instantaneous fishing mortality coefficient	0.202	0.186	0.327	0.318	0.196	0.302	0.236	0.172
		Instantaneous natural mortality coefficient	0.488	0.434	0.303	0.302	0.454	0.618	0.734	0.798
		Conditional fishing rate	0.18	0.17	0.28	0.27	0.18	0.26	0.21	0.16
		Conditional natural mortality rate	0.39	0.35	0.26	0.26	0.37	0.46	0.52	0.55

Based on the reports by the Regional Fisheries Research Laboratories participating in the Cooperative *Iwashi* Resources Investigations.

* As no data were made available for the Japan Sea Region during most months of 1955, the calculation has been made by assuming that the number of eggs spawned in those months in the region was either (a) zero or (b) the average in the preceding years.

have a decisive influence in determining the population size.

Conclusions: It is concluded that the fishery did not excessively catch the sardine made the population to decrease to a level too low to retain the size during the recent years since 1949. MURAKAMI and HAYANO (1955), and YAMANAKA and ITÔ (1957) also stated that the natural factors inserted more serious effects on the population than the exploitation during the period under discussion. Although YOKOTA and ASAMI (1956) noted the sardine stock being damaged by overexploitation, the excessive fishing effort was a limited one exerted only on 0-age fish in the northwestern waters off Kyûshû. But, for the natural causes of depletion, no evidence of environmental changes in these years is as remarkable as the shift of the Kuroshio Current observed in the 1940's.

Chapter 4. Comments on management and investigations of the sardine fishery

As has been stated in Chapter 2, the Japanese sardine was widely distributed and abundantly exploited in the waters surrounding the Japanese Islands and the eastern coast of Korea in the prosperous period around 1935. The fish of this species then migrated throughout the above mentioned areas during the life span. However, the significant amount of sardine catch has been obtained from only restricted areas extending between the northwestern Kyûshû and the Japan Sea coast of Honshû with the vestigial catch from the Pacific side during about 10 years after 1945. The recent migratory routes of the fish has not been traced clearly. The decays of supplies of eggs and larvae from the Satsunan Area as well as from the Japan Sea through Tsugaru Straits presumably strengthened the isolation of the stocks in the Pacific waters. Thus, the sardine population is now maldistributed in the area around the northwestern Kyûshû and the Japan Sea.

According to the considerations in Chapter 3, the sudden rise of the sardine catch for the 1924-33 inclusive depended upon not only the increase of the fishing power such as the amount of fishing efforts and the efficiency of gear, but also the increase of the population. The decrease of the catch in the 1940's was not caused by the overfishing, but by the curtailment of the population attributed to the natural factors. At the same time, the main causes of the decrease of the sardine catch in the recent years since around 1950 are hardly regarded as the unfavourably intensive exploitation. However, the population size of this species is far smaller in the recent adverse period than in the prosperous period around 1935. Furthermore, the intensity of fishing has increased rapidly after the World War II. For these reasons, it is probable to regard that fishing mortality has rised recently even though there is no evidence indicating overexploitation on the sardine population as a whole. Accordingly, the further increase of the fishing effort upon the Japanese sardine is not recommendable in order to obtain enough and sustained yields from the population.

NAKAI (1951) pointed out that the fishing being funneled into the northwestern waters off Kyûshû seriously disturbed southward migration of the parent fish for spawning, on the basis of the information concerning to geographical distribution of spawning activity and to the operating circumstances of the purse seiners. Thus, he (*loc. cit.*) proposed that the regulation of purse seine fishing should be effective for the recovery of the sardine population. Although this proposal was not put into effective, its fundamental premise has been that the fishing exerted unfavourable influence upon the population through disturbing the distribution, migration and spawning. Accordingly it should be taken into consideration to establishing the management program of fishery that the influence of operation is not always of thinning but of disturbing reproduction.

The general conclusions in Section 3-3 on the fluctuation and the management of the sardine fishery are concerning to the major stocks off the coasts swept by the Tsushima Current. Another observation is to be given here on the isolated stock in the Pacific coastal waters.

Recently major portion of the sardine stock in the Pacific waters is composed of a number of isolated groups, although a few amounts of eggs and larvae, sometimes large sized fish, are supplied from the Japan Sea through the Tsugaru Straits. HAYASHI (1960) demonstrates that the stock exploited off the coast of Fukushima, Ibaraki and Chiba Prefectures reveals the strong independence from the other fractions of the sardine population. The stock is currently very important for the fishery along the Pacific coast of Japan. The studies relevant to this particular stock are not only for an example of analyses of fluctuation in the local stocks but also for the prediction of the future fluctuation in the entire sardine population. For this reason, the following five aspects of the stock in the East Pacific Area of Honshû* during 1950 through 1960 are examined: (1) Annual change of fishing rate; (2) relationship between catches from the same year classes in the two succeeding years; (3) relationship between the egg abundance in the respective year and catch from the year class; (4) effect of catch upon the spawning amounts in the later period; and (5) relationship between the egg abundance produced by two successive generations**.

* The area covering Fukushima, Ibaraki and Chiba Prefectures is called the East Pacific Area of Honshû or simply East Honshû in the following discussion.

** In order to avoid confusions, the parent and their progeny are called the first, second, third....*generations* as follows:

1st generation: Parent fish
↓ spawn
2nd generation: Eggs —grow to→ Parent fish
↓ spawn
3rd generation: Eggs —grow to→ Parent fish

The round hauls have landed more than 90 percent of the total sardine catch in the East Pacific Area of Honshû. The major fishing season proceeds from north to south during the colder months of the year, *i.e.* November to February in Fukushima Prefecture, December to March in Ibaraki Prefecture and January to April in Chiba Prefecture. Therefore, the catch data including the age composition are compiled for the above season (Table 33). In Table 33, the catch for 1950 in the East Honshû includes the landings on Fukushima Prefecture from November 1949 to February 1950, on Ibaraki Prefecture from December 1949 to March 1950, and on

Table 33. Age composition of sardine catch by round hauls in Fukushima, Ibaraki and Chiba Prefectures, 1950-60.

