Fluctuations in Year-class Strength of Japanese Spanish Mackerel in the Central Seto Inland Sea

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The abundance of larval and juvenile Japanese Spanish mackerel Scomberomorus niphonius in Hiuchi-nada, the central part of the Seto Inland Sea, and its adjacent waters, was investigated by net sampling from 1983 to 1988. The relationships between larval/juvenile abundance, CPUE of subsequent 1-year-old fish and oceanographic conditions were examined. There was a significant, positive correlation between the abundance of juveniles and the CPUE of subsequent 1-year-old fish, although no such correlation occurred between postlarval abundance and either the abundance of juveniles or the CPUE of subsequent 1-year-old fish. This indicates that significant mortality occurs throughout the larval stages and that year-class strength seems essentially determined by the juvenile stage. A strong year-class seems to occur when the boundary between stratified Hiuchi-nada, the spawning area, and vertically well mixed adjacent regions becomes obscure in June.

The Japanese Spanish mackerel Scomberomorus niphonius is one of the important fisheries resources in the Seto Inland Sea. According to catch statistics compiled by the Ministry of Agriculture, Forestry and Fisheries, annual catches of this fish in the Seto Inland Sea have fluctuated between 1000 and 2000 t from the 1940's to the early 1970's, although they began to increase from the late 1970's, reaching levels between 4000-6000 t in the 1980's.

Since the work of Hjort, attention has been paid to high mortality during early life stages, as a cause of resource fluctuation in marine fishes. Although the processes of this high mortality may be generally complex, density-independent processes, e.g. lack of food from destruction of the stable stratified layer, transportation to inopportune areas, and so on, seem to be important factors during the pelagic, planktonic phase of fishes.

This paper studies the abundance of larval and juvenile Japanese Spanish mackerel, the relative abundance of 1-year-old fish, and oceanographic conditions in Hiuchi-nada, the central part of the Seto Inland Sea, and investigates the mechanisms of fluctuations in year-class abundance.

Materials and Methods

Survey Area and Period

Sampling surveys were undertaken three times a year (mid-May, mid-June, early-July) from 1983–1988 inclusive, on the Nansei National Fisheries Research Institute RV Shirafuji-maru (138 t). Twenty-five stations were sampled, throughout Hiuchi-nada, Geiyo Archipelago and Aki-nada (Fig. 1).

In the central and western waters of the Seto Inland Sea, spawning of Japanese Spanish mackerel begins in Hiuchi-nada, the highest water temperature area in the Seto Inland Sea, in May, and moves to Aki-nada, the lowest water temperature area in June. In Geiyo Archipelago, the tidal currents are faster than in Hiuchi-nada, because this area is composed mainly of many narrow straits.

Fig. 1. Map of the central waters of the Seto Inland Sea, showing the sampling stations.
For assessment of the abundance of eggs and fish larvae, their distribution limits need to be identified. Accordingly, samples collected in Hiuchi-nada and adjacent waters were used in the present study, because Hiuchi-nada is an isolated spawning ground, judging by egg distribution and oceanographic structure, and larval distribution also seemed to be isolated from the other areas investigated.

Sampling Method and Treatment of Data

For collection of larval and juvenile Japanese Spanish mackerel, a net with a cylindrical anterior section 3.2 m long, conical posterior section 3.7 m long, mouth diameter 1.3 m, and mesh size 0.315 mm, was used. Oblique hauls from the surface to 4 m above the bottom and back to the surface were carried out. The wire drawing velocity measured about 0.2 m/s, and ship velocity was maintained at 2 kt. The deepest limit of hauling for any station was 30 m, allowing regulation of the hauling time to between mainly 5 and 10 min. The area filtered, measured by a flow-meter mounted on the mouth of the net, ranged mainly between 20 and 30 m² per haul. Samples were taken between about 9 a.m. and 5 p.m., 4 or 5 days being necessary for the sampling.

At each station, water temperatures at the surface and at depths of 5, 10 and 20 m were measured. The surface water temperature is expressed as the water temperature at the 20-30 cm layer taken by a water quality monitor (TSK) from 1983 to 1985, and at the depth of 1 m taken by a CTD (TSK) since 1986.

