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Occurrence and Abundance of *Leiognathus rivulatus* (Temminck and Schlegel) Larvae in Kagoshima Bay, Southern Japan, in 1991

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Abstract Temporal and spatial occurrence and abundance of *Leiognathus rivulatus* larvae were studied with regular monthly collections at 14 fixed stations in Kagoshima Bay in 1991. A total of 1036 larvae (1.1-5.6 mm SL) were collected from June to September. They were poorly represented in the northern part of the bay, but were abundant at most of the coastal stations in the southern part. Larval abundance followed a normal distribution curve during the season, the peak abundance period, analyzed statistically on a daily basis, being from 30 June to 3 August. Areas of larval abundance were determined cruise by cruise using a method for calculating geographic centers of larval abundance from stations having a higher-than-average larval density and the two adjacent stations with the highest larval densities. Abundant areas of *L. rivulatus* larvae were found at three coastal locations in the southern part of Kagoshima Bay.

Leiognathids are small, luminescent, coastal fishes of the Indo-Pacific region. Two genera (*Leiognathus* and *Gazza*) and nine species (of which eight belong to *Leiognathus*) occur around Japan (Senou, 1993). Of the three species of *Leiognathus* (*L. rivulatus*, *L. nuchalis* and *L. elongatus*) known to occur in Kagoshima Bay (Imai and Nakahara, 1969; Haque and Ozawa, 1995), only *L. rivulatus* is commercially important, as it is in several other coastal regions in southern Japan (Ozawa, 1993). A few reports exist on the spawning season of *L. rivulatus* around Japan (Mito, 1966; Yamada, 1986; Kinoshita, 1988), but these comprise only records of larval occurrence.

From February to December, 1991, the Laboratory of Fisheries Biology, Faculty of Fisheries, Kagoshima University, conducted ichthyoplankton surveys in Kagoshima Bay, in which leiognathid larvae were the 10th most abundant taxon (Kawamura, 1992; Fukushima, 1993). This study reports the temporal and spatial occurrence and abundance of *L. rivulatus* larvae in Kagoshima Bay in 1991, and introduces new methods for larval analysis.

Materials and Methods

Kagoshima Bay (Fig. 1) is latitudinally elongated, opening to the south, and is divided into southern and northern parts by the narrow, shallow West Sakurajima Channel. It has maximum depths of 230 m in the southern part and 210 m in the northern part. The specimens used in this study were collected by R/V *Shiranami* (1.5 tons) at 14 fixed stations (Fig. 1). Each set of collections in the southern and northern parts, usually requiring a full day, is termed a cruise. Monthly cruises were made in daytime just after the middle of each month.

A cylindrical-conical type net (1.3 m in diameter, 4.5 m in length and 0.5 mm in mesh size) was towed in step hauls at average depths of 10.4 and 21.6 m (Ozawa, unpubl.) using 50 and 100 m rope lengths (5 min each) at a speed of about 2 knots. A flow meter was set at the center of the net mouth to calculate the volume of water filtered and allow estimation of the density (no./m^3) of specimens collected. The samples were fixed in approximately 5% buffered sea water formalin immediately after collection, the larvae later being sorted and preserved in 70% ethyl alcohol in the laboratory. A total of 1036 *Leiognathus rivulatus* larvae from 56 samples (four cruises from June to September, 1991) were identified and counted. Standard lengths (SL) of the smallest and largest specimens in each sample were measured.

The normality of temporal abundance of the larvae was tested statistically with normal probability paper as follows. Cumulative densities (%) (of monthly averages) were plotted on normal probabil-