Year	(a) catch in 10^3 fish					(b) catch in tons				
	Total	I-age	II-age	III-age	IV-age and older	Total	I-age	II-age	III-age	IV-age and older
1950	76, 388	65, 018	11, 306	64	—	1, 807	1, 272	528	7	—
1951	95, 894	75, 762	17, 116	2, 972	44	3, 647	2, 062	1, 280	299	6
1952	116, 780	113, 858	2, 573	349	—	1, 890	1, 707	152	31	—
1953	279, 602	44, 318	234, 940	344	—	13, 735	1, 323	12, 380	32	—
1954	41, 336	40, 246	439	611	40	1, 004	923	29	48	4
1955	86, 655	48, 200	29, 828	6, 898	1, 729	3, 907	1, 216	1, 954	563	174
1956	76, 406	35, 429	21, 057	17, 938	1, 982	4, 627	1, 304	1, 535	1, 581	207
1957	270, 267	260, 538	6, 837	2, 656	186	9, 338	8, 596	498	223	21
1958	161, 105	111, 859	38, 472	6, 571	4, 203	7, 860	3, 259	3, 361	707	533
1959	138, 930	3, 122	126, 405	8, 286	1, 117	10, 382	112	9, 279	860	131
1960	122, 178	46, 040	18, 688	50, 889	6, 561	7, 403	1, 544	816	4, 456	587

Table 34. Egg abundance of sardine in the waters from off Yotsukura Saki, Fukushima Prefecture to Irô Zaki, Shizuoka Prefecture, 1949-60.

Year	Total	Jan.	Feb.	March	April	May	June
	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}	10^{12}
1949	10. 62	0. 00	0. 00	6. 88	2. 68	1. 06	0. 00
1950	16. 74	0. 00	0. 00	2. 55	8. 93	5. 27	0. 00
1951	23. 77	0. 00	0. 00	8. 90	5. 71	8. 96	0. 20
1952	15. 20	0. 00	0. 00	2. 89	1. 26	8. 02	3. 03
1953	9. 35	0. 00	0. 00	1. 46	4. 43	3. 37	0. 09
1954	18. 42	0. 00	0. 14	5. 60	10. 56	2. 12	0. 00
1955	18. 63	0. 00	0. 00	1. 05	6. 04	11. 30	0. 24
1956	21. 37	0. 00	1. 32	1. 50	8. 10	8. 05	2. 40
1957	25. 88	0. 00	0. 00	14. 79	8. 23	2. 86	0. 00
1958	9. 66	0. 00	0. 00	1. 55	0. 67	7. 33	0. 11
1959	7. 04	0. 00	0. 00	0. 28	0. 64	5. 97	0. 15
1960	46. 87	0. 00	0. 00	7. 31	39. 30	0. 26	0. 00
Mean	18. 63	0. 00	0. 12	4. 56	8. 05	5. 38	0. 52

Chiba Prefecture from January to April 1950. The expression of age was slightly modified for the catch taken in the major fishing season in the area, *i.e.* despite the general rule, the age of fish caught in November and December are shown by that of the same year class taken in the ensuing January. For instance the fish that was born in the early 1949 or the 1949 year class is shown as I-age when they were caught in November and December 1949 as well as in January to April 1950. The spawning usually takes place in the area extending from the Yotsukura Saki, Fukushima Prefecture, to the Irô Zaki, Shizuoka Prefecture, centering around Inubô Saki, Chiba Prefecture. The spawning season is around March and April. Then the egg abundance comprised for the early half of the year in the aforementioned sea were used for the present analyses (Table 34).

(1) *Annual change of fishing rate:* As aforementioned, the major fishing season in the East Honshû is just prior to the major spawning season. Therefore, the stock size of parents (II-age or older) at the beginning of the fishing season is represented by sum of the catch and the spawning fish based on the egg census. In estimating the fishing rate of the parent stock, the author modified the method shown in Section 3-3 taking into account this discrepancy between fishing and spawning seasons. According to the analysis, the fishing rate is generally low, 2 percent on the average under an assumption that a female spawns 40,000 eggs, or 4 percent on the average under another assumption that a female spawns 100,000 eggs, except for

Table 35. Stock size and fishing rate of the parent sardine in the East Pacific Area of Honshû, 1950-60.

		Values estimated under an assumption the effective number of eggs spawned per female is éither one of :					
Year	C_p	40, 000			100, 000		
		P_s	P_0	E	P_s	P_0	E
	10^6	10^6	10^6	%	10^6	10^6	%
1950	11. 4	837. 0	848. 4	1. 3	334. 8	346. 2	3. 2
1951	20. 1	1, 188. 5	1, 209. 6	1. 7	475. 4	495. 5	4. 0
1952	2. 9	760. 0	762. 9	0. 4	304. 0	306. 9	1. 0
1953	235. 3	467. 5	702. 8	33. 5	187. 0	422. 3	55. 8
1954	1. 1	921. 0	922. 1	0. 1	368. 4	369. 5	0. 3
1955	38. 5	931. 5	970. 0	4. 0	372. 6	411. 1	9. 4
1956	41. 0	1, 068. 5	1, 109. 5	3. 7	427. 4	468. 4	8. 8
1957	9. 7	1, 294. 0	1, 303. 7	0. 7	517. 6	527. 3	1. 8
1958	49. 3	483. 0	532. 3	9. 3	193. 2	242. 5	20. 3
1959	135. 8	352. 0	487. 8	27. 8	141. 0	276. 8	49. 1
1960	76. 1	2, 343. 5	2, 419. 6	3. 1	937. 0	1, 013. 1	7. 5

C_p: Catch of parent fish (II-age or older).
P_s: Stock size of spawning fish (II-age or older).
P_0: Stock size of parent fish (II-age or older) just before fishing season.
E: Fishing rate.

three years inclusive of 1953, 1958 and 1959 (Table 35). For the exceptional years, the estimates of fishing rates range between 9 and 34 percent under a condition that a female produces 40,000 eggs, or between 20 and 56 percent under another condition that a female produces 100,000 eggs (Table 35). In the years when the fishing rate was extraordinarily high, the catch mainly consisted of II-age fish, *i.e.* 1951 year class in 1953; 1956 year class in 1958; and 1957 year class with III-age fish of the 1956 year class in 1959. There are two important points worth being mentioned. Firstly, the fishing rate of the sardine in the East Honshû has remarkably fluctuated, as the catch and age composition did, from year to year during the period under discussion. Secondly, the fishing rate rised for the year classes spawned in 1951, 1956 and 1957.

(2) *Relationship between catches from the same year classes in the two succceeding years:* The correlation between catches of I- and II-age fish of the same year class and that of II- and III-age fish were examined in order to check the effect of fishing in a certain year, which might have caused the remarkable fluctuation in the fishing rate.

According to the examination, the catches at the two successive ages from the same year classes are well correlated except for two sets of data. The correlation coefficient between catches of I- and II-age fish reaches to 0.76 except for the 1956 year class, and that between II- and III-age, 0.94 except for the 1951 year class. The catch of the 1956 year class at I-age was too great, the largest during 1950 through 1960, to be compared with the catch from the same year class at II-age (Fig. 56). The largest catch of II-age fish in 1953, from the 1951 year class, during the period under discussion was followed by unexpectedly small catch of II-age fish (Fig. 57). Here it should be noted that the egg abundances in 1951 and 1956 were much larger than those in the other years except 1957.

