

Table 8. Temperature coefficient (μ) for the period from fertilization to the end of every developmental stage in the rearing experiments, 1941 (after NAKAI 1962b).

Period from fertilization to the end of either stage	"
Aa	30300
Ab	31600
Ac	31700
Ba	31400
Bb	30900
Bc	30800
Ca	30900
Cb (hatch-out)	31100

C : a constant,

a : temperature characteristics,

one may see $a=0.18$, $C=1,380$ and $Q_{10}=6.0$.

(ii) Study relevant to net collection: On the basis of occurrences of the eggs it is indicated that the Japanese sardine are supposed to spawn at night roughly from 1900 to 2400 (Section 1-3). The duration of time from fertilization to hatching within the temperature range of 15-20°C is approximately 1.5-3.5 days, *viz.*, three or four days at most. These findings seem to warrant feasibility of using the same procedure as AHLSTROM (1943) did in determining the value

of μ for the Pacific sardine. With this view in mind, an attempt was made to evaluate μ of the Japanese sardine by use of eggs at stages, Ac, Bc and Cb out of the materials collected during 1949 through 1951. To begin with, the duration of time after spawning and fertilization till their being collected has been computed on the same assumption as AHLSTROM (*loc. cit.*) had that the eggs were spawned at a particular time of day, 2200 hour. It was noted, when the materials were sorted depending upon the water temperature at the collection, that the occurring time did not much vary among the eggs of the same stage but did among different stages, and that peaks of the eggs of any stage occurred at an interval of about 24 hours. With help of these inferences, relationship between the reciprocal of the absolute temperature and the logarithm of reciprocal of developmental duration was determined (Fig. 17). According to the result, there were but little differences between the value of μ for the Japanese sardine obtained on the basis of the artificial fertilization and the pelagic eggs collected at sea, while they are considerably different from the value determined for the Pacific sardine (Table 9).

Effect of salinity on the embryonic development: No information has become available for effects of the salinity on the early development of the sardine. In the rearing experiments at Hosojima mentioned above, therefore, further attention was directed to observation of growth, time required for hatching, rates of hatching, *survival* and deformation under various salinity conditions. The study was based on four lots of artificially fertilized eggs from a couple of parents. The eggs were kept in the waters of four kinds of salinities; 8.6 permil or a quarter-concentration, 17.3 permil or a half-concentration, 34.6 permil or natural sea water and 69.2 permil or twice-concentration. When this experiment started, the eggs were in an early stage with the tail, the end of which became free from the yolk mass and posteriorly extended for about 0.2 mm (Fig. 18). In most cases the eggs and larvae under

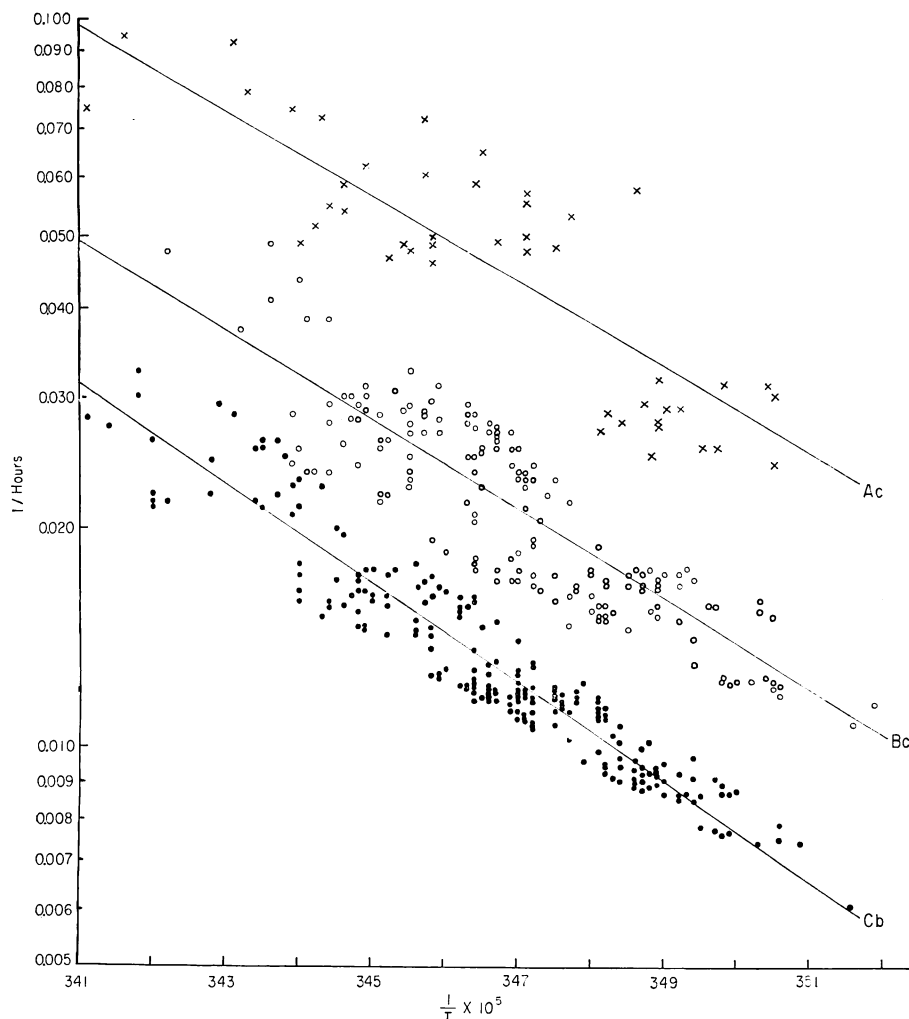


Fig. 17. Relationship between the reciprocal of absolute temperature ($1/T$) and that of time computed as required of netted eggs for the period from the fertilization to three different stages ($1/\text{Hours}$), (after NAKAI 1962b).

Table 9. Temperature coefficients (μ) of sardines in the embryonic stages (after NAKAI 1962b).

Species	Method for obtaining materials	Stage	$\mu \cdot 10^{-2}$	Standard deviation	n	Temp. °C
Japanese sardine	Artificial fertilization	Fertilization to hatching	311			
Japanese sardine	Net collection	Cb	314	0.034	240	11.2-20.0 (surface)
Pacific sardine*	Net collection	XI**	225	0.029		11.2-20.0 (mean at 10 and 20 m layers)

* After AHLSTROM (1943).

** The stage XI designated by AHLSTROM (1943) corresponds to the end of stage Cb.

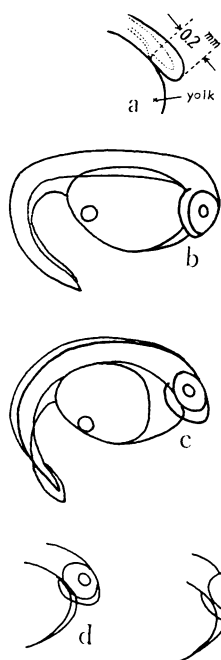


Fig. 18. Explanatory diagrams on embryo (after NAKAI MS).

- a. The measured part of the posterior portion of the embryonic body free from the yolk;
- b. Normal embryo kept in the ordinary sea water.
- c. Abnormal embryo kept in twice concentrated water; showing a wide anterior cavity of the yolk.
- d. Normal embryo kept in a half diluted water.
- e. Normal embryo with a narrow anterior cavity of the yolk kept in a quarter diluted water.

development were observed through the side of a flask, soon after the flask being taken out of the aquarium so that vigor of the embryo might be least affected by change in breeding conditions.

(i) *Relationship of salinity with the hatching rate*: Progress of development in the egg stage was compared among the embryos reared under the four different salinities. The result indicated that the hatching rate was higher for the eggs subjected to the diluted waters than those in the natural sea water and in the twice-concentrated water (Table 10).

Table 10. Hatching rate of the eggs reared under four kinds of salinity levels (after NAKAI MS).

Concentration of sea water	Hatching rate (per cent)
1/4	100
1/2	100
1/1	83
2/1	83

(ii) *Relationships between salinity and the survival rate of larvae*: During the experiment the mortality took over the eggs only kept in the higher salinities—one egg died among the groups in each of the natural sea water and the twice-concentrated water, but all the eggs in the other two salinities survived. The larvae reared in the highest salinity lived the shortest, while those in the lowest salinity had the longest life. The larvae kept in the half-diluted water lived as long as those in the natural sea water.

The findings emphatically point to a fact that the larvae in the natural sea water, which made most normal progress in development, lived unexpectedly short life with the survival rate lower than the others. Nevertheless, one should not interpret the phenomenon in such a way as the lower salinity resulted in a better growth of the larvae, because a greater deformation occurred in the quarter salinity.

(iii) *Relationships of salinity with survival and deformation*: The observation failed to reveal any appreciable difference in size among the eggs reared in the

various concentrations of sea water. Deformation, if any, of the eggs was not thought to have been very serious, with the exception of the eggs in the highest concentration, which had wrinkled already seen in part at the base of the fin. In the lapse following the microscopy, a cavity in the anterior portion of the yolk was much expanded suggestively of abnormal development (Fig. 19). From these evidences one may infer that such a high salinity as twice of natural sea water would be effective at least for condensing the liquid in the perivitelline space. And, if so, the osmotic pressure might as well have affected to some extent the diameter of eggs living in the water with this salinity.