All sampled material was preserved in 5-7% formalin, with eggs and larvae of Japanese Spanish mackerel sorted subsequently. The larvae before and after absorption of the yolk-sac were classified as prelarvae and postlarvae, respectively, and fishes with fins and finlets already formed were classified as juveniles.

The number of larvae and juveniles collected at each station was converted into a density per 100 m², and standard length (SL; from tip of snout to end of notochord or urostyle) distributions of samples which apparently originated in Hiuchi-nada were obtained from every survey.

Densities (number/100 m²) of prelarvae, postlarvae and juveniles for stations at which samples originating in Hiuchi-nada apparent to occur were added up so as to calculate the relative abundance of respective stages for each year.

In addition, the factors influencing the survival rate during the larval stage, that is, larval condition and water temperature regimes around the spawning and nursery grounds were examined.

To estimate larval condition, the ratio of body height (BH) at the anus, excluding fins, to SL was employed. This ratio (BH/SL) is regarded as a sensitive index for environmental condition in larval cod Gadus morhua.9)

Investigation of Recruitment Abundance

In the eastern part of Hiuchi-nada, fishing boats operating from Kan'onji (Fig. 1), use gill nets to catch immature 1-year-old Japanese Spanish mackerel, which migrate to the region within 1 or 2 months of the spawning season.10) Taking the CPUE (catch per unit fishing effort) of this 1-year-old fish to be an index of the recruitment abundance of those originating in Hiuchi-nada, the catch records of 1-year-old fish and the number of boats operating from Kan'onji were investigated every day during the fishing season. For calculation of CPUE, data after May was used, because the fishing effort in May tended mainly towards spawning adults, whose market price is relatively expensive. CPUE is expressed as the total catch divided by the total number of boats operating.

Since Japanese Spanish mackerel in both the central and western waters of the Seto Inland Sea, including Hiuchi-nada, were regarded as a single stock,11) it is not certain whether all of the 1-year-old fish landed in Kan'onji did in fact originate in Hiuchi-nada. However, this uncertainty should not have much bearing on the final conclusions, because Hiuchi-nada seems to be the major spawning ground for the stock as can be seen in Figs. 2 and 3.

Results

Distribution Area of Larvae and Juveniles Born in Hiuchi-nada

For location of spawning grounds and movement of larvae and juveniles of Japanese Spanish mackerel throughout the central waters of the Seto Inland Sea, the distribution of eggs and larvae in May 1983 and June 1984, when eggs or larvae were abundant, are given below.

The distribution of eggs and larvae and surface water temperatures on 23-26 May 1983 are presented in Fig. 2. The region of dense isotherms (indicated by a cross in the right lower panel ofFig. 2) is thought to be the tidal front which was
Fig. 2. Distribution of eggs and larvae of Japanese Spanish mackerel, and surface water temperatures on 23-26 May 1983. Densities are expressed as number/100 m². △: in the right lower panel indicates the station where the differences in water temperature between the surface and at a depth of 10 m exceeds 1°C. ×: indicates the location of the tidal front.

Fig. 3. Distribution of eggs, larvae under 8 mm, and larvae and juveniles over 8 mm, and surface water temperatures on 15-18 June 1984. Legends as same as in Fig. 2.
observed by Yanagi and Yoshikawa. During this season the Hiuchi-nada side of the tidal front was stratified by surface heating, while adjacent waters were made cooler by the vertical mixing of tidal currents. At this time, eggs, prelarvae and postlarvae were distributed mainly in Hiuchi-nada, where the surface temperature was high.

Distributions recorded on 15–18 June 1984 are shown in Fig. 3. Although the spawning ground moved from Hiuchi-nada to Aki-nada, where it was cooler, larvae and juveniles were distributed in and around both Hiuchi-nada and Geiyo Archipelago. In Aki-nada, where eggs were recorded, larvae were not collected, although a few were found in early July, some two weeks later. In Fig. 3, the distribution of larvae under 8 mm SL, and larvae and juveniles over this size are shown separately. Specimens examined showed flexure of the notochord from about 8 mm SL. Figure 3 shows that the distribution of larvae over 8 mm centered in Geiyo Archipelago and the northern part of Hiuchi-nada, whilst that of smaller larvae was in Hiuchi-nada.

