Interannual Fluctuations in Recruitment and Egg Production of Japanese Sardine in the Seto Inland Sea

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Information about changes in abundance of fish stocks is important for understanding the biological traits of target species. However, reliable estimates of sardine biomass in the Seto Inland Sea were not available until the aerial survey method was used to estimate biomass. In this paper, the egg production and the recruit abundance of sardine in the Seto Inland Sea were estimated by the egg survey method and by virtual population analysis. The annual egg production in the Seto Inland Sea in 1980 was 2.09 trillion. It increased temporarily in 1983 but remained low during 1984–1992, then markedly increased in 1993 and 1994. The egg production decreased rapidly in 1998–1999. The recruits of sardine in the Seto Inland Sea in 1986 were estimated to be $2{,}271\times10^6$ in number, decreased rapidly thereafter. The recruits in 1995 increased temporarily, then markedly decreased in 1998. In the Seto Inland Sea, the recruits in number of sardine did not correlate with egg production. While, the recruits of sardine along the Pacific coast of Japan were positively correlated with the recruits in the Seto Inland Sea. Migration from the Pacific coast to the Seto Inland Sea is thought to be responsible for the recruitment in the Seto Inland Sea.

Key words: Sardine, Egg production, Recruits, Seto Inland Sea

Introduction

The Japanese sardine *Sardinops melanostictus* is an important commercial species. The sardine has shown large fluctuations in stock size within a period of several decades (Kondo *et al.*, 1976). The annual catch along the Pacific coast of Japan decreased to 3.0×10^3 metric ton in the 1960s. It recovered in the late 1960s and formed the second peak in this century in 1988. However, the catch in 1998 fell to one-thirtieth of that in 1988 (Fig. 1; Wada and Jacobson, 1998). When the stock size became smaller, their distribution area was found to become rather limited (Zenitani and Yamada, 2000).

The catch in the Seto Inland Sea decreased to 6.9×10^3 metric ton in the 1998 (Fig. 1), although the occurrence of many by-catch sardines in the Seto Inland Sea, Aki-nada and Hiuchi-nada where the sardine is not normally distributed, were observed during the period of the dramatic reduction of stock size around Japan (Ishikawa *et al.*, 1995). Many eggs of sardine were observed in the central area of the Seto Inland Sea in 1993 and 1994 (Watanabe *et al.*, 1995). These phenomena in the Seto Inland Sea may be caused by changes in the sardine's life pattern in accordance with its stock size.

This study was designed to clarify the characteristics of fluctuations of sardine biomass in the Seto Inland Sea. Data on changes in abundance of fish stocks is important information for understanding the biological traits. However, reliable estimates of the sardine biomass in the Seto Inland Sea were not available until the initiation of the aerial survey method to estimate biomass was used from 1975 to 1992 (Matsukawa and Ogawa, 1996). In this paper, the egg production and the recruit abundance of sardine in the Seto Inland Sea were estimated by the egg survey method and by virtual population analysis.

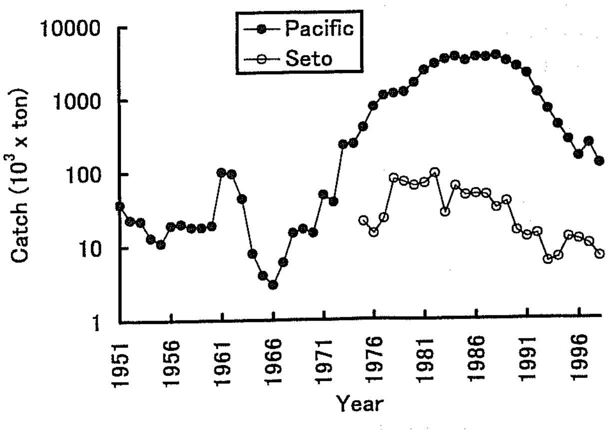

Figure 1. Inter-annual fluctuations in catch of the Japanese sardine in the Seto Inland Sea and along the Pacific coast (Wada and Jacobson, 1998) of Japan.

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Materials and Methods

Egg survey method in the Seto Inland Sea

Intensive egg surveys of coastal pelagic fishes in the Seto Inland Sea have been carried out every year since 1980 by the 12 Prefectural Fisheries Experimental Stations located on the Seto Inland Sea coast. The 20 years' data from 1980 to 1999 census statistics were analyzed in this study.

Vertical tows of a conical net with a side length of 80 cm (Nakai, 1962) or a cylindrical conical net with a side length of 65 cm at the cylindrical part and 130 cm at the conical part (Mori, 1992) were used for ichthyoplankton collection. The nets have a 45 cm inside mouth diameter and a mesh aperture of 0.33 mm. The nets were equipped with a flowmeter to standardize the filtering efficiency and the length of the tow path of the net. Each net was retrieved vertically at 1 m/s from 50 m depth or the bottom at stations shallower than 50 m. Tow samples were preserved in 5–10% seawater formalin. The number of total tow samples in a year ranged from 1,333 to 2,812 and sampling stations covered the Seto Inland Sea. Sardine eggs were sorted from tow samples. A vertical profile of the sea water temperature was recorded at each tow station. The sea surface temperature was used for calculating the egg incubation time, as the main distribution layer of sardine eggs is the sea surface layer (Konishi, 1980).