In addition to the morphological changes in the eggs, a few more phenomena made it nearly unrefutable that the salinity would have influence upon density of the liquid in the eggs. As for the egg stage, except developmental progress that somewhat varied between the eggs in the water with the quarter-salinity, half-salinity and normal salinity, no morphological variation

due to salinity could be distinguished among the eggs in the four different salinities. However, the fact that the salinity strongly influenced the formation of larvae having completed hatching may warrant detailed description of the result obtained from the experiment. The highest and lowest salinities had such an influence on the growth of the larvae as to lead them all to deformation, while the half and natural salinities allowed every larva living there to maintain a normal form (Fig. 20). On the basis of the survival rate of eggs and larvae, and frequency of abnormal individuals in order of time under different salinities, it is concluded that all the members, both normal and abnormal combined, in the water with the highest salinity lived a shorter spell from egg to larva with a lower survival rate than in any other salinity; and

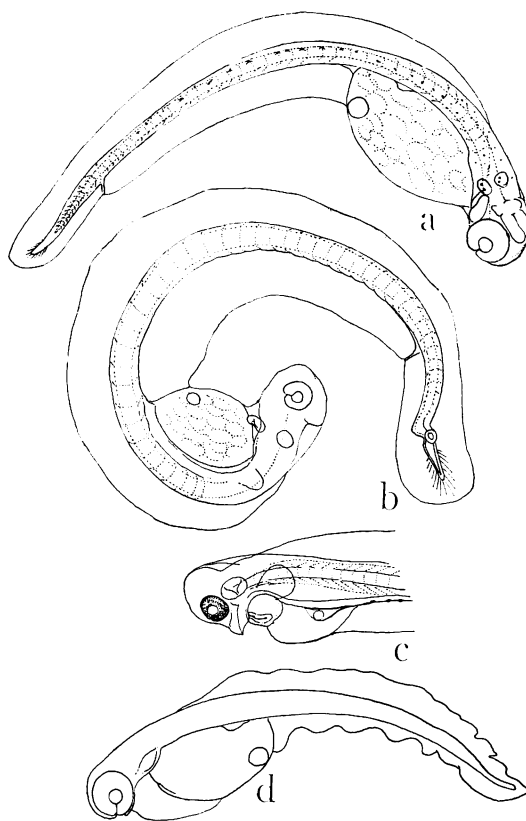


Fig. 19. Sardine larvae reared under different salinities (after NAKAI MS).

- a. Abnormal, in quarter diluted water, 4.8 mm in length; about 5 hrs. after hatch.
- b. Abnormal, in quarter diluted water, 6.4 mm in length; about 28 hrs. after hatch.
- c. Normal, in half diluted water, 5.53 mm in length; about 51 hrs. after hatch.
- d. Abnormal, in twice concentrated water, 3.5 mm in length; about 5 hrs. after hatch.

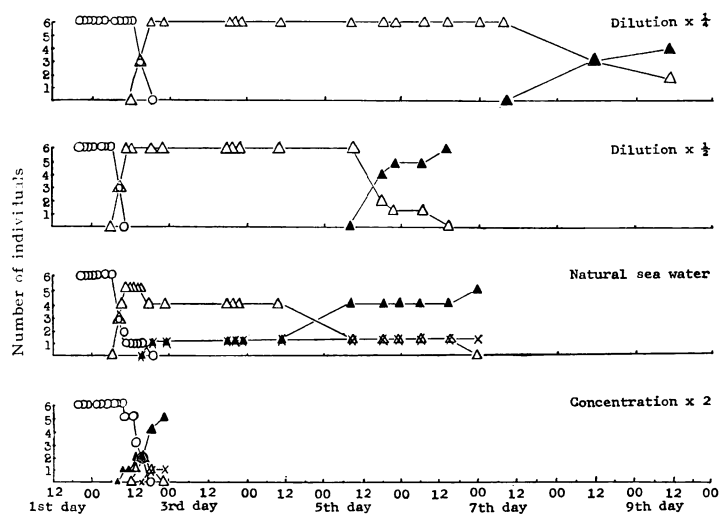


Fig. 20. Number of individual eggs and larvae survived or expired under different salinities (after NAKAI MS).

○: Egg alive, △: Larva alive, ●: Egg expired, ▲: Larva expired.

The experiment began at 2000 on February 21st, 1941, with each group consisting of six alive eggs.

that the normal forms of them survived at the lowest rate as well (Fig. 20). On the other hand, the eggs and larvae in the lowest water lived for the longest period with the highest survival rate. However, because they turned to the anomaly immediately after hatching, the survival rate of normal larvae was lowered nearly to that of the water with the twice-concentration. Thus, the growth of larvae in both extreme salinities proved to be the worst. In case of the natural- and half-salinity lives, their total survival rate inclusive of eggs and larvae lowered on a occasion much earlier than that in the quarter-salinity. Notwithstanding, there occurred no deformed larva among them at all, allowing the normal forms in the intermediate salinities to keep a high survival rate for much longer a spell than those in the quarter-salinity. Particularly a point calling for attention as well as further scrutiny is that the half-salinity could sustain life for the longest period of all, with the high survival rate for normal larvae.

Survival rate of eggs and larvae: A valuable contribution to the population study is expected from determining the survival rate at every stage of early development from egg to postlarva. With this view in mind, the materials collected during 1949 through 1951 were counted by three embryonic stages, *i. e.* egg, larva and postlarva. The postlarvae measuring 6 mm or larger in total length were grouped into 2-mm interval.

The chronological age corresponding to each of these stages was estimated as follows. As for the egg stage the number of days required for completing the

classes, A, B and C, was calculated on the bases of the relationship between water temperature and development, the average temperature of 14.2°C (Section 1-3) and value of μ of 31,000. The estimation of postlarval stage has been made on the ground that the growth of animals in general at their early development is expressed by the exponential curve. Therefore, when dt_k , time needed for growing to a certain length class (l_k to l_{k+1}), is known, dt_i , time for growing to the other class (l_i to l_{i+1}), can be estimated. In this connection, times, dt_0 , for the growth from l_0 to l_1 , and dt_1 , from l_1 to l_2 , and so fourth, were calculated one after another. The relationship is expressed as:

$$dt_i = t_{(i+1)} - t_i = dt_k \times \frac{\log l_{(i+1)} - \log l_i}{\log l_{(k+1)} - \log l_k}$$

where, dt_i : time required for completing i -th length class,
 t_i : time for reaching i -th length class after hatching,
 t_{i+1} : time for completing i -th length class after hatching,
 l_i : lower limit of i -th length class,
 l_{i+1} : upper limit of i -th length class,
 l_k : a certain length class in which the growth rate was estimated.

KAWAMURA (1953) showed the length composition of postlarval sardine caught in Fukuoka Bay during April 21 to June 2, 1953. On the basis of his data, it was estimated that the postlarvae when measuring about 25 mm in total length grew 10 mm in 15 days. The number of materials in each class collected per day (24 hours) was determined by dividing the total materials of each length class with the number of days required for the larvae in developing to the respective classes which were obtained in the way mentioned above.

Based on these computations, it was indicated that the eggs

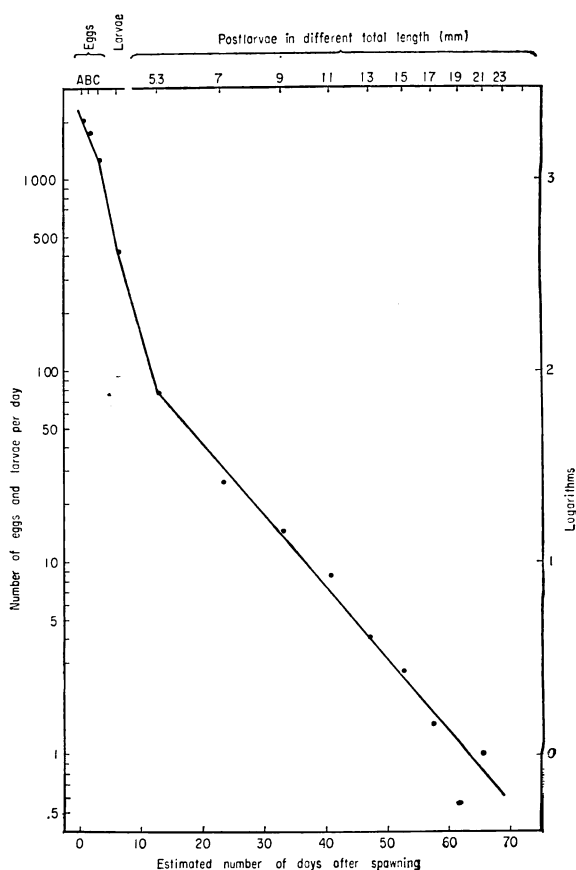


Fig. 21. Survival of sardine at early stages estimated from vertical collection, 1949-51 (after NAKAI and HATTORI 1962).

decreased in number sharply down to the beginning of postlarval stage when the yolk was just absorbed. In the later part of postlarval stage the decrease was slackened a little but still followed a straight line. The survival rates for different stages were: 3.5 percent at the beginning of postlarval stage, 5.3 mm in total length, about two weeks after fertilization; 0.10 percent when measuring 15 mm in 54 days of life; and 0.07 percent when 17 mm in the length about 58 days old (Fig. 21).