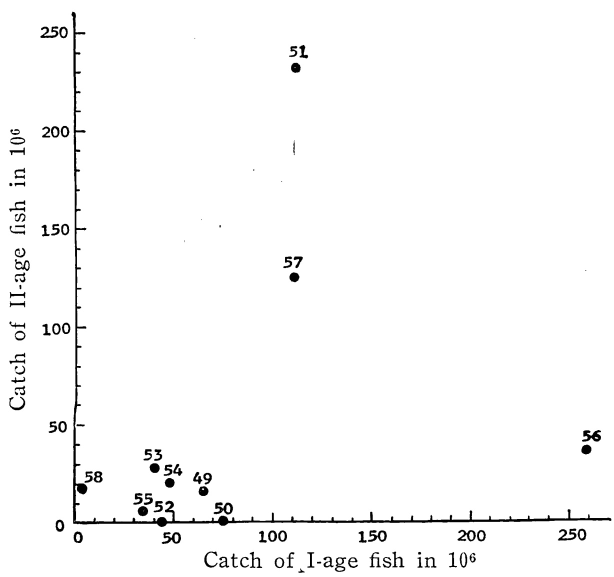

Fig. 56. Relationship between catches of I- and II-age fish of the same year class. Numerals denote the year class.

The above findings show that usually the fishing intensity was not so high as to disturb the relationship between the catches from the same year class in the two succeeding years, except for the two large year classes, as shown from the estimation of the fishing rates of the parent stock. The fishing rate in 1959, mainly for II-age fish of the 1957 year class, was very higher than the others, although both the catches at two successive ages from this particular year class were large. The reason of this phenomenon will be discussed later.

The above relations between catches from the same year class at three successive ages may contribute to the prediction of the sardine catch on the basis of catch statistics one or two years before.

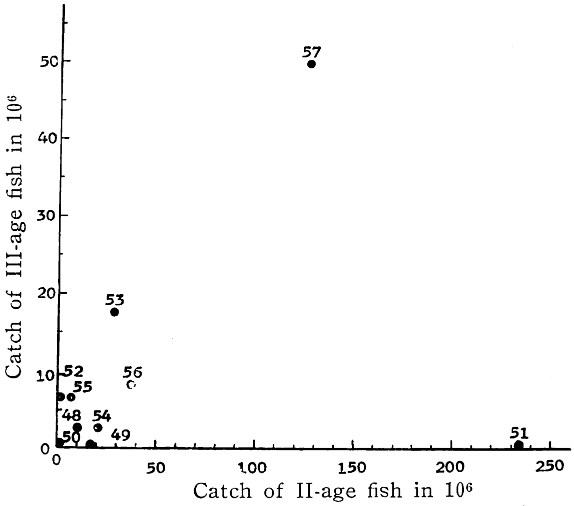

Fig. 57. Relationship between catches of II- and III-age fish of the same year class. Numerals denote the year class.

(3) *Relationship between the egg abundance in the respective year and catch from the year class:* For nine years since 1949, the egg abundance in respective year is positively correlated with the total catch from the year class, which was bred in the year throughout the exploited phase, at a coefficient of 0.75 (Fig. 58). The cumulative catch from a year class will be predicted on the basis of the stock size at egg stage by the following formula:

$$C = 16.82\,P_e - 145.36$$

where, C: cumulative catch, or catch at ages throughout the exploited phase, from a year class, in 10^6 fish,

P_e: stock size of a year class at the egg stage, or egg abundance in the year of their birth, in 10^{12} eggs.

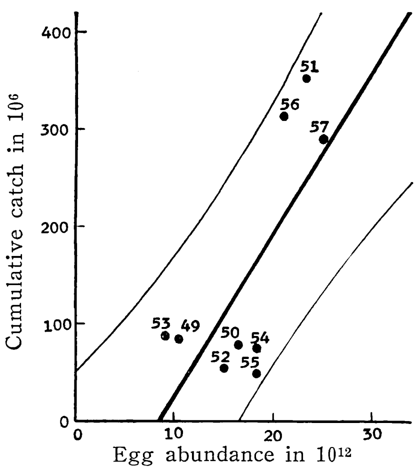

Fig. 58. Relationship between egg abundance in any year and cumulative catch from the year class.

Numerals denote the year class.

——: The regression line of the catch on the egg abundance.

——: The confidencial interval at 80 percent level.

There are two groups of the year classes, A and B, differing from each other in both the egg abundance and the catch (Fig. 59). The group-A comprises small year classes, being less than 20×10^{12} in the stock size at egg stage and less than 100×10^6 in the cumulative catch. The year classes of B-group amounted more

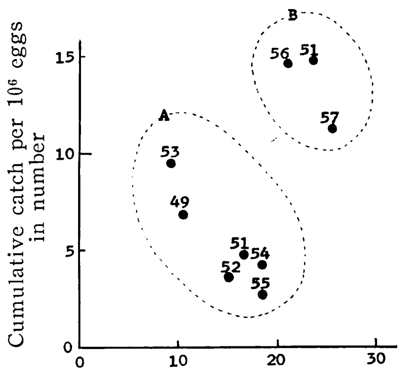

Fig. 59. Relationship between egg abundance in any year and cumulative catch per 10^6 eggs from the year class.

Numerals denote the year class. For A and B, explanations appear in the text.

than 20×10^{12} at the egg stage and the cumulative catch from the year classes exceeded 300×10^6 fish. Roughly, the catch per egg from respective year class seemed to be positively correlated with the egg abundance or the size of parent stock (Table 36, Fig. 59): *i.e.* the catch per 10^6 eggs is estimated about 10 for A-group and 11 to 15 for B, respectively. Within each group, however, these two measures seem to have been negatively correlated with each other.

These facts that the two groups of year classes differ from each other in their stock sizes at egg and exploitable stages and that their stock sizes at the above two stages indicate negative correlations within groups may be attributed to the density effect on the abundance, the physiological and ecological differences between the large and small year classes, and the difference between the fishing rate on A and on B as well as observational errors. Generally speaking, the density effect is responsible for causing the negative correlation within each group of the year classes. The difference in the catch per egg is contrary to be explained only by the density effect. As aforementioned, the fishing rates for the large year classes spawned in 1951, 1956 and 1957 are remarkably high and fluctuate to wide extent. Furthermore, the variation of catch by age per egg is also large among the above nine year classes. These phenomena indicate the variation of the fishing rate for different year classes.

Table 36. Catch from respective year class in number of fish per 10^6 eggs spawned in the year of their birth, 1949–59 year classes.