The survey area in the Seto Inland Sea was divided in the 8 sea areas and tow samples of each year were assigned to one of the sea area (Fig. 2). The average egg production ($E_{i,j}$) and variance ($Var(E_{i,j})$) standardized by the incubation time in the i-th sea area in month j was calculated as

$$E_{i,j}=D_jA_i/m_{i,j}/s\ \textstyle\sum_k(X_{i,j,k}/I_{i,j,k}),$$

$$Var(E_{i,j})=(D_j\,A_i/s)^2V_{i,j}$$

$$V_{i,j}=[\textstyle\sum_k(X_{i,j,k}/I_{i,j,k})^2-\{\sum_k(X_{i,j,k}/I_{i,j,k})\}^2/m_{i,j}]/\{m_{i,j}(m_{i,j}-1)\}$$

where, D_j is the number of days in month j, A_i is the area in square meters of the i-th sea area, $m_{i,j}$ is the number of stations in the i-th sea area in month j, and s is the survival rate during egg stage, assumed as $s=0.56$ after Watanabe (1983). $X_{i,j,k}$ is the density of eggs in the i-th sea area in month j at the k-th station and expressed as the number per square meter of sea surface. $I_{i,j,k}$ is the egg incubation time in days in the i-th sea area in month j at the k-th station, which was calculated using the Arrhenius' equation after Watanabe (1983) as

$$I_{i,j,k}=9.86\ \exp\{21900/2/(t_{i,j,k}+273)\}10^{-17}$$

where $t_{i,j,k}$ is the sea surface temperature in the i-th sea area in month j at the k-th station. The incubation time standardized egg production (E_j) and variance ($Var(E_j)$) of month j over the entire survey area was calculated as

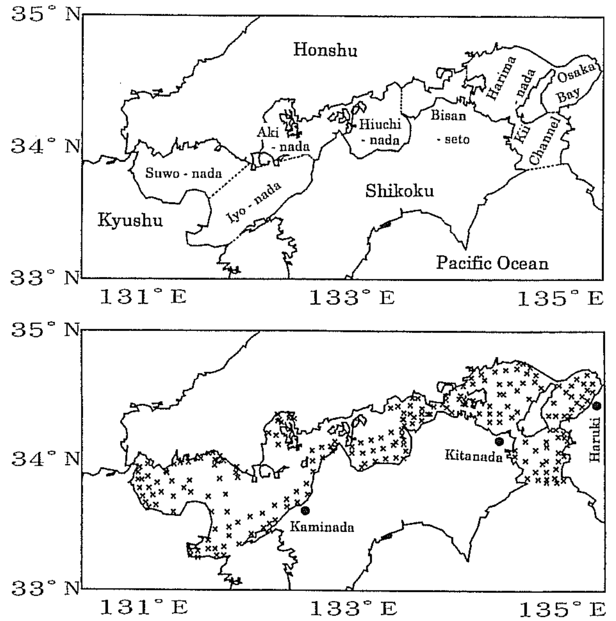

Figure 2. Map showing the 8 sea areas (top) and distribution of stations (bottom) for the spawning survey of Japanese sardine in the Seto Inland Sea.

$$E_j=\textstyle\sum_i\{E_{i,j}\}$$

and

$$Var(E_j)=\textstyle\sum_i\{Var(E_{i,j})\},$$

respectively.

The annual production of eggs (E) and variance ($Var(E)$) was calculated by summing the monthly production from January to December.

Virtual population analysis

We used virtual population analysis (VPA; Megrey, 1989) to estimate the sardine recruitment (during 1985–1992, and 1995–1998) based on catch data of July–September from Haruki, Kitanada, and Kaminada of the Osaka, Tokushima, and Ehime Prefectural Fisheries Experimental Stations, respectively (Fig. 2). The majority of sardines caught in the Seto Inland Sea are taken by small purse seine, set net, and boat seine. In order to estimate the length–frequency distributions in each period, up to 100 sardine were selected at random from each sample and the body length was measured to the nearest 0.5 cm. The length–requency distribution was converted to give the age–frequency distribution using length frequency analysis (Aizawa and Takiguchi, 1999) and the length–weight relation in 1996 (Fig. 3). The catch-at-age was estimated by the following equation (Quinn and Deriso, 1999),

$$C_{a,y}=C_yFr_{a,y}/\textstyle\sum_a(W_{a,y}Fr_{a,y})$$

where,

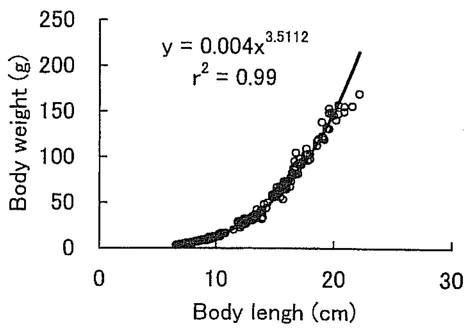

Figure 3. Relationship between body length and body weight of Japanese sardine in the Seto Inland Sea.

$C_{a,y}$; the catch at age a in year y (fish),
C_y ; the catch in year y (metric ton),
$W_{a,y}$; average weight at age a in year y (g),
$Fr_{a,y}$; the age–frequency at age a in year y.

To compute population estimates, we used a variation of Pope's (1972) approximation, which can be stated in the form

$$N_{a,y}=N_{a+1,y+1}\exp(M)+C_{a,y}\exp(M/2),$$

where,

$N_{a,y}$; the population estimate at age a (=0∼2+) in year y (fish),
M ; natural mortality coefficient.

