# Environmental Constraints on the Sand Lance Population in the Eastern Seto Inland Sea

H. NAKATA*, S. KIMURA*, M. J. KISHI* and T. FUJIWARA†
**Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai, Nakano, Tokyo, 164 Japan*
*†Government Industrial Research Institute, Chugoku, Hiro-suehiro, Kure, Hiroshima, 737-01 Japan*

**In this paper, focusing on the recruitment processes, we synthesize the results of our recent analytical and numerical studies on the population ecology of the Japanese sand lance in the eastern part of the Seto Inland Sea. Among physical processes, the wind-induced current has a significant effect on the transport and distribution of the larvae. Prey-predator interactions, compeition for the specific habitats, and other ecological processes could affect the recruitment. In addition to the year to year variability of the larval hatching and apparent survival rates, some recent trends of the variation in the larval population are also discussed.**

The Japanese sand lance *Ammodytes personatus* Girard is one of the commercially important fish in the coastal waters of Japan. In the eastern part of the Seto Inland Sea (Bisan Strait, Sea of Harima and Osaka Bay, Fig.1), its annual catch amounts to approximately 39,000 tons (average from 1974-1984), which accounts for about 22% of the total fisheries production in this area. It is also known that the catch varies considerably due to the recruitment success or failure of the 0-age fish. Thus the environmental factors related to the survival of the sand lance larvae have become a matter of great importance for catch forecasting.

In this paper, focusing on the recruitment processes of the sand lance population in the eastern Seto Inland Sea, we synthesize the results of our recent analytical and numerical studies. Some recent trends of the variation in the larval population are also discussed.

**Environmental factors related to the sand lance recruitment**

The main spawning grounds of the sand lance in the eastern Seto Inland Sea are located in the central Bisan Strait and Shikano-Se in the northeast of the Sea of Harima (Fig.1). The main spawning period is in winter (early December-early January). The eggs adhere to bottom sand for about 25 days, then hatch out and spend about 2 month pelagic period. The 0-age fish (young) become a target of the fishery from late March to late June. After this they estivate in the bottom sand until early December, when they are matured and start to spawn (Hamada, 1985).

Various environmental factors including natural and human impacts related to the recruitment of the sand lance population are summarized in Fig.2. Since strong westerly wind prevails during the main spawning period, wind-induced current has a significant effect on the transport and distribution of the pelagic larvae. In addition, some oceanic conditions such as water temperature and salinity, and ecological processes including prey-predator interactions could affect the larval growth and recruitment; however there is so far little quantitative information about them.

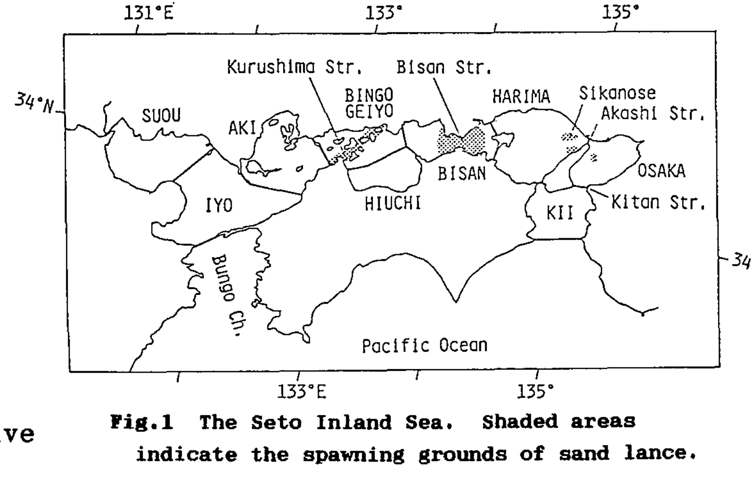


**Fig.1** The Seto Inland Sea. Shaded areas indicate the spawning grounds of sand lance.

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Besides the natural impacts mentioned above, the fishery itself could have a serious impact upon the population. In fact, the apparent increase in the sand lance catch during 1960s was partly due to the development of fishing gears, corresponding with a growing demand (Hamada, 1985). Further, the habitats during both spawning and estivation periods are confined to specific sandy banks. This may possibly determine the carrying capacity of the population; therefore, conservation of the sandy banks against human impacts is essential to the resource management of sand lance.