Year class	Total	I-age	II-age	III-age	IV-age and older
1949	7.77	6.12	1.65	0.03	0.00
1950	4.70	4.53	0.16	0.02	0.00
1951	14.78	4.79	9.88	0.02	0.07
1952	3.53	2.91	0.03	0,45	0.13
1953	9.44	4.30	3.19	1.91	0.20
1954	4.13	2.62	1.15	0.15	0.23
1955	2.68	1.90	0.36	0.35	0.06
1956	14.68	12.20	1.80	0.38	0.31
1957	(11.18)	4.32	4.88	1.97	—
1958	—	0.32	1.93	—	—
1959	—	0.65	—	—	—

As will be mentioned later, it should be noted that the variation of the reproduction rate* is lower than the minimal sustaining level for the 1951 and 1956 year classes, although it is rather high for the 1957 year class.

(4) *Effect of catch upon the spawning amounts in the later period:* In order to estimate effect of the fishing in the winter on the parent stock size in the ensuing spring, catch of II- or III-age fish was compared with the egg abundance produced by the respective age group. The number of eggs produced by each age group (Table 37) was computed on an assumption that the fecundity of an individual female has been proportionate to the body weight by the following formula:

$$\begin{bmatrix}\text{Number of eggs produced} \\ \text{by II- (or III-) age fish}\end{bmatrix} = \left[\text{Total egg abundance} \times \frac{\text{Catch of II- (or III-) age fish in weight}}{\text{Total catch of II-age and older fish in weight}}\right]$$

The eggs produced by II-age fish of the 1951 and 1957 year classes were very few though a large number of II-age fish of those year classes was landed in 1955 and 1959 (Fig. 60). This fact that these two large year classes were landed in great amount in the fishing season just prior to the spawning but they produced only the least egg stocks suggests possibility of heavy fishing having depleted the stock of those year classes at II-age so as to cause decrease of the spawners or to disturb their spawning activity. Another noticeable phenomenon was that II-age fish of the 1956 year class, one of the strongest year classes, was unexpectedly small in catch and in spawning. It is possible to assume that the intensive fishing upon I-age fish of the 1956 year class depleted the stock size prior to II-age.

Table 37. Egg abundance spawned by respective year class at each age, 1949–58 year classes.

Year class	Total	II-age	III-age	IV-age and older
	10^{12}	10^{12}	10^{12}	10^{12}
1949	22.0	19.4	2.6	—
1950	13.3	12.4	—	0.9
1951	20.9	9.0	10.7	1.2
1952	11.7	6.4	4.0	1.3
1953	24.5	13.8	10.0	0.7
1954	18.7	9.7	7.8	1.2
1955	19.1	17.5	1.5	0.1
1956	12.6	7.3	0.6	4.7
1957	(42.1)	6.3	35.8	—
1958	—	6.5	—	—

* In this chapter, the reproduction rate is defined as the ratio of the number of eggs spawned by a year class to the egg abundance in the year of their birth.

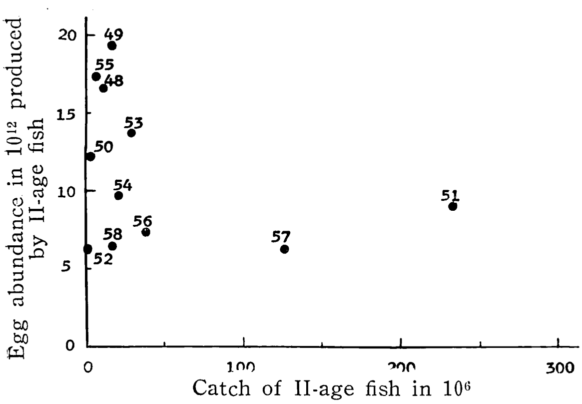

Fig. 60. Relationship between catch of II-age fish in any year and egg abundance produced by II-age fish in the year.

Numerals denote the year class.

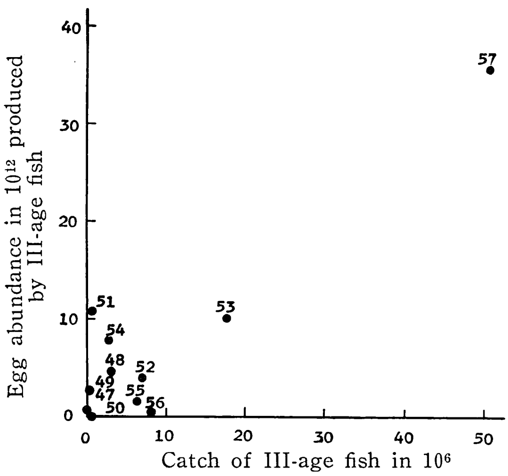

Fig. 61. Relationship between catch of III-age fish in any year and egg abundance produced by III-age fish in the year.

Numerals denote the year class.

The correlation coefficient, 0.68, between the catch of III-age fish and the egg abundance produced by them is significant (Fig. 61). It should be noted that the catch from and the egg abundance spawned by the strong 1951 and 1956 year classes were very low, consequently indicating maleffect of the intensive exploitation on II-age fish of the 1951 year class and I-age fish of the 1956 year class.

In this connection, an explanation is to be given on a fact that the 1957 year class was unprecedentedly large in the fishing and spawning seasons in the fourth year of life (III-age) and quite high in the fishing season in the preceding year (II-age). This year class, therefore, may be large enough to provide the large quantity of catch without any indication of maleffect of fishing.

The catch of I-age fish from respective year class and the spawning amount from the year class in the ensuing year (II-age) are not significantly correlated with each other; the coefficient is -0.28. This implies that at least for a few year classes, especially the large year classes spawned in 1951, 1956 and 1957, the fishing intensity on I-age fish was so high as to deplete the stock sizes in the following year (Fig. 62). If these large year classes were excluded, the correlation coefficient rised to 0.44, though not reached to the statistically significant level, indicating that the fishing intensity was lower upon the small year classes than upon the excluded large classes.

(5) *Relationship between the egg abundance produced by two successive generations:* Influence of the exploitation on the diverse year classes and age groups was

evaluated through examining the relationship between the egg abundance produced by any two successive generations.

The correlation coefficient, −0.37, between the egg abundance in a year and the number of eggs ovulated by II-age fish of the year class is slightly negative (Fig. 63). When the egg abundance in 1951, 1956 and 1957, or the stock sizes at egg stage of the 1951, 1956 and 1957 year classes, are excluded, the coefficient altered to be positive.