The assumed natural mortality coefficient (M=0.4 year^{-1}) was based on a statistical relationship between longevity and mortality rates (Tanaka, 1960). The population for the 2+ age group in year $y+1$ is made up of those in the 2+ age group that survive during year y plus those at age 1 that survive during year y, which results in

$$N_{2+,y+1}=N_{2+,y}\exp(-M)-C_{2+,y}\exp(-M/2)$$
$$+N_{1,y}\exp(-M)-C_{1,y}\exp(-M/2).$$

Fishing mortality coefficient for sardine of ages 1 and 2+ were assumed equal and calculated by "linking cohorts" (Prager and MacCall, 1988). Therefore,

$$N_{2+,y}/N_{1,y}=C_{2+,y}/C_{1,y}$$

Solving for $N_{2+,y}$, $N_{1,y}$ results in

$$N_{2+,y}=C_{2+,y}/(C_{1,y}+C_{2+,y})N_{2+,y+1}\exp(M)+C_{2+,y}\exp(M/2)$$
$$N_{1,y}=C_{1,y}/(C_{1,y}+C_{2+,y})N_{2+,y+1}\exp(M)+C_{1,y}\exp(M/2).$$

Terminal population was estimated by

$$N_{a,yl}=C_{a,yl}\exp(M/2)/\{1-\exp(-F_{a,yl})\},$$

where,

$N_{a,yl}$; the population estimate at age a in terminal year yl (fish),
$F_{a,yl}$; fishing mortality coefficient at age a in terminal year yl.

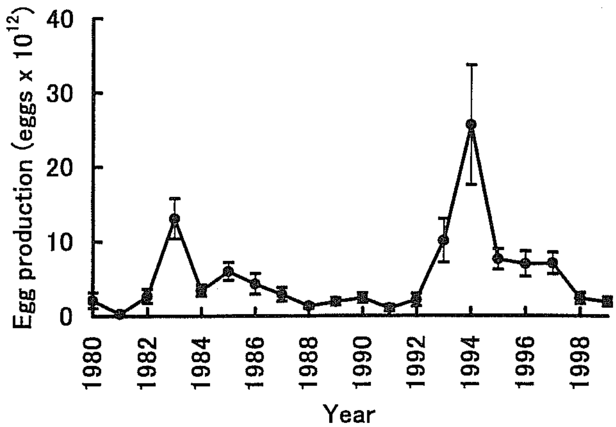

Figure 4. Egg production (±SD) of Japanese sardine in the Seto Inland Sea from 1980 to 1999.

Fishing mortality coefficient at age a in year y was estimated by

$$F_{a,y}=-\ln\{1-C_{a,y}\exp(M/2)/N_{a,y}\},$$

Fishing mortality coefficient for sardine during the terminal year in the VPA were assumed to be equal to average value of fishing mortality for 0 and 1 age over the last 2 years. $F_{2+,yl}$ was estimated by minimizing the residual of squares, $(F_{2+,yl}-F_{1,yl})^2$. The least–squares minimization was performed by the quasi–Newton method in Solver, which is *add in* software for *MS–Excel* (*Microsoft Corp.*, 1996).

Estimates of abundance become progressively less sensitive to the choice of terminal fishing mortality as the back–calculation proceeds (Pope, 1972). Thus, cohort analysis may be a fairly robust procedure for examining historical trends in recruits (Quinn and Deriso, 1999).

Results

Egg survey

The annual egg production in the Seto Inland Sea in 1980 was 2.09 trillion. It increased temporary in 1983, but remained low in 1984–1992, and rapidly increased to 25 trillion in 1994. Then, the annual egg production decreased rapidly in 1998–1999 (Fig. 4, Appendix-table 1). The 20-years' average of regional egg production in the Kii Channel, the Hiuchi-nada, and the Iyo-nada as a percentage of total production was 39.9±24.9%, 20.6±22.4%, and 23.5±18.2%, respectively. These were the three main spawning sea areas of sardine in the Seto Inland Sea in the 20 years studied. The rapid increase in 1994 largely reflected the increase in the Hiuchi-nada, the Aki-nada, and the Iyo-nada (Fig. 5).

The 20-years average of monthly egg production in April, May, and June as a percentage of annual production was 24.4±17.8%, 23.8±22.0%, and 22.4±17.6%, respec-