**Analytical and numerical approaches to the recruitment dynamics**

*Wind-induced larval transport*

Hamada(1966) first reported that there is a positive correlation between the frequency of the strong westerly wind after the peak spawning and the catch of 0-age fish in the Sea of Harima. Nakata(1988) further showed that wind-induced eastward transport of the larvae from the Bisan Strait contributes to the catch increase in the Sea of Harima.

Fujiwara et al. (1990) have recently provided a quantitative basis for the discussion. According to their estimates (averages from 1981-1986) about 65% of the hatched larvae in the eastern Seto Inland Sea originate from the Bisan Strait, and about 86% of the hatched larvae of the Bisan Strait origin are transported into the Sea of Harima from January-February. This transport rate is consistent with the wind-induced eastward volume transport (average 4,000$m^3$/s) estimated by Fujiwara and Higo (1986). The above results support the hypothesis previously presented for the catch forecast, and give a mechanistic basis for it.

*Larval population dynamics*

Fig.3 shows the year to year variations in the number of sand lance larvae collected in February. It is noticeable that large year classes in the Bisan Strait occurred at intervals of 5-6 years. In spite of the appearance of a large 1989 year class, there is a significant decline in the larval density in the Bisan Strait. Some peaks appearing in the Sea of Harima coincide with those in the Bisan Strait (1973, 1989, etc.). The larval density in Osaka Bay (not shown) has rapidly increased since 1985.