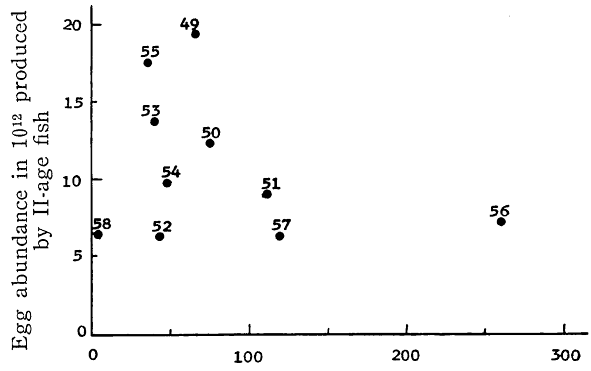

Fig. 62. Relationship between catch of I-age fish in any year and egg abundance produced by II-age fish in the next year.

Numerals denote the year class.

The amount of eggs in a year indicates a positive correlation with the egg abundance produced by III-age fish of the year class, at a coefficient of 0.55. This correlation is attributed to the single year class spawned in 1957 (Fig. 64).

For the 1957 year class, it has been noted that the fishing rate at II-age was estimated to be extremely high as the egg abundance in 1959, when the year class was II-age, was too small to be compared with the huge catch from the year class. If the fishing rate was really high for II-age fish of the 1957 class as estimated above, the catch of III-age fish in 1960 would have been small. Actually, however, the catch at III-age of this year class is far more than that of the other year classes. This contradiction between inference based on fishing rate and that based on relationships between stock sizes at different stages of the 1957 year class may be explained by the following postulations: the mortality rate at the early stage of life was much lower for this particular year class than for the others; consequently the 1957 class has been much larger than the others in the stock size after the critical period of life; most of the 1957 year class did not

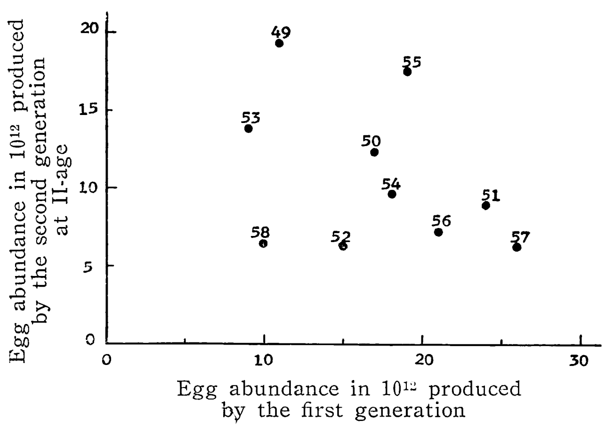

Fig. 63. Relationship between egg abundance in any year produced by the first generation and egg abundance produced by the year class (the second generation) at II-age.

Numerals denote the year class of the second generation.

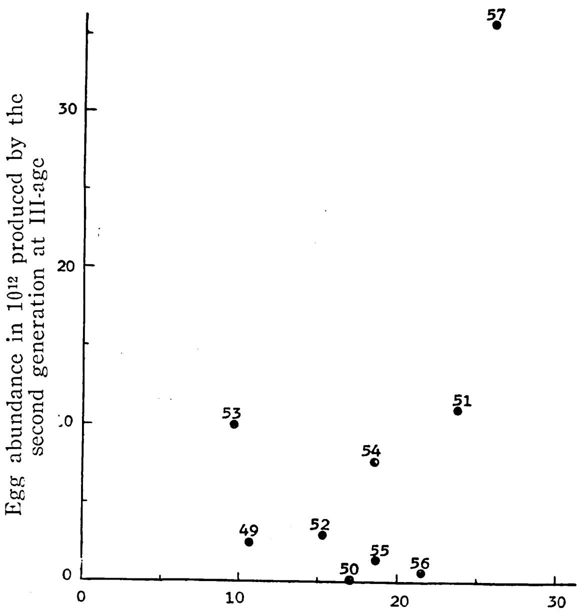

Fig. 64. Relationship between egg abundance in respective year produced by the first generation and egg abundance produced by the year class (the second generation) at III-age.

Numerals denote the year class of the second generation.

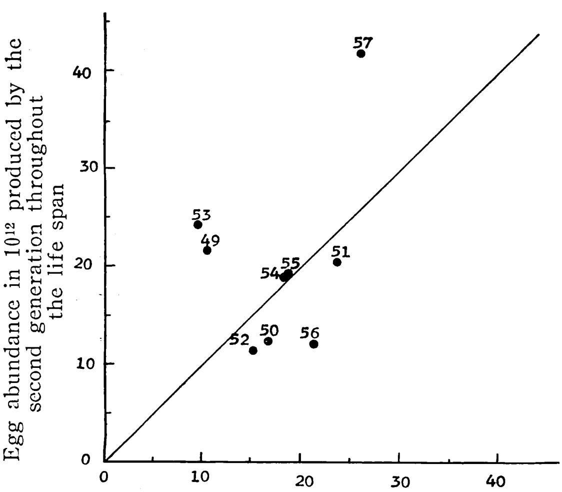

Fig. 65. Relationship between egg abundance in any year produced by the first generation and egg abundance produced by the year class (the second generation) throughout the life span.

Numerals denote the year class of the second generation.

mature at II-age, as the high density resulted delay of the sexual maturation; and then the virtual fishing rate of this particular year class at II-age was computed higher than the actual rate. As will be mentioned later, there is another evidence indicating that the spawners immigrated into the Pacific waters along Honshû from the Japan Sea in 1957.

In the relationship between the egg abundance in a year spawned by the first generation and that produced by the year class, the second generation, thoughout their life span, three year classes spawned in 1949, 1953 and 1957 are found to be very successful (Fig. 65). The 1949 and 1953 classes were the smallest, about 11×10^{12}, in the stock size at the egg stage and the 1957 class was the largest, about 26×10^{12}, at that stage among the year classes under discussion. The reproduction rate or ratio of the egg abundance produced by respective year class, the second generation, throughout their life span to the egg abundance in the year of their birth produced by the parents, the first generation, reached to 2.6 for the 1953 year class, 2.1 for the 1949 class and 1.6 for the 1957 class (Fig. 66).

The decrease of fishing intensity for the small year class may be most responsible for keeping the stock sizes of 1949 and 1953 year classes high until the stage of maturation. As to the 1957 year class, it is concluded that the fishing rate at II-age was estimated higher than actually it was and that there might have been some differences in the stock size and growth as aforementioned.