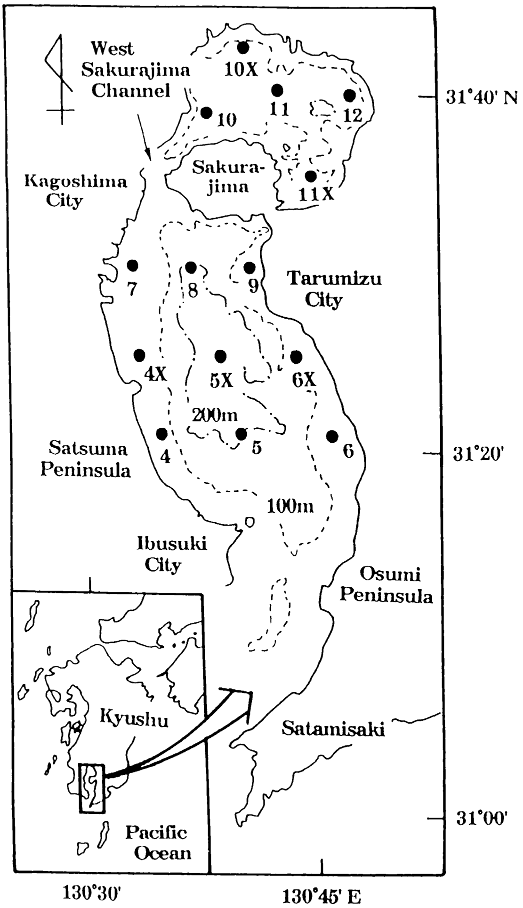

Fig. 1. Ichthyoplankton sampling stations in Kagoshima Bay.

ity paper against N (days of collection after the first day of the year). A straight line was fitted to the combination of N and Z (standard normal variates) converted from cumulative densities. A statistically significant slope indicated a normally distributed temporal occurrence of the larvae. When significant, mean and standard deviations of N were estimated by dropping perpendiculars from 50% (μ, mean), 15.9% (−SD) and 84.1% (+SD) cumulative density points on the straight line to the abscissa. Because it could be considered that 68.26% of the larvae were collected between the days corresponding to 15.9% and 84.1% cumulative densities, this period was regarded as the peak abundance period.

In calculating the peak abundance period and centers of larval abundance, only the larval densities in the southern part of the bay were used, because of the poor larval representation at the northern stations.

To determine abundant areas of larvae in each cruise, centers of larval abundance were calculated from larval densities of three adjacent stations using the following formulae and rules. Each station had adjacent stations as follows (Fig. 1): three adjacents for stations 4, 6, 7 and 9; five adjacents for stations 5, 4X, 6X and 8; and eight adjacents for station 5X.

The values of x (abscissa) and y (ordinate) for a center of larval abundance were calculated by the formulae:

$$x=(X_1a_1+X_2a_2+X_3a_3)/\sum a_i,$$
$$y=(Y_1a_1+Y_2a_2+Y_3a_3)/\sum a_i$$

where X_i, Y_i and a_i were values of the abscissa, ordinate and larval density, respectively, of the respective stations.

The values of X and Y of all sampling stations were determined from a map of Kagoshima Bay (Fig. 1). The X-axis was set west-east and the Y-axis, south-north. The origin 0, 0 was put at 31°10′N and 130°30′E. X_i was equal to the longitudinal value of station i minus 130°30′ and Y_i, to the latitudinal value of station i minus 31°10′.

The rules for calculating centers of larval abundance were: (1) Determine stations having a density equal to or more than the cruise average density (candidate stations). (2) Begin the calculation with the candidate station having the highest density. (3) Calculate the center of larval abundance from the larval densities of the candidate station and the two adjacent stations with the highest density values. (4) When three candidate stations formed a line, calculate the center of larval abundance regardless of the station order. (5) Calculate centers of larval abundance for lower candidate stations as above, under the following conditions: (i) pass the calculation when a candidate station is used in former calculations, but (ii) include the two upper noncandidate stations used in former calculations. (6) Centers of larval abundance not to be adopted when the average density of the three stations concerned is lower than the cruise average.

To cover all cases and ensure objective or consistent results, the above rules were applied to many trials. Not all could be applied in some cases. For example, rule 4 was not used in this study (see Fig. 3).

Results

The larvae of *Leiognathus rivulatus* were collected from June to September, 1991. The cruises within this period covered all sampling stations, resulting a total of 1036 larvae (1.1–5.6 mm SL) from 56 hauls in four cruises. Monthly larval totals were 37 in June, 821 in July, 152 in August, and 26 in September. Larvae were more numerous at stations in the southern part of the bay, the highest total number of larvae per station (238) being collected at station 7, and the lowest (20) at station 8. In the northern part, larvae collected were negligible, the highest total number per station being only six (station 10) and the lowest zero (station 10X). The temporal and spatial occurrences were analyzed based on the density of larvae (no./m^3).