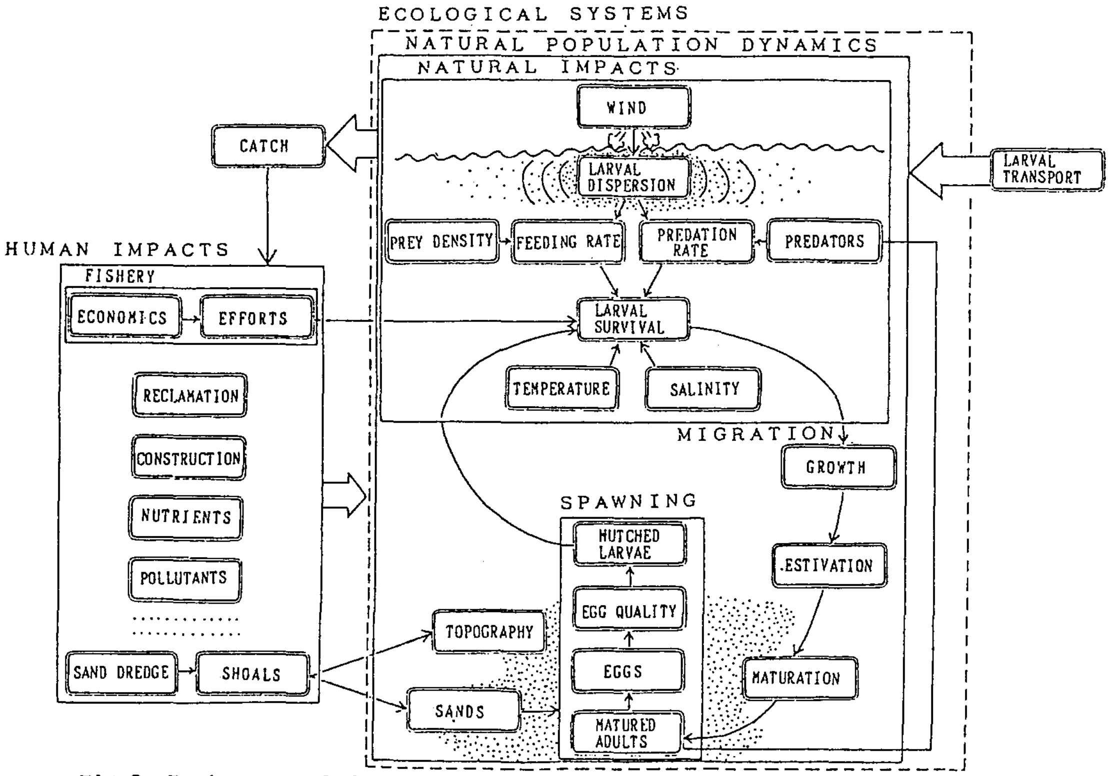


**Fig.2** Environmental factors related to the recruitment of the sand lance population in the eastern Seto Inland Sea.

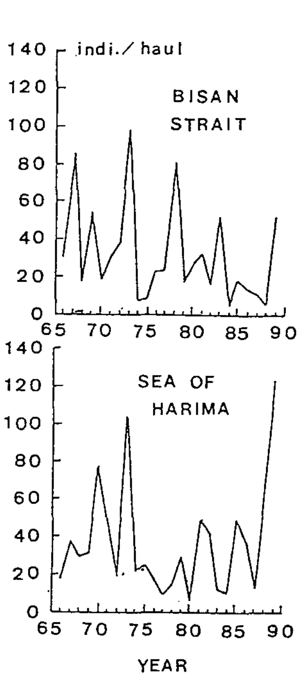


**Fig.3 Year to year variation in the abundance of sand lance larvae collected in February.**

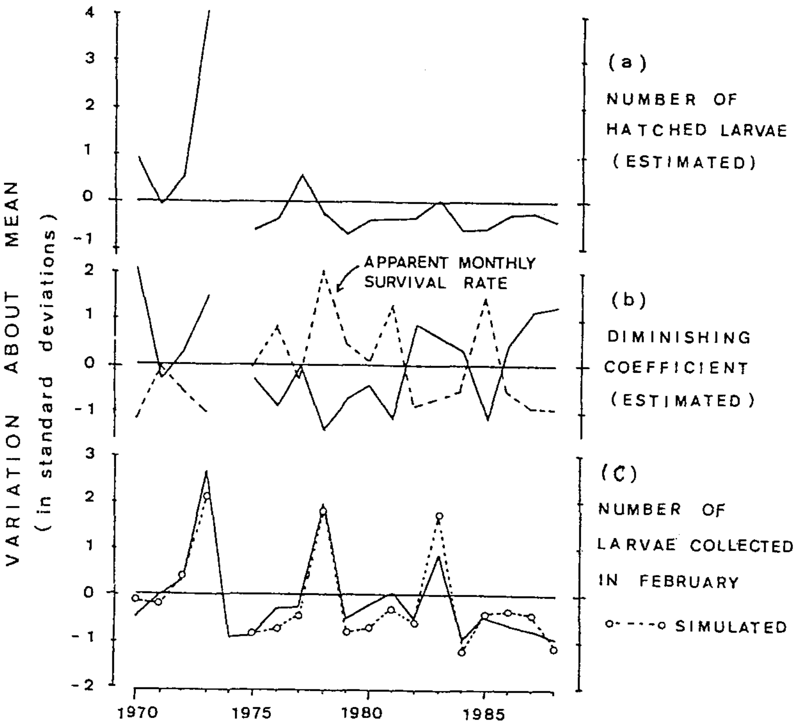


**Fig.4 Normarized values of (a) total number of the larvae hatched, (b) diminishing coefficient of the survival rate function (apparent monthly survival rate), and (c) larval density observed in February in the Bisan Strait.**

Based on the averages of the larval density from 1981-1986, Fujiwara et al. (1990) proposed an analytical method for determining biological parameters such as hatching intensity and survival rate of the larvae. They considered the eastern Seto Inland Sea as an ecologically semi-closed area for the sand lance population, and analyzed the time change of the larval density and age composition in this area from January to February. The total number of hatched larvae estimated by this method is $2.76 \times 10^{12}$ with maximal hatching intensity of $6.86 \times 10^{10}$ ind./day. The survival rate function is, on the other hand, given as the exponential function with diminishing coefficient of 0.071/day, showing an apparent monthly survival rate is 0.119.