The larvae and juveniles collected in Geiyo Archipelago were considered to have originated in Hiuchi-nada and to have been transported by surface currents, since Geiyo Archipelago was apparently not a large spawning ground in May and June, and drift card analysis in May showed that surface water in Hiuchi-nada was moving to the west through Geiyo Archipelago with a velocity of 2–3 cm/s, and with some current diffusion. Therefore larvae and juveniles collected from stns. 1 to 17 in and around Hiuchi-nada and in Geiyo Archipelago were considered to have originated in Hiuchi-nada.

Size Composition of Larvae and Juveniles

Standard length frequency distributions for all larvae and juveniles collected in May 1983, and June 1983–1988 inclusive are presented in Fig. 4. Stations 1–17 yielded a few postlarvae only in May (except in 1983), and only a few larvae and juveniles in July.

Individual size at transition from prelarval to postlarval stage varied between 4 and 6 mm, and from postlarval to juvenile stage, between 11 and 12 mm.

Between 5 and 11 mm SL (mainly postlarval stage), logarithmic transformations of larval density decreases plotted against SL produced straight line relationships in May 1983 and in June from 1984 to 1987 inclusive. Such was not apparent in 1987 and a density decrease was hardly observed in 1984. In 1988, the densities of larvae under 11 mm SL increased with size, in contrast with earlier years. This may reflect a gradual decline in spawning owing to the water temperature having approached the upper limit of suitability for spawning, since the water temperature in Hiuchi-nada in 1988 was the highest in June throughout the survey period (Fig. 7). In 1984, however, the surface water temperature in June was the lowest recorded for that month, yet still within the suitable range for spawning (19–20°C), so the maintenance of densities between 5–11 mm is thought to reflect low larval mortality when compared with the other years.

In 1984, the coefficient of decrease (the slope of the line fitted to density decrease versus size) for SL over 11 mm was greater than that for larvae under 11 mm. This may be caused by an increase in net avoidance owing to the development of functional fins etc., since 11 mm SL marks the approximate size for onset of juvenile character development.

Abundance of Larvae and Juveniles, and Recruitment

Fig. 4. Density distributions of standard lengths of samples apparently originated in Hiuchi-nada for May (1983 only) and June. Density is expressed as total number/100 m² (stns. 1–17).
The relationships between relative abundance of prelarvae and postlarvae (Fig. 5, A), postlarvae and juveniles (Fig. 5, B), and juveniles and CPUE of subsequent 1-year-old fish landed in Kan'onji (Fig. 5, D), are presented. Although the correlation coefficient (r) between the abundance of prelarvae and postlarvae was significant (r = 0.946, Fig. 5, A) at the 1% level, there was no positive correlation between the abundance of postlarvae and juveniles (r = 0.111, Fig. 5, B). It is therefore inferred that the correlation between postlarval abundance and the CPUE of subsequent 1-year-old fish was nonsignificant (r = 0.419, Fig. 5, C). There was a significant (p < 0.01) positive correlation, however, between the abundance of juveniles and the CPUE of subsequent 1-year-old fish (r = 0.944, Fig. 5, D). Figure 5, D shows that the abundance of juveniles was highest in 1984 and that the CPUE of 1-year-old fish in 1985 (1984 year-class) was also the highest. Both the abundance of juveniles and CPUE of 1-year-old fish were lower from 1985 to 1988 inclusive.

Factors Influencing the Abundance of Juveniles

Initially, larval condition was assessed. Averages in BH/SL for every 0.5 mm class of larvae under 8.5 mm SL in May 1983 and in June from 1984 to 1987 inclusive, when samples were relatively abundant, are indicated in Fig. 6. BH/SL usually remained on the same level below 5 mm SL (a single decrease recorded), but then increased linearly. Average BH/SL ratios in 1984 and 1985 were higher than those for the other years in almost every length class. Significance testing (one-sided t-test) of the differences between BH/SL averages in every SL class revealed that those for 1984 and 1985 were significantly larger than the others (except for the 4.5 to 5.0 mm SL class) at the 5% level of significance.