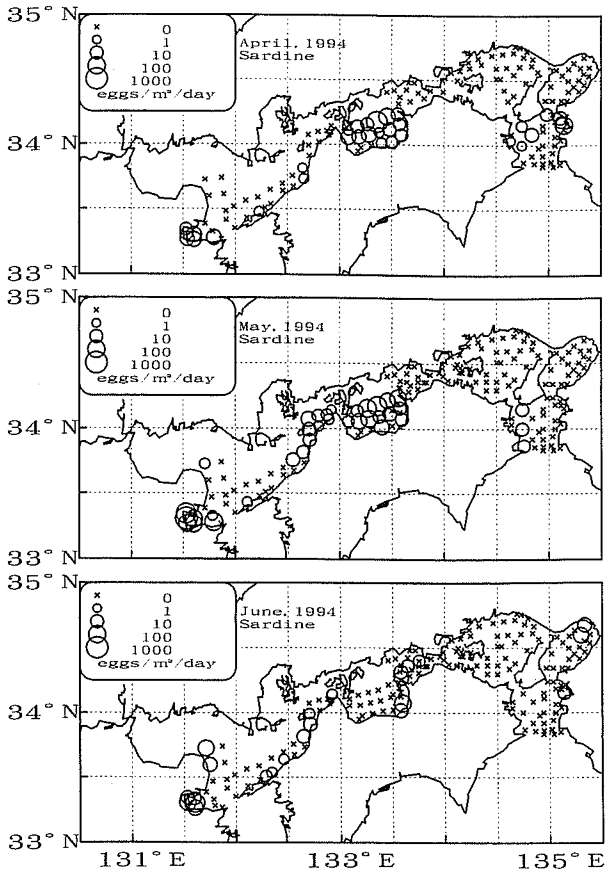

Figure 5. Monthly egg distributions in April, May, and June 1994 in the Seto Inland Sea. Open circles indicate the daily egg production per m^2, standardized for incubation time.

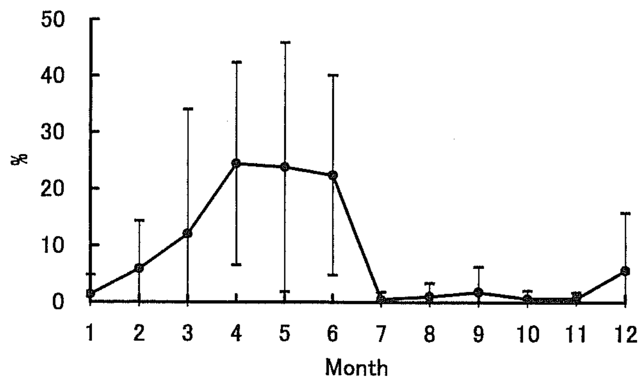

Figure 6. Twenty-years' average (±SD) of the monthly egg production as a percentage of the annual production.

tively (Fig. 6). These were the three main spawning months of sardine in the Seto Inland Sea in the 20 years studied.

Virtual population analysis

Annual changes in body length distributions of sardine in the Seto Inland Sea from 1985 to 1992, and from 1995 to 1998 are shown in Fig. 7, and reveal that the major size-classes of sardine caught by small purse seine, set net, and boat seine varied from year to year. According to Hayashi (1978), the sardine ranging from 5.0 to 13.0 cm in body length were 0 age-year-old fish. Each body length class was converted into an age class using length frequency analysis (Fig. 7).

Annual changes in the recruitment in number (0 age), total stock, and fishing mortality coefficient estimated using VPA are shown in Table 2. In the Seto Inland Sea, fishing mortality coefficient at 0 age was estimated to be higher than that at 1 to 2+ age, except 1989 and 1991. The fishery mainly caught the small sized fish. The recruitment of sardine in the Seto Inland Sea in 1985 were $1{,}506\times10^6$ fish, decreased markedly to 377×10^6 fish in 1991, then temporally increased to $1{,}838\times10^6$ fish in 1995, but markedly decreased to 114×10^6 fish in 1998. The total stock of sardine in the Seto Inland Sea in 1985 was $4{,}412\times10^6$ fish, decreased rapidly to 643×10^6 fish in 1991, then temporally recovered to $2{,}717\times10^6$ fish in 1995. Since 1996, The total stock decreased and the proportion of 1+ year old increased.

Discussion

The annual egg production of sardine along the Pacific coast of Japan experienced a remarkable increase in the 1970s, peaked in 1988, and has been declining since 1991 (Wada and Jacobson, 1998). However, the annual egg production in the Seto Inland Sea remained low during 1984–1992 (Fig. 4). In 1994, the spawning population of sardine caught in the central part of the Seto Inland Sea, a part of the population was found to have migrated from the Pacific to the western Seto Inland Sea before 1992 (Watanabe *et al.*, 1995). The increase in egg production in 1993 and 1994 may be related to the immigration of the spawning population from the Pacific coast to the Seto Inland Sea.

In the Seto Inland Sea, the recruits of sardine did not correlate with egg production (Fig. 8). While, the recruitment of sardine along the Pacific coast of Japan (X_1; Table 1; Wada and Jacobson, 1998) positively correlated with the recruitment in the Seto Inland Sea (Y_1; Fig. 9): $Y_1=282\ \ln(X_1)-1603$, ($r^2=0.62$, $P<0.020$). Immigration from the Pacific coast to the Seto Inland Sea is thought to be partly responsible for the recruitment in the Seto Inland Sea. In order to manage the sardine stock in the Seto Inland Sea, we must take the immigration from the Pacific coast into account.

In the Seto Inland Sea, the recruitment rate (Y_2) was negative correlated with year (X_2): $Y_2=0.083\exp(-0.220(X_2-1985))$, ($r^2=0.63$, $P<0.012$). Although the egg production was high during 1993 to 1997, the recruitment decreased after 1996. The egg production in the Seto Inland Sea increase during 1993–1997, however the potential for