Using the same method as Fujiwara et al. (1990), we look at the interannual changes of the number of hatched larvae and the diminishing coefficient of the larval survival function in the Bisan Strait from 1966 to 1988 (except for 1969 and 1974 because of incomplete data set). The results of the analysis are shown with the normalized values in Fig.4. Extremely high hatching intensity, against high diminishing coefficient, led to largest 1973 year class, while higher abundance of hatched larvae did not result in large year classes in 1970 and 1977 due to poor conditions of survival (and/or transport loss). For 1978, the total number of hatched larvae was below average, but large year class resulted from some favorable survival conditions. It is also noted that higher hatching intensity often corresponds to higher diminishing coefficient; this may suggest a density dependent mortality. The larval density simulated (Fig.4c) by using the hatching intensity and survival rate functions successfully accounts for the observed data (r=0.93).

The diminishing coefficient (apparent survival rate) shown in Fig.4 includes advective loss due to wind-induced larval transport from the Bisan Strait to the Sea of Harima. We therefore plotted the deviations from the mean in a wind index-diminishing coefficient diagram (Fig.5). The wind index (WI) is an appropriate indicator of the westerly monsoon in winter (high value of WI correlates with strong westerly wind)(Fujiwara, 1990). There is apparently no correlation between variations of the diminishing coefficient and WI. This could be probably due to some density dependent processes (1970, 1972, 1973 and 1983) and favorable survival conditions despite the wind-induced transport loss (1967, 1978, 1981 and 1985), which make the correlation unclear.

It should be noted in Fig.5 that high diminishing coefficients obtained in 1987 and 1988 were not resulted from wind-induced transport loss; some other unknown factors could cause poor conditions for larval survival in addition to the low hatching intensity (Fig.4) in recent years.

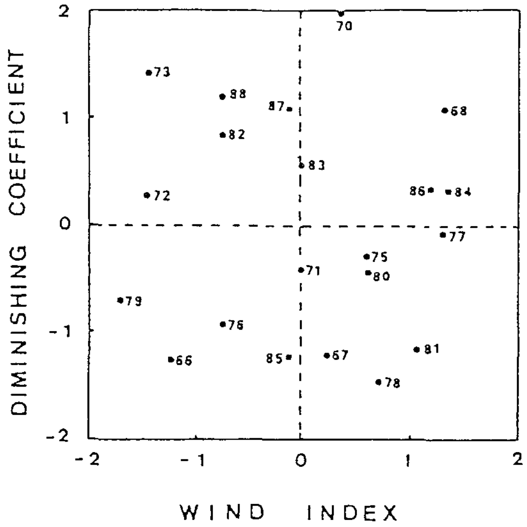


Fig.5 Relation between the variations (in SD) in diminishing coefficient and wind index (Jan.-Feb.). Numerals indicate the calendar years.

*Ecosystem modelling*

A biomass-based ecosystem model of the sand lance population in the eastern Seto Inland Sea has been developed by Kishi et al. (1990). The following six state variables were taken into the model: eggs, larvae, young, one-year old and two(or more)-year old adults of the sand lance, and zooplankton. The transition between stages of the sand lance is given according to calendar date, and the zooplankton biomass is assumed to be a function of water temperature. The emphasis is placed upon a numerical balance of the model parameters to maintain a steady population rather than a numerical simulation of actual dynamics. Physical processes such as wind-induced larval transport has not been included in the model.

According to the estimate based on this model, the mortality rate of estivating young could be higher than that previously expected. This suggests the importance of the ecological study on the estivating young to detect the factors crucial to the mortality during the estivation period. In addition, the sensitivity analysis of the model shows that the biomass of zooplankton could play an important role in the variation of the sand lance abundance. In this model, the zooplankton functions as a predator against the sand lance larvae besides functioning as its prey; this complicate the interpretation of the results. Further elaboration of a sophisticated ecosystem model which takes actual prey-predator interactions into account is necessary.