There is another biological evidence to explain the increase of the 1957 year class. The sardine stock in the East Pacific Area of Honshû is an open stock althogh it is fairly independent from the other stocks of the species. The fluctuation in an open stock is caused by movements of some individuals, *i. e.* some fish emmigrate from, or immigrate into the stock, as well as by fishing mortality, natural mortality and recruitment based upon reproduction. As to the 1957 year class of the sardine stock in the East Pacific Area of Honshû, no remarkable change is found in the natural mortality and in the recruitment. This decrease of the fishing intensity during 1955 through 1957 seems to be an important factor that caused increase of the year class. At the same time, the increase may be also responsible for the immigration of the large sized fish from the Japan Sea through the Tsugaru Straits into the area under discussion in the summers of 1955 and 1956. The sardine catch by drift nets in the Aomori Prefecture, which has consisted of the large sized sardine taken mainly in the early summer from May to late June or early July, increased suddenly in 1955 and decreased again in 1958 (Table 38). The major groups of the catch were II-, III- and IV-age fish (Table 39). Under the assumptions that fishing rate of the drifters is constant during the recent six years and that the annual survival rate of the large sized sardine in Aomori Prefecture is 0.46 as in the major fishing ground (Section 3-3), the parent stock in the waters along the Pacific coast of the prefecture was very large in summer 1957 than in the other years (Table 40). This suggests that the immigrants from the Japan Sea might have contributed the increase of egg abundance in the East Pacific Area of Honshû in 1957.

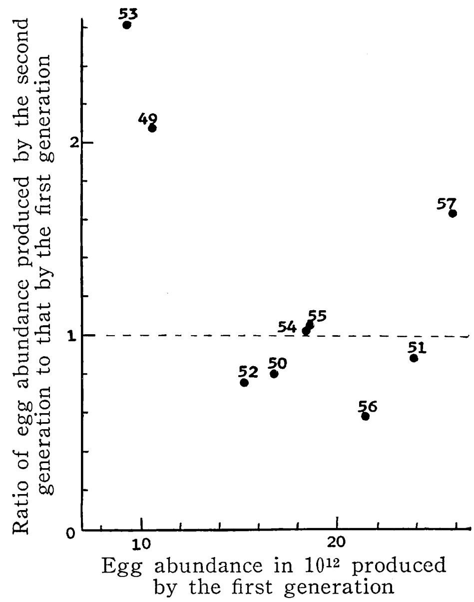

Fig. 66. Relationship between egg abundance in any year and ratio of egg abundance produced by the year class (the second generation) throughout the life span to the egg abundance produced by the first generation.

Numerals denote the year class of the second generation.

Whereas it should be taken into account that the reproduction rate differs depending upon the fishing rate in the years prior to the occurring season of respective year class: the rates for the 1950, 1951 and 1952 year classes do not reach to 0.9,

Table 38. Sardine catch landed by drifters on Aomori Prefecture in May-July, 1949-60.

Year	Total	The Japan Sea	The Pacific Ocean
1949	25 tons	No data tons	No data tons
1950	124	No data	No data
1951	494	1	493
1952	391	111	280
1953	631	301	330
1954	0	0	0
1955	5, 624	2, 122	3, 502
1956	6, 692	4, 351	2, 341
1957	6, 146	4, 342	1, 804
1958	2, 439	1, 872	567
1959	1, 166	1, 095	71
1960	0	0	0

Table 39. Age composition of sardine catch by drifters on the Pacific waters along Aomori Prefecture in May-July, 1955-57.

Year	Total	I-age	II-age	III-age	IV-age	V-age	VI-age	Age unknown
	10^3	10^3	10^3	10^3	10^3	10^3	10^3	10^3
1955	33, 053	542	18, 125	13, 486	900	—	—	—
1956	21, 336	2	4, 453	12, 125	3, 090	1, 068	579	19
1957	15, 132	—	2, 138	8, 402	4, 436	139	17	—

Table 40. Relative stock size of parent sardine in springs, supplied from the Japan Sea to the Pacific area in the previous summers, 1955-60.

Year	Total	III-age	IV-age	V-age
1955	0	0	0	0
1956	15. 4	8. 3	6. 7	0. 4
1957	16. 0	2. 1	9. 4	4. 5
1958	12. 2	1. 0	4. 9	6. 3
1959	2. 6	0	0. 4	2. 2
1960	0. 2	—	0	0. 2

If the survival rate and fishing rate are constant every year, the stock size, P_i, in i-th year is estimated by

$$\sum_{j=1}^{k} C_{i-j}\frac{S^j}{E},$$

where, C_{i-j}: catch from the respective year class in the i-j-th year,
S: annual survival rate,
E: fishing rate,
j: number of years after the year class was recruited to the available stock,
and k: maximal age of the available stock minus the age just before recruited to the stock.

As E was not estimated for the fishery in question, only relative stock size was calculated under an assumption that S was 0.46, on the analogy of the rate for the whole population. Therefore, the unit of the relative stock size is $10^3/E$ (see Section 3-3).

while the rates for the 1954 and 1955 classes are almost 1.0. The very low reproduction rate, 0.59, of the 1956 year class might have been responsible for the facts that the fish of this class were landed in a large quantity at I-age, and that they were fished intensively at II-age as shown by the fishing rate.

Finally, it is to be noted that there is a symptom of a sudden recovery of the sardine stock in the East Pacific Area of Honshû. As a matter of fact, the egg abundance exceeded 100×10^{12} in the 1961 season.

On the basis of the analyses mentioned in Chapter 3, along with the discussion on the recent fluctuation in the sardine stock in the East Pacific Area of Honshû, the further step will be advanced in order to judge the present and future stata of the sardine population, and to set up the major subjects of the investigation on the population and fishery.

Recently the population size of sardine has dropped to the lower level than it was. But the major cause of the depletion is not thinning by the fishery. The sardine population in the period consists of several local stocks that are isolated from each other to some extent. In the last two years, the stock in the East Pacific Area of Honshû has indicated a sudden increase.

As outstanding features, remarkable annual fluctuations are found in the amount and the age composition of catch, the egg abundance and the fishing rate in the major fishing season. These fluctuations are regarded to reflect the change in amount and distribution of the stock. The thinning of fishery might have not serious enough to deplete the stock size at the later stage except for the 1951 class at II-age and the 1956 class at I-age.

The reproduction rate decreased for the 1951 and 1956 year classes that were large at the egg stage and in the cumulative catch and that were intensively exploited. This indicates that the increase of fishing intensity on some large year classes had to be regulated in order to retain the reproduction rate. The fishery exploited the 1957 year class, being large in the stock size at the egg stage than the others, so severely that the cumulative catch from the year class is the largest among the classes under discussion. However, the 1957 year class has been large enough, in spite of being exploited intensively to produce a greater amount of eggs not only at II-age but also at III- and IV-ages. The appearance of this dominant year class may be responsible for the reduction of the fishing intensity during 1955 through 1957 and the mass immigration of larged sized fish from the Japan Sea.