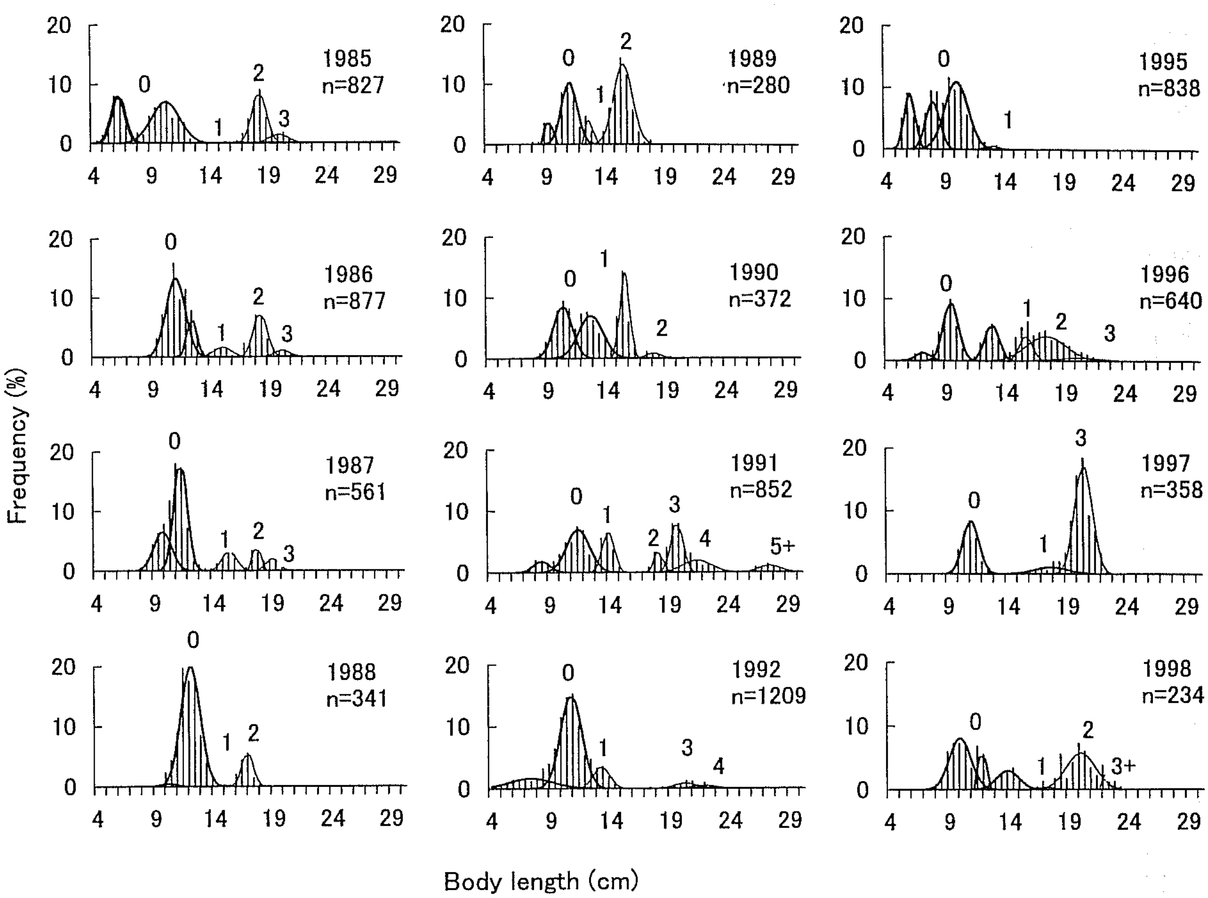

Figure 7. Frequency distribution of sardine body length in the Seto Inland Sea from 1985 to 1992, and from 1995 to 1998. *n* indicates number of the individuals measured. Curves in each panel show the theoretical length frequencies (normal distributions) and age in years, respectively.

Table 1. Recruits, total stock and fishing mortality coefficient for Japanese sardine in the Seto Inland Sea.

Year	Recruits in the Seto Inland Sea (A): (fish×10⁶)	Total stock in the Seto Inland Sea (fish×10⁶)	Fishing mortality coefficient in the Seto Inland Sea: 0 year old	Fishing mortality coefficient in the Seto Inland Sea: 1 to 2+ years old	Egg production in the Seto Inland Sea (B): (eggs×10¹²)	Recruitment rate (A/B×100): (%)	Recruits along the Pacific coast*1 (fish×10⁶)
1985	1506	4412	0.89	0.16	5.95	0.025	249815
1986	2271	4339	0.52	0.23	4.27	0.053	264435
1987	1490	3495	3.02	0.00	2.87	0.052	143803
1988	1153	2272	2.35	0.84	1.30	0.089	14263
1989	1050	1755	0.54	2.35	1.90	0.055	12392
1990	487	943	1.49	0.46	2.38	0.020	3989
1991	377	643	0.20	0.48	1.02	0.037	3321
1992	929	1248	0.84	0.47	2.09	0.045	20591
1993	—	—	—	—	10.03	—	14506
1994	—	—	—	—	25.65	—	15767
1995	1838	2717	2.11	0.04	7.57	0.024	13053
1996	198	916	1.07	0.21	6.96	0.003	—
1997	163	600	0.21	0.20	7.05	0.002	—
1998	114	443	0.64	0.20	2.36	0.005	—

*1 After Wada and Jacobson (1998).