Assuming that a majority of the young sardine were sampled at a representative frequency and that the growth rate was estimated satisfactory, it is possible to assert that about 99.9 percent of the eggs were likely to die within 60 days of life. Furthermore, no appreciable discrepancy was present among the survival rates, each computed from the materials for everyone of the years, 1949 through 1951. In this regard an attention should be drawn to the facts that the sardine at their early developmental stages, particularly the egg and larval stages, could survive but at such a low rate, and that the postlarval fish measuring more than 15 mm in total length were subjected to the commercial exploitation.

Section 1-5. Age and growth

Since KISHINOUE's work (1908), many authors have already dealt with the growth of the Japanese sardine. The present author also defined the scale annuli with the materials taken from the western Japan Sea during 1936 through 1942, and studied the validity of the scale reading method and the growth rate of the fish with the materials collected in the waters surrounding Japan from 1949 to 1951.

Method of scale reading: KISHINOUE (1908) stated that the scale method as well as the otolith reading were not applicable in determining age of the sardine. In the 1930's, however, several workers dealt with the sardine scales for the purpose of age determination (FURUKAWA 1934, NAKAI 1938a, 1941, AIKAWA and KONISHI 1940, SAWADA 1940, YASUDA 1940). Since then the scale reading has been developed by many workers (KUBO *et al.* 1948, AMEMIYA and TAMURA 1948, 1949, KUBO 1950, YASUDA and OGURA 1950, SATÔ *et al.* 1950, TATSUKI and ASAMI 1952, TAMURA 1952, MURAKAMI 1952, 1953, YOKOTA 1953, KITAKA 1954, NAKAI 1962, NAKAI and HAYASHI 1962 a and b).

Among those workers, FURUKAWA (1934), AIKAWA and KONISHI (1940), SAWADA (1940) and YOKOTA (1953) believed that two distinct rings had formed on a sardine scale every year. On the other hand, YASUDA (1940), NAKAI (1940), SATÔ *et al.* (1950), TATSUKI and ASAMI (1952), TAMURA (1952), MURAKAMI (1952, 1953), NAKAI (1962), and NAKAI and HAYASHI (1962 a and b) concluded the distinct sardine rings having been annuli. The other authors reported the ring formation in various seasons of the year. Thus, there are two different theories on the ring formation of the sardine, one being annual, and the other, twice or more a year. A reason why these workers disagreed about the ring formation is attributable fundamentally to variation of the

definitions of the scale rings.

Here the present author is concerned with major points of the method employed for obtaining the data as follows:

- (1) Remove normal scales, if possible, from the dorsal side of the body between the posterior end of the opercle and the most anterior end of the base of dorsal fin.
- (2) Keep the removed scales as fresh as possible. Otherwise the visibility of the surface structure will be affected by gelatinoid oozing out of the scale.
- (3) After removing offal, mount five or six scales for a fish between two glass slides to examine them under a microscope.
- (4) Adjust the angle and amount of the reflecting light by changing directions of the mirror, and sometimes, of the worker's eye to identify the annulus that is the most conspicuous and acceptable as such.
- (5) When the annulus can not be easily read owing to presence of false rings or scars, characteristics of the growth zones of the scale observed as above should be counted into consideration as an evidence of annulus.

On the scale of young sardine caught off Wokpo, Korea, during December 1936 through the following April, no ring formed before January when the fish were about one year old. When counted on March 6, one ring was seen on the scale of 83 percent of the fish, then of all the rest observed on April 8 (Table 11).

Table 11. Ring number composition of scale of young sardine caught at Wokpo, Korea (after NAKAI 1962a).

Date of catch	Number of individuals	Mean body length	Ring number composition	
			0	1
1936 Dec. 22	10	13.0 (cm)	100 (%)	0 (%)
29	11	12.8	100	0
1937 Jan. 5	11	12.7	100	0
15	9	13.2	100	0
Mar. 6	12	14.4	17	83
Apr. 18	9	14.5	0	100

As to the medium sized sardine taken at Shiogama, Miyagi Prefecture, and Kuji, Ibaraki Prefecture, during November 1941 through July 1942, it was found that the fish with one ring dominated among those collected in the months from November to the ensuing March. The dominant group changed from one- to two-ring fish at once in April. Judging from the monthly average body length of the fish, there is a good reason to believe that one-ring fish belonged to the same year class with the two-ring ones, and that the second ring formed sometimes around March 1942 (Table 12). In an attempt to examine the growth of the scale, the

Table 12. Ring number composition of scales of medium sized sardine, 16–17 cm in body length taken on the Pacific coast of Honshû (after NAKAI 1962a).

Date of catch	Port	Number of individuals	Ring number composition	
			1	2
1941 Nov.	Shiogama	18	100 (%)	0 (%)
Dec.	Kuji	30	94	6
1942 Jan.	„	43	95	5
Feb.	„	51	78	22
Mar.	„	35	89	11
Apr.	„	89	20	80
May	„	68	2	98
June	„	35	0	100
July	„	14	0	100

relative marginal increment* of the fish measuring 16.2 to 16.7 cm in body length were sampled out of the above materials. It is obvious from the examination that most of the second ring formed in March, because the relative marginal increment declined sharply in that month, and because the value was a minimum (Table 13).

Table 13. Monthly relative marginal increment of scale of the medium sized sardine, around 16–17 cm in body length, taken on the Pacific coast of Honshû (after NAKAI 1962a).

Date of catch	Landing port	1-ring			2-ring		
		Number of individuals	Mean body length (cm)	Mean increment	Number of individuals	Mean body length (cm)	Mean increment
1941 Nov.	Shiogama	18	16.2	0.16			
Dec.	Kuji	27	16.5	0.16			
1942 Jan.	„	41	16.4	0.14			
Feb.	„	40	16.6	0.15			
Mar.	„	31	16.3	0.15			
Apr.	„	18	16.2	0.15	71	16.3	0.04
May	„				67	16.7	0.05
June	„				35	16.7	0.07
July	„				14	16.4	0.09

Another examination on ring formation was carried out to find dominant age groups of the sardine caught off the eastern coast of Korea (western part of the Japan Sea) in spring (May and June) and in autumn (September and October), 1938 to 1942. From this examination it was indicated that the fish with three rings were

* YASUDA (1940) first used the ratio of distance from the outermost annulus to the scale margin on the scale length for studying the scale of sardine. Here the ratio is called the *relative marginal increment*.

always dominant in the period except only for September 1940. Suppose that the fish really formed the summer ring as a rule, and that the fish in that area had not been replaced with different year classes during the months, they should have one more ring added when examined in September or October. Even if did the replacement occur with different year classes during the seasons, the number of rings when counted in the autumn ought to be always even, while in the spring odd, because of an additional ring that was said to have formed in the summer (Table 14).

Table 14. Dominant ring-count-group of the sardine in the western part of the Japan Sea, 1938-42 (after NAKAI 1962a).

Season	Year	May			June		
		Number of individuals	Dominant ring count	Frequency %	Number of individuals	Dominant ring count	Frequency %
Spring	1938	324	3	53.1	270	3	56.2
	1939	607	3	49.3	368	3	34.5
	1940	243	3	35.6	467	3	33.5
	1941	137	3	35.9	345	3	37.1
	1942	—	—	—	130	3	46.2
	Year	September			October		
		Number of individuals	Dominant ring count	Frequency %	Number of individuals	Dominant ring count	Frequency %
Autumn	1938	58	3	41.5	69	3	47.3
	1939	—	—	—	167	3	35.5
	1940	117	1	59.7	157	3	30.3
	1941	265	3	33.3	453	3	37.5
	1942	—	—	—	399	3	62.9

Through the above findings, it has been proved that the ring forms once a year, mostly in the winter months.

Validity of the scale method: Among the biologists having engaged in the Co-operative Investigations, SATÔ *et al.* (1950) and MURAKAMI (1952, 1953) also advanced the methods of scale reading of the sardine. In order to test similarity of these three sets of definitions of annuli, six workers read 50 samples collected during 1949 through 1951 independently. The workers were Dr. S. SATÔ of the Hokkaidô Regional Fisheries Research Laboratory, Mr. T. YOKOTA of the Nankai Regional Fisheries Research Laboratory, Dr. S. MURAKAMI of the Seikai Regional Fisheries Research Laboratory, Dr. S. ITÔ of the Japan Sea Regional Fisheries Research Laboratory, and Dr. S. HAYASHI and the present author of the Tôkai Regional Fisheries Research Laboratory. The workers were arbitrarily designated as A, B,... F in the following description.

In determining the ages of the fish of Nos. 1-30 as 0, I and II, the six workers

completely agreed with each other. In the older fish (Nos. 31-50), some of the determinations disagreed among the workers except F who, with assignment out of the region where the old fish would not occur, had read no comparable materials. The least agreement was found between readings of the workers B and C; their readings differed each other for five fish out of 20 or at the ratio of 25 percent of total (Table 15).

Table 15. Ages of 50 fish determined by six workers (after NAKAI and HAYASHI 1962b).

