Recruitment of an inherent piscivore, Japanese Spanish mackerel *Scomberomorus niphonius* (Scombridae)

JUN SHOJI,¹ TSUTOMU MAEHARA,² AND MASARU TANAKA¹

¹ Laboratory of Marine Stock-enhancement Biology, Division of Applied Biosciences, Graduate School of Agriculture, Kyoto University, Kitashirakawa, Kyoto 606-8502, (shog@kais.kyoto-u.ac.jp), and ² Toyo Branch, Ehime Prefecture Chuyo Fisheries Experimental Station, Kwarazu, Toyo, Ehime 799-1303, Japan

SUMMARY: The hypothesis that prey abundance and larval growth rate are related to recruitment was tested in Japanese Spanish mackerel in the central Seto Inland Sea, Japan. The relationships among larval abundance, growth rate, prey fish (clupeiform larvae) abundance, and the catch per unit fishing effort (CPUE) of the subsequent 1-year-old fish were examined from 1995 to 1999. A significant, positive correlation was found between the larval growth rate and the CPUE, but not between the larval abundance and the CPUE. There also existed a significant positive correlation between the abundance of clupeiform larvae and the larval growth rate, which varied from 0.4 to 1.0 mm/day. Both the larval growth rate and the CPUE were higher in 1995 and 1999, when the period of peak occurrence of clupeiform larvae timed well with that of the mackerel larvae. It has been concluded that the prey abundance during the early larval period is one of the most important determinants of the growth and recruitment of Japanese Spanish mackerel.

KEY WORDS: Spanish mackerel, larvae, piscivory, growth, recruitment, Seto Inland Sea

INTRODUCTION

Scombrid fishes have the 'fast growth with large prey' survival strategies in their early life stages.¹⁾ A rapid growth rate throughout the larval stage increases the probability of survival due to an enhanced ability to catch prey and avoid predators.²⁾ Among *Scomberomorus* fishes, an extremely high growth rate is observed during the larval period: king mackerel *S. cavalla* (1.30 mm/day)³⁾ and Japanese Spanish mackerel *S. niphonius* (1.03 mm/day).⁴⁾ Those high growth rates have been related to the early appearance of piscivory and precocious development of their digestive systems.⁵⁾

The high growth rate of *Scomberomorus* larvae should be advantageous to survival due to the reduced period vulnerable to predation. On the contrary, fewer opportunities to encounter ichthyoplankton compared with invertebrate plankton prey seem disadvantageous to survival. There is some evidence of a high rate of starvation mortality and low ability to withstand starvation in *Scomberomorus* larvae.^{6,7)} The size-selective mortality of slower growing fish found in 6-day-old larvae of king mackerel and Spanish mackerel *S. maculatus* in the southeastern United States³⁾ indicates that there is a large size variation in the early larvae around the first feeding. These results and observations suggest that prey abundance would be a possible determinant for growth and survival of the *Scomberomorus* larvae.

The Japanese Spanish mackerel is an important fishery resource in the Seto Inland Sea, southern Japan. The total catch in the Sea exceeded 6000 t in the mid 1980s, but has recently decreased to < 500 t. Recovery of the stock is awaited. Based on the relationship between oceanographic condition during early life stages and the catch per unit fishing effort (CPUE) of the subsequent 1-year-old fish from 1983 to 1988 in the central Seto Inland Sea, Kishida⁸⁾ found

that a strong year-class occurred when the stratification around the spawning area was weakened. He almost concluded that the year-class strength of the Japanese Spanish mackerel is determined by the very early juvenile stage (10 mm in standard length: SL). However, there has been no any other biological information related to the recruitment of the Japanese Spanish mackerel.

The objective of the present study is to test the hypothesis that the prey abundance and growth rate in the early larval period are related to the recruitment of the Japanese Spanish mackerel. We investigated the abundance and growth rate of the Japanese Spanish mackerel larvae (Fig. 1), abundance of prey (clupeiform larvae), and relative abundance of 1-year-old fish in the central Seto Inland Sea, from 1995 to 1999.

Fig. 1 Wild Japanese Spanish mackerel larvae (5.9 and 6.1 mm SL). Eyes of fish larvae ingested are visible in the stomachs.