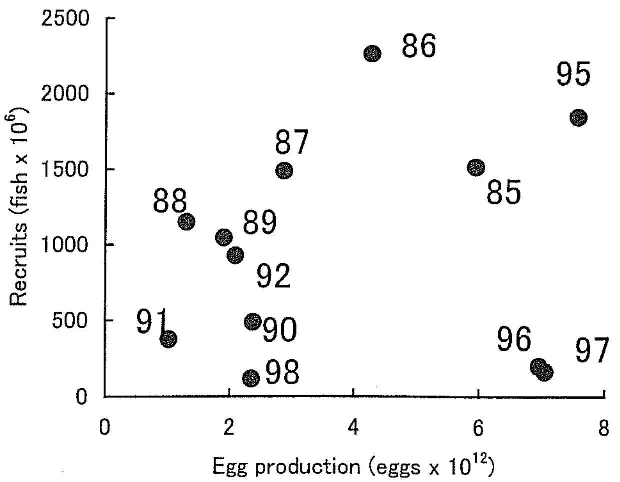

Figure 8. Correlation of recruits with the egg production in the Seto Inland Sea.

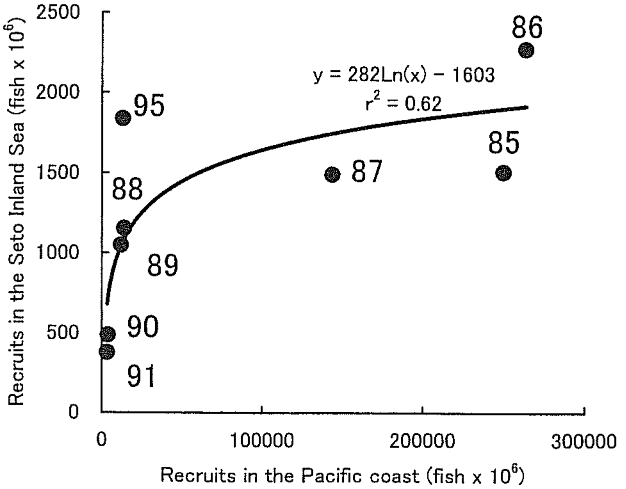

Figure 9. Regression of recruits in the Seto Inland Sea on the recruits along the Pacific coast of Japan.

recruitment success in the Seto Inland Sea was low. Shoji *et al.* (1999b) suggested that there were two spawning seasons in the Hiuchi-nada, central part of the Seto Inland Sea, from May to June and from November to January, which correspond to the warming and cooling seasons. However, the quantitative survey on the occurrence of eggs indicates that the main spawning season was during April–June (Fig. 6). Funakoshi (1990) pointed out that the absence of predatory plankton and competitive pelagic fish larvae during the main spawning period (February–March) of sardine along the Pacific coast of Japan was greatly advantageous to the recruitment success. In the Seto Inland Sea during the main spawning period of the sardine (April–June), the presence of predatory fish larvae (Spanish mackerel; Kishida, 1988; Shoji *et al.*, 1999a) and competitive pelagic fish larvae (anchovy; Mito, 1964; Ishikawa *et al.*, 1995) may be disadvantageous to the recruitment success of sardine.

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References

Aizawa, Y. and N. Takiguchi (1999) Consideration of the methods for estimating the age-composition from the length frequency data with MS-Excel. Bull. Jpn. Soc. Fish. Oceanogr., **63**, 205–214.

Funakoshi, S. (1990) Studies on the reproduction mechanisms of Japanese anchovy *Engraulis japonica* (Houttuyn) in Enshu nada, Ise and Mikawa Bays. Bull. Aichi Fish. Res. Inst., **10**, 1–208. (in Japanese with English abstract)

Hayashi, Y. (1978) On the catches and fishing ground of sardine purse seining in Osaka bay. Bull. Osaka Pref. Fish. Expl. Stat., **5**, 136–160. (in Japanese)

Ishikawa, S., H. Hashimoto and K. Gushima (1995) Incidental catch of sardines by the seine fishery in Hiroshima Bay. Fish. Sci., **61**, 523–524.

Kishida, T. (1988) Vertical and horizontal distribution of eggs and larvae of Japanese Spanish mackerel in the central waters of the Seto Inland Sea. Nippon Suisan Gakkaishi, **54**, 1–8. (in Japanese with English abstract)

Kondo, K., Y. Hori and K. Hiramoto (1976) Life pattern of the Japanese sardine, *Sardinops melanosticta*, (Temminck et Schlegel) and its practical procedure of marine resources researches of the stock (2nd Edition). In Fish. Res. Ser. 30, Jap. Resour. Conserv. Ass., Tokyo, 68 pp. (in Japanese)

Konishi, Y. (1980) Vertical distribution of eggs and larvae of sardine, *Sardinops melanosticta* (T. et S.), and round herring, *Etrumeus micropus* (T. et S.). Bull. Nansei Reg. Fish. Res. Lab., **12**, 93–103. (in Japanese with English abstract)

Matsukawa, Y. and Y. Ogawa (1996) Aerial observation of Japanese sardine schools and estimation of its stock and exploitation rate in Seto Inland Sea. Bull. Natl. Res. Inst. Fish. Sci., **8**, 1–14. (in Japanese with English abstract)

Megrey, B. A. (1989) Review and comparison of age-structured stock assessment models from theoretical and applied points of view. Am. Fish. Soc. Symp., **6**, 8–48.

Microsoft Corporation (1996) Microsoft Excel for Windows 95. Microsoft Corp., Singapore, 228 pp.