Fish number	Worker						Agreed by majority
	A	B	C	D	E	F	
1-10	0	0	0	0	0	0	0
11-20	I	I	I	I	I	I	I
21-30	II	II	II	II	II	II	II
31	IV	IV	IV	IV	IV	—	IV
32	III	III	III	III	III	—	III
33	IV	IV	IV	IV	V	—	IV
34	V	V	V	V	V	—	V
35	III	III	IV	IV	III	—	III
36	III	III	III	III	III	—	III
37	IV	IV	IV	IV	IV	—	IV
38	IV	IV	III	III	III	—	III
39	III	III	III	III	III	—	III
40	III	III	III	III	III	—	III
41	?	V	V	V	V	—	V
42	III	III	IV	III	IV	—	III
43	III	III	III	III	III	—	III
44	III	III	III	III	III	—	III
45	III	II	III	III	III	—	III
46	IV	IV	IV	IV	IV	—	IV
47	IV	IV	IV	IV	IV	—	IV
48	IV	V	IV	IV	IV	—	IV
49	IV	IV	IV	IV	IV	—	IV
50	V	V	V	V	V	—	V

—: No age was given for the specimen.

In order to examine whether the five workers gave the same definition to the annuli, applied were two methods both introduced by MASUYAMA (1948). Firstly, the contingency coefficient for five series of the age determinations has been calculated by

$$W=12 \cdot S\{m^2(n^3-n)\}$$

where W : contingency coefficient,

m : number of workers,

n : number of fish,

$$S: \sum \left\{ a_i - \frac{m(n-1)}{2} \right\}^2$$

a_i : sum of the rank of i -th fish by all the workers.

Significance of the contingency is tested approximately by

$$F_0 = (m-1)W/(1-W), \quad n_1 \doteq (n-1)-2/m, \\ n_2 \doteq (m-1) \cdot (n-1)-2/m.$$

The calculation gave the value of 0.823 as the contingency coefficient that has shown highly significant agreement among the above readings. But, if there were any *parallel differences* depending upon workers—for instance, a series of fish that were determined by one worker to be at the age of I, II, IV, III *etc.* were read as II, III, V, IV *etc.* by another, respectively—this method would have no validity for the present purpose. The data have not shown such a discrepancy as this. Instead, probability of matching of 15 pairs of 20 by chance, the least agreement described above, has been calculated in the second test to be only 0.0014. After reading, all the workers told that the present ratio of this disagreement seemed to be higher than that in the routine examinations, taking unusual number of fish with the false rings into consideration. These findings establish that there has been practically no difference in the definition of the annuli among the workers.

Seasonal change of growth rate: In case of migratory fishes, it is difficult to obtain the data pertinent to study the growth of them because of the following reasons:

- (1) An exact time of early stages in the life can hardly be known.
- (2) Available stocks for fisheries often change from time to time.
- (3) The size composition of catch is often affected by selectivity of gear.

Therefore, it may be worth paying attention to samples from any dominant year class caught by gear with little selectivity. An example was the 1951 year class exploited mainly by set nets and round hauls in the area extending between Aomori and Ibaraki Prefectures from summer 1951 to the end of 1952.

The data from this year class revealed that the monthly increment of body length decreased from July to December 1951, then increased till following May and became small again in December 1952 (Fig. 22). Although the values in the period from June to November 1952, were not made available, it is almost sure that the fish showed a periodic growth. Logarithms of the monthly increments decreased linearly from July 1951 to January 1952, and increased linearly since then till May of the year (Fig. 23). As far as this linear relationship holds valid, the body length increases as an exponential curve:

$$\log (dl/dt) = kt + a, \quad \text{or} \quad dl/dt = A \cdot \exp(kt),$$

where k and a are growth coefficients and A is $\exp(a)$. Then the growth is expressed by

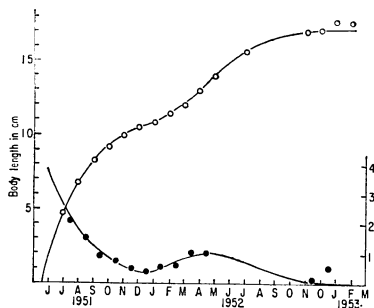


Fig. 22. Monthly mean body length and its increment, with the calculated curves of the sardine from northeastern Pacific coast of Honshu, 1951-53 (after NAKAI and HAYASHI 1962c).

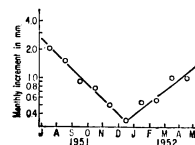


Fig. 23. Monthly increments of mean body length of sardine from northeastern Pacific coast of Honshu, 1951 and 1952 (after NAKAI and HAYASHI 1962c).

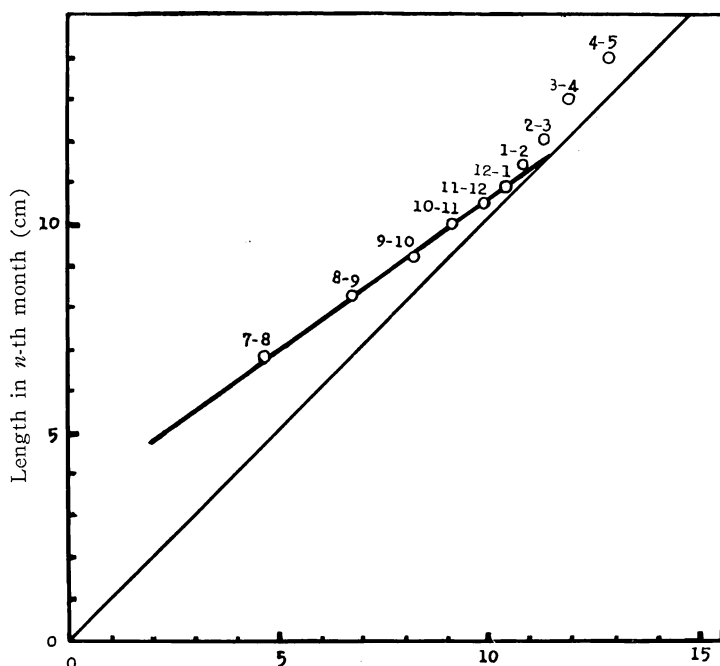


Fig. 24. Finite difference diagram for growth of sardine in the first year of life, northeastern Pacific coast of Honshu, 1951 and 1952 (after NAKAI and HAYASHI 1962c).

Numerals denote the month in which the data were obtained.

$$l = c(1 + A \cdot e^{kl}/kc),$$

where, c is a constant derived by integration.

This equation becomes a Marthusian curve if k is larger than zero, or Bertalanffy's curve if k is less than zero.

As far as the body length in a month, l_t , is correlated linearly with the length in the next month, $l_{t+\Delta t}$, the growth tendency can be expressed by Bertalanffy's curve as in the data obtained during July 1951 through January 1952 (Fig. 24). The parameters, k and l_∞ , are estimated from those of the regression equation of $l_{t+\Delta t}$ on l_t . The time when l was zero, t_0 , is an arithmetic mean of $t + \log(l - l_t/l_\infty)/k$.

Working with the present data, the body length and the monthly increment of the 1951 year class in the first year of life were found expressible by the following equations, respectively (Fig. 22).

$$l = 11.63\{1 - e^{-0.36(t-5.60)}\} \text{ cm,}$$

$$dl/dt = 4.19 \cdot e^{-0.36(t-5.60)} \text{ cm per month.}$$

The calculated hatching time, May, seems to agree with that determined from the study of egg census (Section 1-3), though the former estimate may not be always highly reliable. Because the growth rate of the sardine would be first on the increase as mentioned above, the actual growth curve might have an inflection point at very young stage.

In the second year of life, the sardine might not grow along the Bertalanffy's curve because the growth rate has been on the increase in early summer. Here, it is reasonable to expect that replacement of the growth types might be gradual but not abrupt. In other words, $l_{1.0}$ of $l_1 = l_{1.0} + g(t)$ may be neither the asymptote of body length in the equation of growth for, nor body length at the end of, the first year of life. Taking this into account, the value of $l_{1.0}$ was assumed to be 10.00 cm that corresponds to the length in November of the first year. Then the equation has been examined with the increment of body length in the second year, $l'_1 = l_1 - 10.00$. After study of the finite difference diagram, the logistic curve was adopted (Fig. 25), and the parameters, k and l_∞ , were obtained from the regression equation of reciprocal of l'_1 on that of $l'_{1-\Delta t}$.

Working with the actual data, the equations to express the growth and the rate were estimated as below (Fig. 22).

$$l = 10.00 + 7.14/(1 + e^{3.64 - 0.57t}) \text{ cm,}$$

$$dl/dt = 0.0798(l - 10.00)(17.14 - l) \text{ cm per month.}$$

Summarizing above, it is concluded that the sardine grow more rapidly in the warmer months than in the colder months of the year. The growth in the second year of life is expressed by the logistic curve. This type of curve, although being less suitable than the Bertalanffy's curve to express the growth in the later half of the first year, may be useful to approximate the growth within a year because of

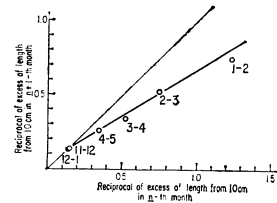


Fig 25. Finite difference diagram for growth of sardine in the second year of life, northeastern Pacific coast of Honshū, 1952 and 1953 (after NAKAI and HAYASHI 1962c).

Numerals denote the month in which the data were obtained.

the seasonal fluctuation in the growth rate.