**Concluding remarks**

As described above, recent analytical studies have quantified wind-induced transport, hatching intensity, and apparent survival rate of the larval population. In the Bisan Strait, high hatching intensity did not always lead to larval abundance (Fig.4). The transport loss due to the westerly wind was not the only factor determining the apparent survival rate (Fig.5); there are still uncertainties in the mechanism of the variability of the survival rate. Due to low hatching intensity and relatively high diminishing coefficient (probably high mortality), the larval abundance in the Bisan Strait has declined in recent years (Fig.4). The subsequent catch of 0-age fish also shows a decreasing trend (not shown). Human activities such as sand dredging in the spawning grounds could affect the larval hatching and the survival rate during post-larval period. In addition, among physical properties salinity shows positive deviations from 1984-1988 (not shown). Further investigation is required on the causal factors of recent reduction in the larval density in the Bisan Strait.

On the other hand, the wind-induced transport of the larvae originating from the Bisan Strait contributes to the larval abundance in the Sea of Harima. Fig.6 further shows the relation between the larval abundance and the subsequent catch of 0-age fish. It is evident in the Sea of Harima that the larval abundance in February is closely correlated with the catch during 1960s and 1970s. The corrrelation coefficient is 0.78 except for the data from 1973, when the larval hatching was extremely large. However, during 1980s especially from 1985 when the larval density in Osaka Bay rapidly increased, the catch in the Sea of Harima seemed to decline in spite of rather high larval density. The catches of 0-age fish in the Bisan Strait (not shown) were rather small when the larval densities in February were over 50 (ind./haul). These imply existence of density dependent processes in the post-larval period. We have also referred to a density dependent mortality during the larval period (Fig.4).

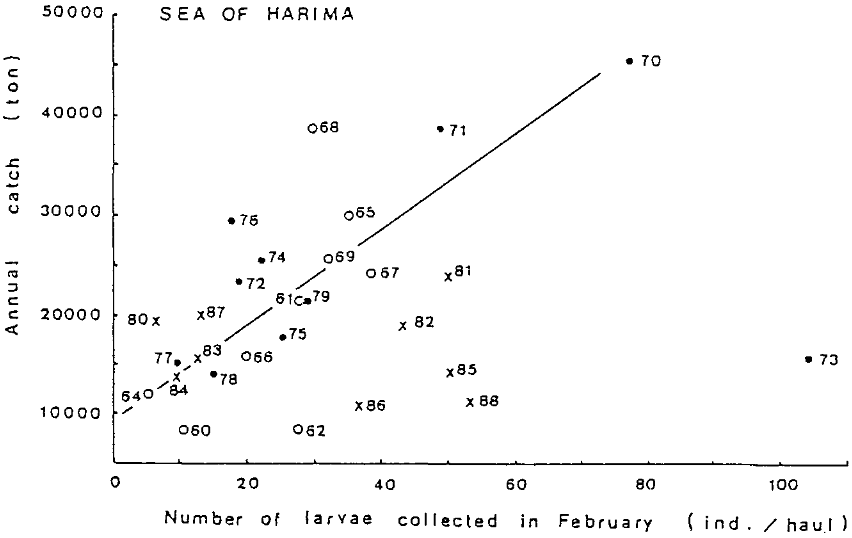


Fig.6 Relation between larval abundance in February and the subsequent catch of the 0-age fish in the Sea of Harima. The data from 1960s, 1970s and 1980s are plotted with dots, open circles and crosses, respectively.

These density dependent processes possibly include competition for the prey and the habitats (i.e. sand banks). The larval mortality due to cannibalism (adult predation on the larvae) is also a possible mechanism (Hamada,1985). A more detailed field survey of the above ecological problems and ecosystem modelling of the prey-predator interactions would be enlightening.

The data obtained from long-term monitoring by the Hyogo and Okayama Prefectural Fisheries Experimental Stations enable us to carry out the analyses presented above. We would emphasize that the continuous monitoring, combined with well-designed experiments (including numerical studies), holds the key to unveiling the dynamic behaviours of the larval population in recent years.

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