Mito, S. (1964) Studies on the fish eggs and larvae found in Inland Sea – I. abundance and distribution. Nankai Reg. Fish. Res. Lab., **C2**, 1–24. (in Japanese with English abstract)

Mori, K. (1992) Vertical tow net with a small mouth opening. In. Manual for pelagic fish egg and larval survey, ed. S. Kume, National Research Institute of Fisheries Science, Tokyo, 8–14. (in Japanese)

Nakai, Z. (1962) Apparatus for collecting macroplankton in the spawning surveys of *iwashi* (sardine, anchovy, and round herring) and others. Bull. Tokai Reg. Fish. Res. Lab., **9**, 221–237.

Pope, J. G. (1972) An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northwest Alt. Fish. Res. Bull., **9**, 65–74.

Prager, M. H. and A. D. MacCall (1988) Sensitivities and variances of virtual population analysis as applied to the mackerel, *Scomber japonicus*. Can. J. Fish. Aquat. Sci., **45**, 539–547.

Quinn II, T. J. and R. B. Deriso (1999) Quantitative fish dynamics. Oxford University Press, Oxford, 542 pp.

Shoji, J., T. Maehara and M. Tanaka (1999a) Short-term occurrence and rapid growth of Spanish mackerel larvae in the central waters of the Seto Inland Sea, Japan. Fish. Sci., **65**, 68–72.

Shoji, J., T. Maehara and M. Tanaka (1999b) Two spawning seasons of the Japanese sardine in Hiuchi-nada, the central Seto Inland Sea. Fish. Sci., **65**, 784–785.

Tanaka, S. (1960) Studies on the dynamics and the management of fish populations. Bull. Tokai Reg. Fish. Res. Lab., **28**, 1–200. (in Japanese with English abstract)

Wada, T. and L. D. Jacobson (1998) Regimes and stock - recruitment relationships in Japanese sardine (*Sardinops melanostictus*), 1951 – 1995. Can. J. Fish. Aquat. Sci., **55**, 2455–2463.

Watanabe, T. (1983) Spawning survey method. In. Population dynamics of fishery resources. ed. T. Ishii, Koseisha-Koseikaku, Tokyo, 9–29. (in Japanese)

Watanabe, A., K. Shiota and Y. Nishiyama (1995) Analysis of fluctuations in sardine's catch in Hiuchi-nada and Iyo-nada. Fisheries Biology and Oceanography in the South–Western waters of Japan, **11**, 59–64. (in Japanese)

Zenitani, H. and S. Yamada (2000) The relation between spawning area and biomass of Japanese pilchard, *Sardinops melanostictus*, along the Pacific coast of Japan. Fish. Bull., **98**, 842–848.

Appendix-table 1. Annual egg production (E) in each area of the Seto Inland Sea.

Year	Suwo-nada				Iyo-nada				Aki-nada			
	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two
1980	0.00	0.0000	—	322	0.15	0.0234	—	319	0.00	0.0000	—	133
1981	0.08	0.0017	55.4	484	0.13	0.0057	—	372	0.00	0.0000	—	184
1982	0.24	0.0230	63.6	520	0.77	0.1898	56.8	341	0.00	0.0000	—	162
1983	1.43	0.3756	42.7	497	0.00	0.0000	—	348	0.00	0.0000	—	170
1984	0.07	0.0009	44.5	482	0.61	0.1080	—	379	0.00	0.0000	—	176
1985	0.00	0.0000	—	144	1.18	0.2456	42.1	292	0.00	0.0000	—	177
1986	0.00	0.0000	—	108	0.58	0.0454	36.9	340	0.02	0.0004	100.0	178
1987	0.00	0.0000	—	131	0.86	0.3284	66.7	350	0.00	0.0000	—	191
1988	0.00	0.0000	—	144	0.34	0.0309	51.8	317	0.23	0.0209	61.9	171
1989	0.05	0.0026	100.0	144	0.83	0.0853	35.4	312	0.00	0.0000	—	141
1990	0.00	0.0000	—	143	1.25	0.2837	42.7	363	0.00	0.0000	—	161
1991	—	—	—	0	0.18	0.0049	39.4	345	0.00	0.0000	—	157
1992	—	—	—	0	0.12	0.0036	48.9	371	0.00	0.0000	—	49
1993	—	—	—	0	3.56	3.9223	55.6	360	0.00	0.0000	—	21
1994	—	—	—	0	16.51	56.6272	45.6	332	2.18	0.3334	26.5	18
1995	—	—	—	0	0.45	0.0299	38.3	208	0.05	0.0020	100.0	27
1996	—	—	—	0	0.10	0.0051	74.2	120	0.00	0.0000	—	24
1997	—	—	—	0	0.77	0.1030	41.7	280	0.26	0.0699	100.0	24
1998	0.00	0.0000	—	348	0.79	0.0211	18.4	354	0.00	0.0000	—	80
1999	0.00	0.0000	—	348	0.15	0.0032	38.5	422	0.00	0.0000	—	80

Appendix-table 1. Annual egg production (E) in each area of the Seto Inland Sea (continued).