Age dependent change of regional variation of body length: During 1949 through 1951, there was seen remarkable regional variation of the body length at the end of the first year of life. In the Sekai Region, 0-age fish reached to 13-14 cm in body length at the end of the year, while the length of the same age group in the Japan Sea remained only 10-11 cm. The growth of the fish in the Tōkai and Nankai Regions was similar to that in the Seikai in contrast to those from Hokkaidō and Tōhoku Regions resembling that in the Japan sea (Table 16).

Table 16. Body length of sardine by age at the end of year, 1949-51
(after NAKAI and HAYASHI 1962b).

Region	Year	Body length by age						Age of oldest fish
		0	I	II	III	IV	V	
		cm.	cm.	cm.	cm.	cm.	cm.	
Hokkaidō	1949	9-10*	—	—	—	—	—	III
	1950	11-15	16	—	—	—	—	III
	1951	12-15	16-18*	19	—	—	—	II
Tōhoku	1949	10-12	16-17*	19-20*	—	—	—	III
	1950	10-15	16-17*	19-20*	—	—	—	IV
	1951	9-15	16-17	19-21*	—	—	—	IV
Tōkai	1949	13-14*	16-18*	—	—	—	—	IV
	1950	9-15	15-18	—	—	—	—	III
	1951	13-15	15-18	19-20	—	—	—	II
Nankai	1949	13-16*	16-18*	—	—	—	—	II
	1950	14-16*	14-16*	—	—	—	—	I
	1951	11-14	13-17	15-17*	—	—	—	III
Seikai	1949	12-16	17-19	20-22	21-23	21-23.5	—	V
	1950	10-15	17-20	20-22	21-23	21-23.5	21-24	VI
	1951	13-16	18-20	19-21	21-24	21-24	21-24	VIII
Japan Sea	1949	8-13	18-20*	19-22*	21-22*	22	23*	VI
	1950	9-13	17-20	19-22	21-23	21-23.5	22-24	VI
	1951	10-13	18-20*	20-22	21-23	21-23.5	22-24	VII

* Estimated from data in other months than December of the year and following January.

The regional difference of length among older fish was not as significant as that among 0-age ones. The fish older than I-age reached to 20 cm or more in every region under study. The phenomena might be interpreted as follows. When the fish grow older, effects of the difference in the hatching time become less apparent due to the compensation of growth, and to the intermingling of the fish from one region with those from the other regions.

General growth curve during 1949 through 1951: The growth of every age group from the Seikai Region, the most prosperous fishing area in 1949 through 1951, was fitted to the logistic curves (*a*-line in Fig. 26). The calculated length of I-, II- and III-age fish in June and of 0-age fish in July were examined to test the fitness for the Bertalanffy's curve. July was chosen for 0-age fish instead of June because the length in June was calculated smaller than it actually was. As the finite difference chart indicates that the lengths of two successive age groups were

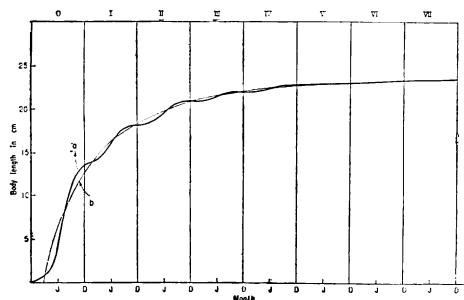


Fig. 26. Growth curves of the sardine taken in 1949-51 (after NAKAI and HAYASHI 1962b).

Line *a*: drawn on the monthly basis.

Line *b*: drawn on the annual basis.

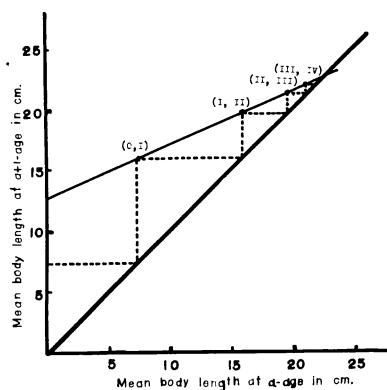


Fig. 27. Finite difference diagram for the sardine growth estimated on the annual basis, 1949-51 (after NAKAI and HAYASHI 1962b).

correlated linearly (Fig. 27), the parameters were calculated as follows:

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

The curve can approximate the growth of the fish during the period under discussion (*b*-line Fig. 26). When compared with the previous results, the present estimate of growth does not differ much from that of fish taken in the earlier years of the 1900's (KISHINOUE 1908), but is faster than that in the prosperous period around 1935 to 1940 (AIKAWA and KONISHI 1940, YASUDA 1940, SATÔ *et al.* 1950). The annual variation of the growth rate will be discussed in Section 2-3.

Section 1-6. Maturity and fecundity

An essential factor computing the absolute number of parent fish on the basis of the egg abundance in the spawning ground is the number of normally fertilized eggs per female in a spawning season. Of two methods for estimating the number of such eggs, one is based on data of the ratio of matured fish, the total number of spawned eggs and fertilization rate under natural conditions. The other method, as will be described in Section 3-3, is based on the mortality rate of the fish in every stage of the life, and the sex ratio and the relative stock sizes of the parents for the several succeeding years.

In the past many workers attempted to determine the fecundity of the sardine by the first method. According to KISHINOUE (1908) the number of ova to be found in the ovary of the sardine at their third year of life ranged from 60,000 to 70,000. CLARK (1931) estimated that about 100,000 to 200,000 eggs would be emitted by an individual of the Pacific sardine during a spawning season. Recently, YAMANAKA and ITÔ (1957) stated that a female produced 30,000-100,000 eggs at a spawning activity. In studying number of spawning activities of an individual fish during a

year, several authors have taken notice of modes of the ovum diameter (AMEMIYA and TAMURA 1944, ASAMI 1953, ITÔ 1954, CLARK 1934). In order to advance this kind of study, it is necessary to collect and examine the parent fish in the major spawning season.

Seasonal variation of maturity: On the basis of data collected by the Cooperative Investigations during 1949 through 1951, the maturity of the large sized fish was determined by the diameter of the largest ovum in each ovary, the maturity coefficient and the weight of gonad.

Frequency distributions of the ovum diameter have been obtained from the large sized sardine sampled during the spawning season in the southwestern part of the Japan Sea and in the northwestern waters off Kyûshû. In that part of the Japan Sea, the spawning season began in December and lasted till following May with March and April as its peak (Section 1-3). For the ova from the Japan Sea, two modes were outstanding in December; the one ranged from 0.2 to 0.4 mm in diameter, occurring much more than the others, 0.9 mm in diameter. In April there was only a mode of large sized ova, whereas the small ova reappeared in May with a mode of 0.3 mm as the largest. The evidence indicate that most of the fish whose ova had been about 0.8 mm in diameter in April became fully mature and finished

the ovulation within the month. In the sea northwest of Kyûshû, a majority of the ova were still small in December, measuring around 0.2 mm across. Nevertheless, the ova with modes at 0.5 to 0.8 mm were prevalent in February, but no one was smaller than 0.4 mm in the size. Some of the parents were presumed to have been immediately before the ovulation as they had ova as large as 1.0 and 1.1 mm across. The fish examined in April had small ova again with the highest frequency at 0.1 mm, and next to it, 0.5 mm; but there was no larger ova than 0.8 mm at all (Fig. 28).

Another attempt to illustrate the gonad development of sardine, which was thought to be dependent upon the geographical and seasonal conditions, was carried out on the bases of the maturity coefficient and the gonad weight obtained during 1950-51 season from the northwestern coast of Kyûshû and during 1949-50 and 1950-51 seasons from the

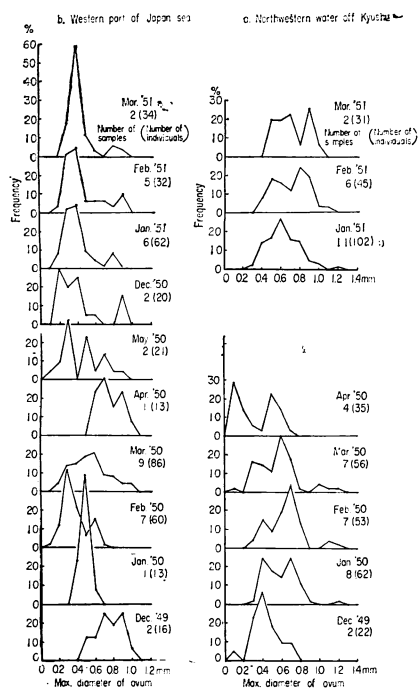


Fig. 28. Maximum ova composition of large sized sardine by month, 1949-51 (after NAKAI and USAMI 1962).