If the sardine stock in the East Pacific Area of Honshû continues to develop so as to expand the distribution range and thus migratory route, it is possible to expect a substantial recovery of the sardine population to the level in the prosperous years around 1935. Therefore, the study should be advanced to regulate the fishery in order to keep the increasing tendency through retaining the reproduction rate over one.

The fluctuation in any fish population is studied on the basis of various information on both biology of and fishing exploiting the species in question. Especially the age composition of catch and the egg census are the most important and fundamental data. As to the Japanese sardine, these two basic data have been obtained by the epoch-making surveys since 1949. In addition, the significance of studies on the mechanisms of recruitment and natural mortalities has been accepted in the course of the recent investigations on the sardine population. The research of the last subject is not advanced enough at present, and this defficiency makes it difficult to predict the long-term fluctuation in the sardine population.

For these reasons, the author recommends to promote the study on the mechanisms underlying the changes in natural mortality, especially at the early stage of life, as well as to make up the fullness of the researches on the age composition of catch and the egg census as well as the catch statistics. Only the establishment of the investigations along the above line can contribute to increase the productivity and profitness of the fishery, through regulation of the intensity and prediction of the fluctuation in the population.

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Summary

Since the inception of the 20th century, the sardine catch in the Far East has fluctuated remarkably. The author has analysed the mechanisms underlying the fluctuation as well as biological information needed for the study.

1. Following is a summary on the biological information pertinent to the study of the fluctuation in the sardine population.
   a. The investigation of literature and published data revealed that almost all the sardine catch in the Far East has been composed of a single species, Japanese sardine, *Sardinops melanosticta* (TEMMINCK & SCHLEGEL)

b. The Japanese sardine has been widely distributed in the coastal waters along the Japanese Islands. The distribution range and migratory routes have changed according to fluctuation in the population size.
c. The Japanese sardine mainly spawn in the waters south of the central part of Japan during winter and spring. The spawning ground also indicated a large scale shift depending upon the population size.
d. It has been estimated that almost all the sardine eggs are fertilized just after they were discharged in the sea. The development changes depending upon the temperature, along the ARRHENIUS's equation with the coefficient of μ of about 31,000. The mortality rate at the early stage, around time of the absorption of yolk, is very high, only 0.1 percent of fertilized eggs may survive at a postlarval stage of 15 mm in total length.
e. Most of the distinct scale rings are annuli that form during winter and early spring. The growth rate of the fish increases in the spring and decreases in winter. The growth of the fish throughout their life span fits to BERTALANFFY's equation. An example of the growth curves is calculated on the basis of data taken during 1949 through 1951 as follows:

$$l=22.39\{1-e^{-0.87(t-0.0483)}\}\ \text{cm}.$$

f. The study on fecundity of the sardine is less conclusive. It is estimated that a female ovulates 24,000—48,000 ova at one spawning activity and that many fish spawn two or more times in a season.
g. Postlarvae just after absorption of yolk feed mainly on copepodan eggs and nauplius. After that stage, the sardine eat zooplankton and phytoplankton *in situ*.
h. Major gear to catch the sardine are round hauls, drift nets, set nets, lift nets, and boat and beach seines. The fishing season differs depending upon the locality of fishing ground, and the size and the age of fish to be caught. A remarkable fluctuation has been observed in the geographical locations of the major fishing grounds.

2. The sardine was fished since the ancient years. There are records indicating that the fluctuations in the sardine catch caused prosperity and collapse of some fishing villages. The following outstanding phenomena were observed since the research systems on the catch and biological backgrounds of the sardine were established in the inception of the 20 th century.
   a. The annual sardine catch in the Far East was less than 150,000 tons before 1910, increased rapidly since around 1924, and exceeded 2,000,000 tons around 1935. The catch was on the tremendous decrease in the 1940's, until it dropped to merely 160,000 tons in 1945. Since then the sardine landings recovered slightly, being between 300,000 and 500,000 tons up to 1953, but decreased again in 1955 to around 200,000 tons. In the prosperous period around 1935, the major

portion of the sardine catch were obtained on the Pacific coast of northeastern Honshû and Hokkaidô, and the Japan Sea coast of North Korea. Sardine were also caught then in the waters adjacent to Coast Range and Sakhalin. After 1945, no commercial fishery was present on the North Korea, Coast Range and Sakhalin. Around 1950 the waters northwest of Kyûshû were the most important fishing grounds of the sardine, and, since around 1955, the major catch has been brought from the waters around the Noto Peninsula.

b. In the prosperous period around 1935, the major portion of eggs were spawned in the Satsunan Area off the southern tip of Kyûshû. The major swawning ground shifted to the northwestern waters of Kyûshû around 1950, and to the waters adjacent to the Noto Peninsula around 1955.

c. In the prosperous period, III-age fish represented dominant spawning group, followed by IV- and II-age fish. Since 1950, the major spawners have been II-age fish. The growth rate has increased in accordance with decrease of the population size. For instance the mean body length of III-age fish was about 18 cm before 1940, and increased year after year until it exceeded 20 cm in 1944. The mean length of III-age fish has ranged between 20 and 21 cm in the recent years.

d. There was observed a major group of the sardine that migrated over wide range in the prosperous period. They were spawned in the Satsunan Area and drifted by the Kuroshio Current along the Pacific coast of Honshu during the egg and larval stages. This major group showed seasonal migration during their second and third years of life (as I- and II-age) in the Pacific waters along northeastern Honshû and Hokkaidô. In the third autumn, II-age fish of the major group migrated into the Japan Sea. The adults, III-age or older fish, moved up north in spring and down to the south in autumn. In the adverse period, no wide migration has been traced and presence of fairly isolated local groups has been observed.

e. Mass mortality of the grown fish was found in the waters near the northern limits of their distribution during the prosperous period. But it did not cause depletion of the population. On the other hand, the meandering of the Kuroshio Current, by which the eggs and larvae were drifted, since around 1938, is to be noted, because the mortality rate is extremely high at the early stage of life.

3. The causes of the flctuation in the catch since 1924 are revealed on the bases of the catch statistics, and biological and environmental data.

a. The rise of the catch between 1924 and 1933 was caused by increase of the population as well as development of fishery.

b. The major cause of the disasterous decline of catch in the 1940's was mass mortality of the major larval stock on the way of drifting from the spawning ground to the nursery grounds.

c. The decrease of catch since 1949 was mainly caused by the decline of the population. Usually the maleffect of exploitation is not serious on the fluctuation in the whole population. The change in natural factors have been postulated to prohibit the recovery of the population, although this posturation is not suported by evidences as remarkable as those for the theory on the decrease in the 1940's.