Year	Hiuchi-nada				Bisan-seto				Harima-nada			
	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two
1980	0.00	0.0000	—	187	0.00	0.0000	—	332	0.00	0.0000	—	344
1981	0.00	0.0000	—	225	0.00	0.0000	—	484	0.00	0.0000	—	335
1982	0.00	0.0000	—	264	0.00	0.0000	—	481	0.00	0.0000	—	358
1983	0.03	0.0004	—	222	0.00	0.0000	—	480	0.00	0.0000	—	362
1984	0.00	0.0000	—	260	0.00	0.0000	—	490	0.00	0.0000	—	356
1985	0.02	0.0002	71.0	186	0.00	0.0000	—	450	0.00	0.0000	—	354
1986	1.10	0.7474	78.7	207	0.00	0.0000	—	350	0.02	0.0004	100.0	322
1987	0.06	0.0006	40.3	238	0.03	0.0003	65.4	458	0.02	0.0005	100.0	363
1988	0.10	0.0040	66.4	234	0.01	0.0000	69.8	459	0.00	0.0000	—	364
1989	0.00	0.0000	—	228	0.13	0.0161	100.0	459	0.00	0.0000	—	394
1990	0.38	0.0776	73.4	270	0.00	0.0000	—	483	0.00	0.0000	—	393
1991	0.65	0.1853	65.7	232	0.00	0.0000	—	447	0.00	0.0000	—	378
1992	1.01	0.2575	50.2	230	0.10	0.0109	100.0	287	0.04	0.0019	100.0	306
1993	5.61	4.5295	37.9	134	0.02	0.0003	72.6	257	0.00	0.0000	—	315
1994	5.79	8.5110	50.3	124	0.22	0.0058	34.9	260	0.00	0.0000	—	312
1995	3.17	0.3355	18.2	162	0.26	0.0266	61.8	236	0.43	0.1599	93.2	286
1996	3.02	0.8419	30.3	176	0.20	0.0046	34.1	276	0.32	0.0141	37.5	318
1997	3.62	1.1101	29.1	168	0.87	0.0865	33.6	294	1.28	0.7224	66.6	327
1998	0.18	0.0337	100.0	48	0.25	0.0292	68.2	367	0.10	0.0056	74.0	372
1999	0.49	0.0760	56.0	36	0.11	0.0019	39.2	310	0.18	0.0116	58.8	342

Appendix-table 1. Annual egg production (E) in each area of the Seto Inland Sea (continued).

Year	Osaka Bay				Kii Channel				Total			
	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two	E (eggs×10^{12})	$Var(E)$ (eggs×10^{24})	CV (%)	No. of net two
1980	0.00	0.0000	—	160	1.94	1.0778	53.5	378	2.09	1.1012	50.1	2175
1981	0.00	0.0000	—	214	0.07	0.0023	70.8	422	0.27	0.0098	36.2	2720
1982	0.04	0.0008	80.3	237	1.63	0.6570	49.8	398	2.67	0.8706	34.9	2761
1983	0.00	0.0000	—	236	11.58	6.8255	22.6	429	13.04	7.2015	20.6	2744
1984	1.37	0.3171	41.0	240	1.36	0.0900	22.0	429	3.41	0.5160	21.0	2812
1985	2.89	0.9468	33.6	240	1.85	0.2358	26.2	440	5.95	1.4283	20.1	2283
1986	1.93	0.9417	50.4	238	0.63	0.1250	56.0	422	4.27	1.8603	31.9	2165
1987	0.04	0.0012	100.0	238	1.86	0.4951	37.8	427	2.87	0.8262	31.7	2396
1988	0.00	0.0000	—	180	0.62	0.0432	33.7	423	1.30	0.0992	24.3	2292
1989	0.00	0.0000	—	240	0.89	0.1379	41.5	432	1.90	0.2419	25.9	2350
1990	0.07	0.0020	61.4	240	0.68	0.0646	37.5	446	2.38	0.4280	27.5	2499
1991	0.00	0.0000	—	239	0.19	0.0059	40.9	444	1.02	0.1961	43.4	2242
1992	0.02	0.0002	100.0	160	0.79	0.4280	82.7	339	2.09	0.7020	40.1	1742
1993	0.00	0.0000	—	160	0.84	0.0843	34.6	308	10.03	8.5363	29.1	1555
1994	0.27	0.0294	64.2	120	0.68	0.0812	42.0	291	25.65	65.5880	31.6	1457
1995	0.00	0.0000	—	107	3.21	1.3334	36.0	320	7.57	1.8874	18.1	1346
1996	0.00	0.0000	—	119	3.33	1.9944	42.5	300	6.96	2.8601	24.3	1333
1997	0.00	0.0000	—	120	0.25	0.0175	52.8	246	7.05	2.1093	20.6	1459
1998	0.00	0.0000	—	120	1.03	0.4277	63.4	260	2.36	0.5174	30.5	1949
1999	0.00	0.0000	—	120	1.00	0.2728	52.1	329	1.93	0.3655	31.2	1987

Recruitment and Egg Production of Japanese Sardine in the Seto Inland Sea

瀬戸内海におけるマイワシの新規加入量と産卵量の経年変動

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産卵調査による産卵量およびコホート解析による新規加入量をもとに瀬戸内海におけるマイワシ資源変動の特性を検討した.

瀬戸内海における年間産卵量は1983年に一時的に13兆粒に増加したものの1984～1992年においては1～6兆粒と低水準であった. 1993年に10兆粒に急増し，1994年には26兆粒まで増加した．しかし，1995年以降漸減し，1999年には2兆粒となった．また，新規加入量は1986～1991年に漸減した. 1994年に一時増加したが，1996年以降激減した．瀬戸内海におけるマイワシの産卵量と新規加入量の間には有意な相関関係が見いだせなかった．一方，太平洋側での新規加入量と瀬戸内海での新規加入量の間には正の相関関係があった．瀬戸内海における新規加入量の多寡は太平洋からの移入量に規定される可能性が示唆された.

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