Japan Sea. The mean coefficient in the northern part of the Japan Sea stood at about 10 in April and May both in 1949-50 and in 1950-51, the value being much higher than that in the other areas. But the coefficient declined abruptly in June 1950. In the waters southwest of the Japan Sea and northwest of Kyûshû, the coefficients followed the seasonal fluctuation nearly as the same as that of the ovum diameter in the respective areas. The maximal value approximated to 10 in April and May in the northern half of the Japan Sea as aforementioned; while it bore less than 10 in February and March in the southwestern part of the Sea; less than 7 in January and February in the Kyûshû area. The coefficient reached to the peak in

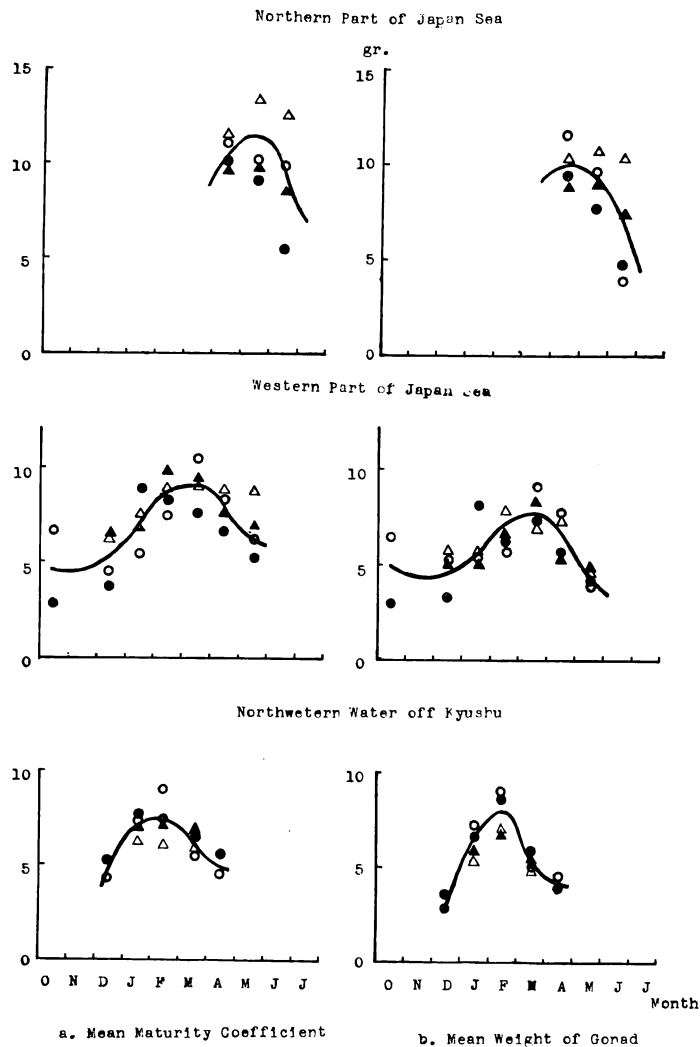


Fig. 29. Monthly fluctuation in maturity coefficient and gonad weight of large sized sardine (after NAKAI and USAMI 1962).

○ = △ } 1949-50 △ = ● } 1950-51
 ● = ♀ }
 ▲ = ♂ }

the later season and to a higher value for the fish in the northern waters than for those in the southern waters (Fig. 29).

The seasonal and regional progression of the mean gonad weight and regional changes in the frequency exhibited similar trend to that of the maturity coefficient (Fig. 29).

The above three factors point to regional characteristics in the spawning season of the sardine, which are coincident with the evidence acquired from collections and analyses of spawned eggs (Section 1-3). It is very interesting to note that the maturity coefficient as well as the gonad weight in the spawning season are indicative of greater values in the northern area than in the southern area.

Fecundity of the large sized sardine: On the basis of the measurements obtained from seven specimens of twelve taken in 1937, 1940, 1941 and 1948 (Nos. 5, 7-12 in Table 17), the numbers of their ova were determined at 0.05 mm intervals (Table 18). The positions of modal diameters of the largest ova in these specimens were arranged in an increasing order (Fig. 30); the order nearly reflects matured degree of the fish. The frequency distribution points two or three distinct groups of the ova: they are ova smaller than 0.3 mm in diameter, those ranging from 0.3 to 0.6 mm, and those over 0.6 mm. Here let them be called the first, second and third groups in the sequence of the increasing diameter.

Although no large discrepancy in the range of diameters has been evident between the first and the second groups of ova from every specimen examined, the third group in a specimen, No. 10, had the mode at 0.7 mm, and in another, No. 11, that had transparent ova, the mode reached to 1.05 mm. Degree of difference between the second and the third groups becomes greater as the third group matures.

Among the 12 specimens, only three, Nos. 4, 7 and 8, were used for counting the ova falling under the first group. These fish had the ova of that group numbering 200,000 to 300,000; No. 4 pre-

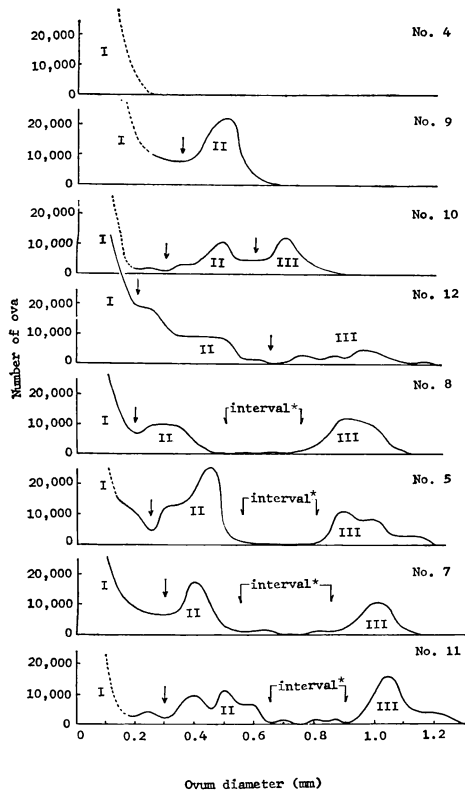


Fig. 30. Apparent progress in maturity of parent fish as indicated by frequency of ovum diameter (after NAKAI 1962b).

* Interval of diameter class in which few or no ova are included.

Roman numerals show different size groups of ova.

Table 17. Information on sardine specimens used for examination on fecundity, 1937-48 (after NAKAI 1962b).

Specimen number	Fishing			Body length (cm)	Body weight (g)	Ovary weight (g)	Weight of ova fraction (g)	Remarks
	Locality	Date	Gear					
1	Wokpo, south Kyongsan, Korea	1937/3/26	Drift net	18.2	70.4	4.26	0.10	For ova less than 0.86 mm For ova larger than 0.1 mm Only transparent ova were examined.
2	"	1937/4/18	Set net	19.6	77.8	4.50	0.10	
3	"	"	"	19.8	84.6	4.35	0.10	
4	"	"	"	17.9	58.9	0.25	0.01	
5*	Itô, Shizuoka Pref.	1940/5/9	"	20.7	—	25.01	0.33	
6*	Hosojima Lt. S 3', Miyazaki Pref.	1941/2/19	Drift net	19.5	—	21.5	0.1	
7*	"	"	"	18.9	—	15.9	0.05	
8*	"	"	"	19.1	—	17.4	0.05	
9	Kamo, Yamagata Pref.	1948/6/?	"	—	—	6.98	0.02	
10	"	"	"	20.1	—	10.9	0.05	
11*	"	"	"	21.6	135.0	24.8	0.025	
12*	"	"	"	22.9	—	11.52	0.05	

* Presented transparent ova of the most mature stage.

Material of Nos. 5 and 7 to 12 were also used for measurement of diameter of ova.

Table 18. Number of ova in sardine specimens by size group in decreasing order of maturity, 1937-48 (after NAKAI 1962b).

Specimen number	Group** I		Group II		Group III		Group II & III	Total number of ova (10 ³)
	Ovum diameter (mm)	Number of ova (10 ³)	Ovum diameter (mm)	Number of ova (10 ³)	Ovum diameter (mm)	Number of ova (10 ³)	Number of ova (10 ³)	
11*	0.20-0.30	6.0	0.30-0.65	46.7	0.70-1.30	47.7	94.4	—
7*	0-0.30 0.20-0.30	247.3 16.2	0.30-0.70	42.8	0.80-1.20	28.7	71.5	318.8
5*	0.10-0.25 0.20-0.25	30.3 9.7	0.25-0.60	80.4	0.85-1.20	41.1	121.5	—
8*	0-0.20	218.6	0.20-0.60	39.0	0.75-1.15	43.9	82.9	301.5
6*	—	—	—	—	0.80-1.00	41.1	—	—
12*	0.075-0.20	93.0	0.20-0.65	86.8	0.70-1.20	23.5	110.3	—
10	0.20-0.30	2.2	0.30-0.60	29.0	0.60-1.00	33.8	62.8	—
2	0.05-0.20	54.6	0.20-0.40	11.4	0.60-0.80	24.2	35.6	—
1	—	—	0.20-0.50	20.2	0.50-0.80	18.7	38.9	—
3	—	—	0.20-0.32	10.6	0.50-0.80	31.3	41.9	—
9	0.10-0.35 0.20-0.35	39.4 31.8	0.35-0.70	69.3***	—	0	69.3	—
4	0-0.20	300.0	—	0	—	0	0	300.0

* Including transparent ova of the most mature stage.

** May exclude the ova smaller than the specified range of diameter.

*** Presumably groups II and III are mixed.

senting no ova of any other group at all. It is worth recalling here that along the eastern coast of Korea there used to be exploited in summer and autumn a great amount of sardine that always presented no other types of ova but the first group. In the second group the number of ova largely fluctuated from 10,000 to 90,000 depending upon specimen.