4. The final discussions based on the above analyses as well as a study of the local stock in the East Pacific Area of Houshû, cover conditions for the recovery of sardine population and the subjects to reveal the present conditions as well as to predict the fluctuation in the population. Through analyses of the data taken in the East Pacific Area of Honshû, it is revealed that the fishery at times depleted the reproduction of particular year classes. Since there is a possibility that the increase of this particular local stock may cause recovery of the whole population, the fishery, especially that for the immature fish should be regulated.

Various biological information are required for the purpose of revealing the effects of fishing and of predicting the fluctuation in the population. Especially the distribution and abundance of eggs, and the structure of catch as well as the catch statistics should be surveyed with the more extensive scale. In addition, the study should be advanced on the natural mortality at the early stage of life. Only the investigation thus advanced can contribute to establishing the management program of the fishery and to improving the profitness of that marine industry.

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日本産マイワシの漁獲量変動機構に関する研究

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要 約

極東水域のマイワシ漁獲量は過去において大きな変動を示した。筆者は本種の生物学的知見を総合し，それに基づいて1900年代における漁獲量の変動機構を検討した。

1. 資源変動の追究に必要な生物学的知見を要約すると次の通りである。
   a. 既往の報告によると極東水域におけるマイワシ類漁獲物の大部分はマイワシ *Sardinops melanosticta* (TEMMINCK & SCHLEGEL) である。
   b. マイワシは主として冬から春にかけて日本の中南部海域で産卵する。産卵場は資源の消長にともなって著しい変遷を示した。
   c. 放出された卵の恐らく大部分は直ちに受精する。卵の発育速度と温度との関係は ARRHENIUS の式で近似され，温度係数 μ は約31,000である。卵黄吸収期前後の死亡率は非常に高く，受精から全長15 mm の後期仔魚期までの生残率は0.1% 内外に過ぎない。
   d. 年令は鱗に生ずる年輪によって推定される。成長度は春に増大し，冬に減少する。生涯にわたる成長はBERTALANFFYの式で示される。成長曲線の一例を1949-51年に得られた資料に基づいて示すと次のとおりである。

$$l=22.39\{1-e^{-0.87(t-0.0483)}\}\ \mathrm{cm}.$$

   e. 個体の産卵回数に関しては十分な知見は求められていないが，一尾の雌は年に2〜3回産卵し，1回に24,000〜48,000の卵を産むと考えられる。
   f. 卵黄吸収直後の後期仔魚は主として橈脚類の卵，小型ノープリウスをとる。その後は動物性および植物性プランクトンをかなり無選択的に捕食する。
   g. 本種は主として旋網，流網，定置網，敷網，地曳網，船曳網で漁獲される。全分布域を通して見ると漁期は周年にわたる。漁場の分布は資源の増減と共に大きく変った。

2. マイワシは日本において石器時代から漁獲の対象となっており，19世紀以前にも本種の消長が漁村の興廃をひき起したことが記録されている。20世紀にはいり科学的調査が行なわれるようになってからマイワシ資源に認められた顕著な変動を要約すると次のとおりである。
   a. 極東水域におけるマイワシ漁獲量は1910年以前は15万トン以下であったが，1924年頃から急増を始め1935年頃には200万トンを越えた。1940年代に入ると漁獲量はいちじるしい減少を示し，1945年には16万トンに過ぎなかった。その後多少の回復は見られ1951年には48万トンに達したが，1955年には再び20万トンに急減した。1935年頃の豊漁期には主漁場は東北，北海道の太平洋沿岸と北朝鮮沿海であった。この時代には漁獲海域は沿海州，樺太にも拡がっていた。1945年以降になると北朝鮮，沿海州，樺太には産業的な意味での漁獲はあげられなくなった。1950年頃の主漁場は九州北西沿海に移り，さらに1955年以降になると能登半島を中心とする本州日本海沿岸が主産地となった。

b. 1940年頃までの豊漁期には九州南端の薩南海域が主な産卵場であった。漁場の場合と同様に産卵場の中心も1950年頃には九州北西沿海，1955年頃には能登半島近海或はその以北に移行した。

c. 豊漁時代にはIII年魚が主産卵群で次いでIV年魚，II年魚が多かった。これに対して1950年以降における産卵親魚の多くはII年魚である。資源量の減少にともなう成長度の増大が認められた。たとえばIII年魚の平均体長は1940年頃には約18cmであったが，1944年には20cmを越えた。近年におけるそれは20〜21cmである。

d. 豊漁期には大回遊を行なう卓越群の存在が認められた。この卓越群は主として薩南近海を中心とする九州南部海域で産まれ，卵，稚仔時代に黒潮によって本州太平洋沿岸まで運ばれた。彼等はI年魚からII年魚時代には主に東北地方および北海道の太平洋沿岸に分布し，その主体はII年魚時代の末に日本海に移動した。III年魚時代に入り成魚となってからは，日本海，東支那海を分布域とし春に北上，秋に南下した。第2次大戦後の不漁期になると大回游をする卓越群は見られず，かなり独立性の大きい地方群の存在が目立つようになった。

e. 豊漁時代には分布の末端水域で成長した親魚の大量斃死が認められたが，これが資源を減少させた主因であるとは考えられない。一方卵，稚仔漂流の原動力となっていた黒潮の変化が1938年頃から注目された。これは発生初期における死亡率が高いという事実等と関連して重要な現象であると思われる。

3. 漁獲統計，生物学的知見および環境条件に関する資料に基づいて1924年以降の極東水域における漁獲量変動の要因を検討して次の結果を得た。

a. 1924-33年における漁獲量増大には漁業の発展のみでなく，資源量自体の増大が関与している。

b. 1940年代における漁獲量の急激な減少は産卵場から漂流中の稚仔の大量斃死による資源量の減少に基づくものである。

c. 1949年以降における主分布海域であり，又主漁獲海域でもある対馬海流域の漁獲量減少は主として資減量の減少によると考えられる。この海域の漁獲は資源保存に悪影響をおよぼしているとは言えず，環境条件の変化が資源の回復を妨げていると見られるが，現在その具体的条件の詳細を明らかにするまでにはなっていない。

4. 最後に大戦後の不漁期において，独立性の大きい一地域集団とみられる千葉〜福島県に水揚げされる本州東岸の資源について，その現状と動向の予測ならびに資源を回復させるための条件について論じた。この地域集団では戦後卓越年級が出現した特定の年において主として未成魚に対する漁業が，当該年級魚の再生産を妨げている。一方この集団は現在小規模のものであるが，その増加は極東水域全体の資源回復を導く可能性を持つと認められるので，本地方における未成魚の漁獲量を適宜規制することが望ましい。