MATERIALS AND METHODS

Samplings were made in the Hiuchi-nada, the central waters of the Seto Inland Sea, Japan, four to eight times a year from 1995 to 1999 using the R/V *Hiuchi* of the Ehime Prefecture Chuyo Fisheries Experimental Station. A conical larva-net with a mouth diameter of 1.3 m and a mesh aperture of 0.5 mm was towed horizontally in the mid-depth layer (10–15 m) for 10 minutes. A total of eight to fourteen stations⁴⁾ were sampled during each cruise. The

Japanese Spanish mackerel spawns from May to June in this area,⁹⁾ and the larvae occur mainly at the mid-depth layer in the daytime.^{10,11)} Ichthyoplankton samples were preserved in 90% ethanol, and Japanese Spanish mackerel larvae were sorted in the laboratory for otolith analysis. Abundance of the larvae after yolk exhaustion, which was highly correlated with that of yolk-sac larvae,⁸⁾ was used as an index of larval abundance. Age in days of a total of 420 mackerel larvae 3.8–9.8 mm in body lengths was determined by examining otolith microstructures.⁴⁾

Vertical hauls of a conical plankton net (mouth diameter 0.6 m, mesh aperture 0.315 mm) were also made at each station. The abundance of clupeiform larvae, which are main prey of the Japanese Spanish mackerel larvae,^{12,13)} was considered as an index of prey abundance for the mackerel larvae. Water temperature was measured with a salinity-temperature-depth sensor at each sampling station.

We regarded the CPUE of 1-year-old Japanese Spanish mackerel as an index of the recruitment of those originating in the Hiuchi-nada.⁸⁾ Japanese Spanish mackerel distributed in the central and western waters of the Seto Inland Sea has been regarded as a single stock,¹⁴⁾ and the Hiuchi-nada is a main spawning ground of the mackerel stock.^{9,10)} Commercial fishery operating in this area uses gill nets to catch the mackerel. The catch records of 1-year-old fish and the number of boats operating from the Kawarazu Fishing Port were collected every day during the main fishing season (May). CPUE was expressed as the total catch divided by the total number of boats operated.

RESULTS

Water temperature in the sampling area

The mean water temperature at 1 m depth ranged from 11.3 to 21.7°C (Fig. 2). In the period of peak occurrence of the mackerel larvae (Fig. 3), the mean temperature was between 17.5°C (mid May 1998) and 18.2°C (early June 1995). The temperature from April to May in 1998 was higher than in other years ($p < 0.05$, u -test).

Fig. 2 Change of mean water temperature.

Occurrence of Japanese Spanish mackerel and clupeiform larvae

The density of Japanese Spanish mackerel larvae peaked in early June in 1995 and 1996, late May in

1997 and 1999, and mid May in 1998 (Fig. 3). The highest density ($40.2/1000\text{m}^3$) was found in 1997.

The density of clupeiform larvae at the peak occurrence of Japanese Spanish mackerel larvae was higher ($>200/\text{m}^2$) in 1995 and 1999 than other years. On the contrary, the density of clupeiform larvae was lower during the peak occurrence of the mackerel larvae from 1996 to 1998 ($12.8\text{--}95.9/\text{m}^2$). The clupeiform larvae were much less abundant in 1997 ($<113.8/\text{m}^2$). The density of clupeiform larvae seemed to peak before the sampling period in 1998, when the water temperature was highest in April and May among the five years (Fig. 2).

Fig. 3 Seasonal changes in mean density of Japanese Spanish mackerel (line) and clupeiform larvae (shaded area).

Growth of the Japanese Spanish mackerel larvae

The mean growth rate of the Japanese Spanish mackerel estimated from the otolith microstructures ranged between 0.4 and 1.0 mm/day (Fig. 4). Although there was no significant correlation with the water temperature, the growth rate showed a tendency to decrease as the temperature increased. However, when the growth rates of the wild mackerel larvae under higher prey density (number of clupeiform larvae $>100/\text{m}^2$) are combined with the data obtained from the previous rearing experiments, a significant positive correlation ($r=0.799$, $p < 0.01$) exists between the water temperature and the growth rate. Since the reared mackerel larvae are generally supplied ample prey in the captive tanks,^{13,15,16)} they are assumed to exhibit their maximum growth potential. Therefore, the growth rate of the wild mackerel under the higher density of clupeiform larvae can be approximated to their maximum growth rate.

There also existed a significant positive correlation between the density of clupeiform larvae and the growth rate of the wild Japanese Spanish mackerel larvae ($r=0.718$, $p < 0.05$, Fig. 5). The larval growth rate was higher in late May 1995 and 1999,

exceeding 0.9 mm/day.

Fig. 4 Relationship between water temperature and growth rate of wild (●, ○; mean of 20 or more fish) and reared (▲) Japanese Spanish mackerel larvae. Year and period of collection are shown in the figure. E, M, and L mean early, middle, and late 10-day period of month, respectively. ●; wild larvae with prey fish density exceeding 100/m². The relationship between the water temperature (T) and the growth rate (G) indicated by the closed symbols (●, ▲) was $G=0.0643T-0.238$ ($r=0.799$, $p<0.01$). ▲; reared fish data from previous rearing trials: 1; Higuchi & Oshima,¹⁵ 2; Fukunaga *et al.*,¹⁶ 3; Nakamura Y (unpubl. data, 1991), 4; Shoji *et al.*¹³

Fig. 5 Relationship between abundance of clupeiform larvae (number/m²) and the growth rate of Japanese Spanish mackerel larvae. Each point is the mean value for 20 or more fish. Year and period of collection are shown in the figure. E, M, and L mean early, middle, and late 10-days period of month, respectively. The relationship between the density of clupeiform larvae (C) and the growth rate (G) was expressed as follows: $G=0.00195C+0.459$ ($r=0.718$, $p<0.05$).