Transparent ova, the most matured ones of the third group, were present in six specimens. Of them Nos. 5, 6, 8 and 11 were found with these ova numbering more than 40,000; particularly No. 11 had about 48,000 transparent ova, the most numerous of all under report. In Nos. 7 and 12, the transparent ova numbered about 29,000 and 24,000, respectively. However, it could not be assured whether or not the transparent ova remained there after the other ova had been discharged, or they came out of the lamella in the course of discharge. In either event, the transparent ova looked like in a stage ready to be emitted at any moment. The findings suggest that those specimens were capable of discharging, at least, 24,000 to 48,000 ova in a spawning activity.

Despite the presence of the third group, three specimens, Nos. 1-3, from the southern part of the Korean waters had no transparent ova. As yet there are enough reasons to doubt if the fish were really in a normal state for spawning. Because, in those days very few amounts of sardine eggs were spawned in that area; the third group's diameter of the specimens tended to the smaller side of the range; despite their body length being almost the same as that of the other fish, the numbers of ova in general, and especially of the second group, were found few in everyone of them. Nevertheless, one should keep it in mind that such an unusual case would occasionally take place.

Excluding a specimen, No. 8, whose ova were rather small in size, the number of the third group ova per gram of the ovary were averaged to be about 2×10^3 (Table 19). This value, though it has yet to be attested with a greater amount of data, seems to furnish a general picture of the relationship and is nearly affirmed in view of a computed volume of the matured ova. In case the second group of eggs turn to the third group all at once, the ovary of a fish such as No. 12 that abundantly had the second group ova ought to have weighed more than 40 gr. However, no information has been available so far in regard to such a heavy ovary as that. For this reason it is hardly feasible to assert that all the ova of the second group simultaneously develop into the third. The number of ova of the second group is now always integer multiple of

Table 19. Number of ova per gram in the third group that contains transparent ova (after NAKAI 1962b).

Specimen number	Number of ova of the third group per gr.
5	1.6 ($\times 10^3$)
6	1.9
7	1.8
8	2.5
11	1.9
12	2.0

the number of the third group ova, but sometimes less than one half of the latter. However, out of nine specimens that had both groups, six showed the ratio of number of ova of the second group to number of ova of the third group in almost integer multiple ranging one to four. Therefore, following to CLARK (1934), it can be inferred that the Japanese sardine would have spawned at one through four times a season. And if both the second and the third groups would normally mature within a season, there should be 40,000 to 120,000 ova discharged in that season. However, one of requisition for verifying the above formula that were modified from CLARK's (*loc. cit.*) is this. When a part of ova belonging to the first group has attained to maturity and formed the second group, the rest should cease to serve as a source of the second group. As she did not seem to have rendered as verification on this point, further effort has to be paid for solving the question. If a future study finds her formula in need of correction, the frequency and number of ova developing from the second group to the third should be brought to light, as well.

Any way the scientific ground for solving these problems can be sought nowhere else but in securing quantitative and qualitative researches, based on appropriate sampling, on physiological and ecological aspects of maturation, and formation of ova. Some of subjects that may immediately serve as a key to enlightenment of the problems are:

- (1) Morphological and physiological changes that the foricle epithelium and lamella follow after discharging.
- (2) Morphological and physiological changes in the oocytes that have not been normally discharged, and in the tissues attached to them.
- (3) Detailed studies on geographical and seasonal changes in the numbers of pregnant ova according to the ovum diameter.

Section 1-7. Feeding habit

There are a number of works on the feeding habit of the Japanese sardine. The following is a review of the subject based upon these works.

Feeding of the young fish: The postlarval sardine feed chiefly on microcopepods and nauplius; after that until the *kaeri* stage, they feed on copepods. After the *kaeri* stage the fish begin to take diatoms as well, becoming omnivorous (HONJÔ *et al.* 1957).

Feeding of the grown fish: The stomach contents usually increase in the spring months (NAKAI *et al.* 1955). The sardine seem to feed more in quantity in the evening than other times of the day.

Regarding the manner of feeding, KISHINOUE (1908) stated that the sardine appear to take their food by filtration of the water through the gill, and probably by controlling the interspace of gill rakers according to the sizes of food plankton. NAKAI (1938b) observing the innumerable serrated projections ingeniously developed

on the gill rakers, inferred that the projections, when forced to open on both sides by current pressure, would possibly serve as a filter for plankton feeding. The margins of those projections have serrations that bridge over the adjacent gill rakers forming countless microscopic triangular sieve-meshes with apertures of 0.001-0.0015 mm across. Such acute serration should be very effective for the sardine to hook on to minute organisms such as diatoms and other food plankton, while swimming with its mouth open, by controlling swimming velocity and the opening of the mouth so as to make water flow moderately in through the gill rakers.

KISHINOUE (1908) enumerated Diatoms, Flagellata, Foraminifera, Radiolaria, Tintinnopsidae and Copepoda as the major foods of the sardine. In addition, the stomach contents have included Schizopoda, Amphipoda, Decapoda, and eggs and larvae of fishes. Among copepods, *Microsetella* are especially dominant; and *Calanus* frequently occurs. When the stomach is filled up and the contents are 1/10-1/15 of the body weight, the composition usually includes Schizopoda, Copepoda or larval fishes *etc.* Whereas, when the contents are made up of Diatom or Flagellata, the weight represents 1/50-1/70 of the body.

YANKOVSKAYA (1937) stated: "The extremely full stomach is usually filled with such zooplankton as *Calanus finmarchicus*, *Pseudocalanus elongatus*, and *Paracalanus parvus*. And in June the role of zooplankton in sardine feeding greatly increases; the succeeding months produce a great many empty and partly filled stomachs." According to NAKAI (1938b), the stomach contents consist mainly of *Paracalanus parvus*, *Calanus plumchrus*, *C. finmarchicus*, *Centropages abdominalis*, Schizopoda, *Rhizosolenia setigera*, *Thalassiosira decipiens*, *Th. Clevei* and *Lauderia annulata*. He (*loc. cit.*) also pointed out that the small sized fish seem to prefer zooplankton, although they live in the sea where the large sized fish with the stomach filled with diatoms are collected.

In the stomach of sardine from the Japan Sea, YOSHIDA (1955) found such plankton species as *Chaetoceros affinis*, *Ch. danicus*, *Rhizosolenia alata*, *Rh. setigera*, *Skeletonema costatum* and *Thalassionema nitzschioides*. YAMASHITA (1955) stated that the larval sardine of 20-40 mm in body length feed chiefly on *Oncaea* sp., *Microsetella* sp., Lamellibranchia larva, Gastropoda larva and so forth, but not on Diatoms. When the fish grow over about 55 mm, the young fish start to take such microplankton as Diatom, although they also keep eating Copepoda until the body length reaches nearly to 150 mm. After that stage, the fish mainly feed on such diatoms as *Chaetoceros* sp., *Bacteriastrium* sp., and *Thalassiothrix* sp.

It would, therefore, seem that sardine feed on plankton whatever other species are also present. Thus, difference in the specific compositions quoted above would be dependent upon locality and season. Sardine, however, prey on zooplankton until they reach to *kaeri* stage and then gradually become omnivorous.

The heavy feeding in spring nearly coincides with abundance of plankton found

during that season. YOSHIDA (1955) calculated that the sardine measuring 12 cm in body length could strain plankton of about 270 individuals per litre of water. NAKAI *et al.* (1955) found that the maximal stomach contents were 12 g in a specimen measuring 23 cm in body length.

Relation of growth with feeding: The sardine would have to feed for a longer time in the first year of life to show an outstanding growth. The fish in an embayment seem to have a rapid growth. In all probability the growth rate becomes larger in spring when plankton is plentiful than in autumn or winter (NAKAI *et al.* 1955). As in the large sized sardine in the Japan Sea, the greater the stock, the smaller the growth rate (NAKAI *et al.* 1955, YAMANAKA and ITÔ 1957). In conclusion, the relative quantity of food *in situ* should be closely related to the growth.

Section 1-8. Exploitation

Fishing gear: In Japan, almost all kinds of gear are used to catch sardine, except trawls and perhaps long lines. At some localities even angling is employed. Although sardine caught by long lines have occasionally been entered in the landing statistics, the fish are supposed to be hauled by some kinds of nets carried on board long-line boats. Sardine catch by gear in 1932, 1942 and 1957 is shown in Table 20 that may show changes in relative importance of various types of gear during the last two decades.

Table 20. Sardine catch by gear in Japan, 1932, 1942 and 1957.
(Unit: 1,000 tons)

Gear	1932*	1942**	1957
Total	1,350.8	859.5	212.2
Set nets	359.7	137.3	6.3
Round hauls	566.0	483.5	123.6
Lift nets	24.3	36.8	14.2
Beach and boat seines	120.3	124.8	6.3
Drift nets	278.2	74.2	61.7
Others	2.3	2.9	0.1
Source of Data	TAKAYAMA and SAKAI (1936)	Statistics and Survey Division, MAF (1944)	Statistics and Survey Division, MAF (1958)

* Excludes minor amounts landed on a few prefectures.

** Includes minor amounts of the anchovy, *Engraulis japonica* (HOULTUYN) and the round herring, *Etrumeus micropus* (TEMMINCK & SCHLEGEL).

Fishing boats: The majority of round haulers range between 5 and 100 gross tons, drifters are less than 20 tons, and the rest usually around 10 tons. Table 21 may give a general idea about the strength of sardine fishery by major types of boat and gear.