In addition, oceanographic conditions based on the distribution of water temperatures were examined. Water temperatures recorded both at the surface and at 5 m depth in May and June in Hiuchi-nada and Gëiyo Archipelago, are shown in Fig. 7, and are expressed as the averages of stns. 5, 6, 8, 9 and 12 (stns. near the shore were omitted), and stns. 14 and 16, respectively. The center of the vertical distribution range of the larvae in day time is about 5 m,8) which depth is usually included in the surface water layer. According to Fig. 7, in 1983 and 1984, when juvenile...
abundance were high, May to June (incl.) water temperatures in Geiyo Archipelago increased at a faster rate compared with those in Hiuchi-nada, than in other years. Accordingly, differences in water temperatures between these areas became smaller in June in 1983 and 1984. Conversely, differences in water temperatures between these areas remained at nearly the same or became larger in June from 1985 to 1988.

For examination of the vertical structure of water temperature in June, vertical profiles along a line joining stns. 3, 6, 9, 11, 14 and 16, which are distributed from Hiuchi-nada to Geiyo Archipelago, are shown in Fig. 8. These for May 1983 and 1984, when juveniles were abundant, are included. According to Fig. 8, vertical temperature gradients in Hiuchi-nada were large, whereas the waters of Geiyo Archipelago side were mixed vertically, except in June 1983 and 1984. In June 1983 and 1984, oceanic stratification in Hiuchi-nada was weaker and the tidal front observed in May became obscure.

Discussion

To study the mechanism of fluctuations in the year-class strength of pelagic fishes, it is important to clarify when high mortality occurs and when the strength of the year-class can be determined. It is known that in some marine fishes, high mortality occurs at an early larval stage, but in other fishes, during the relatively long period after this stage. In Japanese Spanish mackerel, the strength of the year-class is thought to have been essentially determined by the juvenile stage, because the year-classes, whose juveniles were abundant as in 1984 and 1983, were also rich even when they were 1-year-old, and vice versa. The strength of the year-class, however, seemed not to be determined by the postlarval stage, because there were no positive correlations between postlarval abundance, and either the abundance of juveniles or the CPUE of subsequent 1-year-old fish. Furthermore, a critical period following absorption of the yolk-sac seems to not exist in this fish, and hence a relatively high mortality rate may occur throughout the larval stage, because the size compositions (Fig. 4) show almost constant abundance.
coefficients of decrease during larval stages over 5 mm SL. The rapid increase in densities of larvae under 5 mm SL observed in all years may be owing to the larval hatching at about 3.7–4.4 mm SL.\(^{19,20}\) Loss of posthatched larvae through the mesh is thought to be insignificant, since the body height at the anus in 4 mm SL individuals approximates the mesh size of 0.315 mm (0.315/4 = 0.079, cf. Fig. 6). The maximum body heights, including yolk-sac and/or the dorsal and ventral membraneous fins, are thought to be greater than the mesh size.

Degree of fatness was thought to be an index of nutritive condition, but in larvae over 5 mm SL, such conditions were not always associated with the strength of the year-class. In 1985, for example, the abundance of juveniles was low, although BH/SL was large, whereas in 1983, the abundance of juveniles has been considerable, despite the low BH/SL values that May. In 1984, which saw the strongest year-class, larval condition was also good, with BH/SL values under 5 mm being higher than those for other years. Without more intensive survey programmes, it is not possible to fully interpret such results.

It is suggested that oceanographic conditions are associated with larval survival. In the years when strong year-classes occurred, such as in 1984 and 1983, the water masses in Hiuchi-nada and Geiyo Archipelago seemed to be more homogeneous and the tidal front became obscure in June than in the other years of the survey, although the cause is not known. Therefore the problem of which factor makes such differences in oceanographic condition and how the difference of oceanographic condition influence larval mortality should be solved by further investigation to study the process of larval mortality in Japanese Spanish mackerel.

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**References**