Larval abundance, growth rate and recruitment

The CPUE fluctuated with a magnitude of order during the five years. There was no significant correlation between the larval abundance in the period of peak occurrence and CPUE of subsequent 1-year-old fish landed in Kawarazu Fishing Port (Fig. 6A). However, a significant positive correlation ($r=0.833$, $p<0.05$) was observed between the larval growth rate in the period of peak occurrence and the CPUE (Fig. 6B). Both the growth rate and the CPUE were the lowest in 1997 although the larval abundance was highest among the five years (Fig. 3). The larval

growth rate and the CPUE were higher in 1995 and 1999, when the prey abundance was also high (Fig. 2).

Fig. 6 Relationship between abundance of Japanese Spanish mackerel larvae in the period of peak occurrence and CPUE of subsequent 1-year-old fish (A) and between the larval growth rate in the period of peak occurrence and the CPUE (B). Figures indicate year-classes.

DISCUSSION

Early determination of the year-class strength

The growth rate of fish larvae is an important factor that could determine mortality during the larval period.^{2,17} A high growth rate in the larval period can increase the probability of survival by shortening the period vulnerable to predation. In the present study, the growth rate of the Japanese Spanish mackerel larvae varied between 0.4 to 1.0 mm/day (Figs. 4, 5), indicating that the survival of the mackerel larvae is strongly influenced by prey abundance. We also found a positive correlation between the larval growth rate and the CPUE in the subsequent year (Fig. 6B). These results support the conclusion by Kishida⁸ based on the relationship between the oceanographic condition and the abundance of recruits in the central Seto Inland Sea: year-class strength of Japanese Spanish mackerel is determined by the early juvenile stage (10 mm SL).

Significance of prey fish for the larval survival

The Japanese Spanish mackerel larvae prefer fish larvae to invertebrate plankton prey from the first feeding.¹⁸ Generally, fish prey exist at a much lower density and has a larger body size and higher escaping ability than invertebrate plankton prey. These facts imply that piscivorous Japanese Spanish mackerel larvae are required to exert a greater searching effort and swim faster, resulting in a higher metabolic rate.¹¹ Feeding success has been reported to cause a distinct size variation of the Japanese Spanish mackerel larvae (7.3-10.3 mm SL)⁷ even within several days after the first feeding. Starvation and malnutrition apparently increase the vulnerability to predation in the larval period of Japanese Spanish mackerel due to retarded growth and consequent longer duration of larval period. In the present study, stronger year-classes of the Japanese Spanish mackerel occurred in 1995 and 1999, when the larval growth rate was higher, and the peak occurrence of the larvae corresponded to that of the clupeiform larvae. On the other hand, both the growth rate and the CPUE were the lowest in 1997

growth rate and the CPUE were the lowest in 1997 although the larval abundance was highest over the five years. The lowest prey fish abundance in the early larval period would be the most possible explanation for the lowest growth and survival.

The Japanese Spanish mackerel exhibits an extremely high growth rate (3.0 mm/day) in the following young stages, reaching a total length of 100 mm within a month¹⁸⁾ and 600 mm in the first growing season (May to November),¹⁹⁾ resulting in short duration of the young stages. Thus, the magnitude of cumulative mortality throughout the young stages and its year to year fluctuation might be low. Although we have no evidence concerning the predation on the young Japanese Spanish mackerel, the two piscivorous fish species, chub mackerel *Scomber japonicus* and ribbonfish *Trichiurus lepturus*, could be considered as the most suspicious predators in the Seto Inland Sea.²⁰⁾ The survival during the period after the early juvenile stage should be determined to further understand cause of the recruitment fluctuations.

In conclusion, we found a significant positive correlation between the prey abundance and the larval growth rate and between the larval growth rate and the CPUE of Japanese Spanish mackerel. Our results imply that the prey abundance and larval growth rate are good predictives for recruitment of the Japanese Spanish mackerel in the Seto Inland Sea, although longer term analysis covering pre-recruitment period is still wanting. Oceanographic conditions represented by water temperature affects the timing of occurrence and abundance of the mackerel larvae and their prey, and thus may indirectly influence the growth, survival, and recruitment fluctuation of the Japanese Spanish mackerel.

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