General distribution of fishing area: Geographic distributions of the sardine population have changed remarkably depending on the population size. In the prosperous period, the Pacific coast of northeastern Honshû and Hokkaidô, and the Japan Sea coast of Korea were the main fishing grounds. After the sardine population was depleted, the fish were chiefly landed on the Japanese side of the Japan Sea. Since 1949, the fishing grounds have indicated a tendency to shift further north along that coastal region (Section 2-1).

Depth range of fishing activity: Despite changes in fishing localities, sardine fishery is operated in the coastal waters, but rarely beyond 30 nautical miles off the edge of continental shelf, at a layer usually 50 m or shallower below the surface.

Fishing season: The fishing season varies according to locality, age of the fish, gear, population size and so forth (Table 22).

Age and size compositions of catch: In the prosperous period around 1935, I- and II-age fish, 13-16 cm and 16-18 cm in body length, respectively, dominated among the catch in the Pacific waters, and III-age, over 18 cm, in the Japan Sea (Section 2-3). According to the country-wide investigations since 1949, 0-age fish consisted of about 90 percent in number or about 60 percent in weight. The investigations have shown that the *kaeri*, 4-6 cm in body length, is numerous in number, though light in weight. The length classes, 8-13 cm (0-age) and 18-21 cm (II-age or older), are dominant groups among the commercial catch (NAKAI *et al.* 1955, MURAKAMI and HAYANO 1955, YOKOTA and ASAMI 1956, YAMANAKA and ITÔ 1957). Proportions of the older fish were found to change to some extent from year to year (NAKAI *et al.* 1955, MURAKAMI and HAYANO 1955,

Table 21. Number of important sardine fishing units by gross tonnage of boats operated as of 1957.

Gear	Total	Non-powered boat	Powered boat by tonnage class								
			<3	3-5	5-10	10-20	20-30	30-50	50-100	100-200	200-500
One-boat purse-seine	427	4	—	—	2	47	25	103	242	3	1
Two-boat purse seine	1, 065	435	41	58	50	246	102	68	62	3	—
<i>Nukiri-ami</i> (a kind of purse seine)	339	255	32	35	12	4	1	—	—	—	—
Sardine drift gill net	3, 785	357	1, 365	432	667	929	28	7	—	—	—

From Statistics and Survey Division, MAF (1958)

Table 22. Fishing seasons for various stages of sardine by period, gear, and area.

Period	Type of fisheries	Covering area	Stage of fish	Fishing season
Thriving years about 1935	Round hauls	Pacific waters of southern Honshû	I- or II-age	Throughout the year
	" "	Pacific waters of Hokkaidô and northern Honshû	" "	May to December
	" "	Japan Sea off Korea	Adult	Mainly November
	Drift nets	Japan Sea off Honshû	"	Spring and early summer
	" "	Japan Sea off Coast Range*	"	Summer and autumn
Adverse years after 1945	Round hauls	Western Kyushû and its vicinity	Adult	Late December to March
	" "	"	Young	July to early December
	Drift nets	Japan Sea off western Honshû	Adult	December to March
	" "	Japan Sea off central Honshû	"	March to early June

* KAGANOVSKII (1931)

YOKOTA and ASAMI 1956, YAMANAKA and ITÔ 1957, NAKAI 1960).

Selectivity: Drifters are the most selective in regard to the size of fish, catching the adult fish in the Japan Sea and the young in Tôkyô Bay. The mesh size of drift nets has changed depending on the size of fish for the last 25 years (NAKAI 1960). The round hauls and set nets may catch almost only the fish larger than 7 cm in body length.

In addition to mesh selectivity, other indications possibly attributable to gear selection have been observed. The fish caught by one-boat purse seines that use "fishing light" have been found less mature than those caught by drifters operating in the same season and area (MURAKAMI and HAYANO 1955). For the recent adverse period the round haul fishery has shown a remarkable selectivity with regard to species. Off the western coast of Kyûshû and western Honshû facing on the Japan Sea, the catch was mainly consisted of the sardine in or before 1953; but since 1954 when the sardine stock was on the decrease, the round haulers have mainly caught the mackerels, *Scomber japonicus* HOUTTUYN and *S. tapeinocephalus* BLEEKER, and jack mackerel, *Trachurus japonicus* (TEMMINCK & SCHLEGEL). On the Pacific coast, the anchovy have become the most important species of the catch by round hauls, replacing the sardine that dominated in the years around 1935.

Efforts: Table 23 indicates numbers of trips and fishing days of the important sardine fisheries in Japan during recent years. The data pertinent to the catch by gear, number and scales of gear operated were tabulated in a previous paper (NAKAI 1952).

Management and regulation: Even though there has not been sufficient scientific evidence indicating that the sardine population as a whole was depleted by excessive

Table 23. Number of cruises and days required for sardine fisheries, 1953 and 1957.

Type of boat	1953	1957	
	Cruise	Cruise	Fishing days
One-boat purse seiners	52,411	50,705	54,200
Two-boat purse seiners	74,449	91,673	96,599
Drift netters	114,174	106,803	107,412

From Statistics and Survey Division, MAF (1954 and 1958).

exploitation, a number of regulations have been put into effect over the years since the 1890's by the central or local governments, aiming at sustaining various local stocks and at weakening competitions between different kinds of fisheries. Those regulations include the prohibition of fishing lights and fishing for postlarvae, restriction of certain types of gear, and the stipulation of closed season and area at certain localities. For instance, use of fishing lights for round hauls is prohibited in many parts of the Pacific coast; the round haul is prohibited in the coastal waters to 10 nautical miles from the continental shelf in the western part of the Japan Sea.

Transplantation: The sardine eggs or larvae have been transplanted into lagoons in Kyôto Prefecture (KURITA *et al.* 1955), but details of the results are not yet available.

Chapter 2. Outstanding phenomena in fluctuations of the population

In an attempt to elucidate essential factors responsible for, and mechanisms of the tremendous fluctuations, it is necessary to secure preliminary data and information related with vicissitudes of the fishery as well as changes pertinent to the physiological, ecological and environmental aspects such as the distribution, migration, spawning activity, growth and maturation of the present species. Here an account of the outstanding phenomena brought forth by anomalies in these conditions will be introduced together with a few considerations of the physiological and ecological changes.

Section 2-1. Fluctuation in amount of catch

According to KISHINOUE (1911), skeletons of the sardine including vomer, jaw-bones and vertebrae were unearthed from shell mounds together with hooks and hemp lines that were presumably parts of fishing nets. These shell mounds were located along the Pacific coast of Honshû at Kuwagasaki, Iwate Prefecture, Numazu, Miyagi Prefecture, and Horinouchi, Chiba Prefecture. His findings strongly suggest that some aborigine tribes in Japan had already netted the sardine for human consumption in the neolithic period.

Historical documents and literarily works contain fragmental references to a sardine fishery as early as the 900's. In a section of an imperial document called "*Engishiki*" compiled 907 by TOKIHIRA FUJIWARA, Minister of the Court, the name "*iwashi*" was registered among tributes from various parts of the country. A famous poetese, MURASAKI SHIKIBU (978-1015?) eulogized sardine as a food. According to YAMAGUCHI (1947), the sardine fishery was operated with gill nets and beach seines in the later half of the 1400's at Ine on the Japan Sea coast of western Honshû. The use of beach seine was apparently extended to the areas near Ine during the 1500's. KISHINOUE (1908), quoting from SHUSAKU TAKEI, stated that sardine were produced in large quantities from all the coastal waters of Japan and were used as food and materials for oil in 1831. It is evident that the sardine fishery at time existed throughout most of the coastal regions. The main gear used was probably primitive types of beach seines operated in inshore waters.

FUKUYO (1947) after a study of ancient documents kept in temples at Chôshi, a noted fishing port, suggested that a sardine fishery came into existence there sometime around 1545. Despite the later vicissitudes of the fishery, a type of lift net was introduced in 1644, and 115 units were in use by 1716. A kind of purse seine was introduced in 1888, and then the sardine fishery in that part seem to have shown considerable progress and improvements in the gear made in fast succession.

TAGAWA (1903) reported that sardine fisheries were operated by means of gill nets and a type of lift net at the mouth of Tôkyô Bay around 1810. It is reported that the gill nets, being more efficient than the others in use at that time, gave rise too serious disputes among the local fishermen. According to YOKOTA's account (1953) of historical developments of the sardine fisheries in Shikoku, 162 units of gear, supposedly a variety of boat seine, were operated at Uwajima in 1649. In the 1800's a number of lift and gill nets were introduced. Later, in 1887, a kind of purse seine was invented for the fishery.

UDA (1952) inferred that fluctuations in the sardine population had probably been

taking place in Japanese waters since the 1600's, on the basis of the receiving accounts of sardine kept by wholesalers at various cities. However, for the period prior to 1888, records are too fragmental to indicate a general trend of the sardine catch.

Since 1888 when the Japanese Government began to conduct systematic investigations on the fishing industry in general, the sardine fisheries have made rapid progress and

Table 24. The amount of *iwashi* catch in Japan, 1894-1904.
(Unit: 10,000 tons)

Year	Amount	Year	Amount
1894	21	1900	18
1895	20	1901	20
1896	18	1902	23
1897	14	1903	15
1898	14	1904	13
1899	18		

From Statistics and Survey Division,
MAF (1932).