Figure 2 shows the cruise mean densities of larvae from the southern and northern parts, and the overall total for Kagoshima Bay. Cruise densities from the southern part conformed to the overall cruise densities each month, and were 10 to 100 times higher than those from the northern part of the Bay. Peak density was in July. Densities of the northern part were almost uniform throughout the spawning season, showing a slight peak in August.

The peak abundance period of *L. rivulatus* larvae in southern Kagoshima Bay in 1991 was determined as shown in Figure 2. The cumulative larval densities plotted on normal probability paper were almost in a straight line. The slope of the line, fitted by linear regression $Z=\alpha+\beta N$, was statistically significant ($p<0.05$), indicating that the temporal occurrences of larvae were normally distributed. The perpendiculars drawn from 15.9%, 50% and 84.1% cumulative density points on the straight line to the abscissa intersected at the points for 30 June, 16 July and 3 August, respectively. The period between 30 June and 3 August was considered the peak larval abundance period.

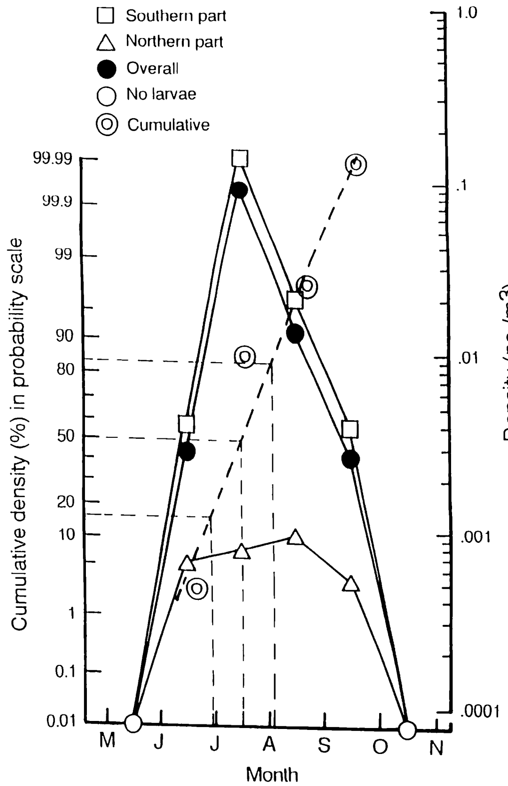

Fig. 2. Average cruise densities (no./m^3) and cumulative densities (%) of *Leiognathus rivulatus* larvae.

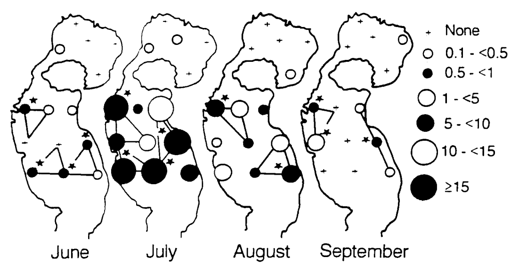

Fig. 3. Density (no./100 m^3) of *Leiognathus rivulatus* larvae. Circles with an asterisk indicate candidate stations of larval abundance. Station densities connected by lines were used to calculate centers of larval abundance.

The densities at each station in each cruise, and the candidate stations for larval abundance are shown in Figure 3, in which the three stations used for each calculation of center of larval abundance are connected by lines. In June the candidate stations were 4, 5, 6X and 7. No larvae were caught at stations 4X and 5X in the southern part, or at any station, except 10, in the northern part. In July the candidate stations were 4, 5, 6X and 7, as in June. In this month no larvae were caught at stations 10X, 11X and 12 in the northern part. In August the candidate stations were 6 and 7, larvae being caught only at station 11X in the northern part. In September the candidate stations were 4X, 6X and 7. In this month no larvae were caught at stations 4, 5, 5X and 8 in the southern part, or at any station, except 12, in the northern part. Throughout the cruises, all of the candidate stations, except 5 in June and July, were

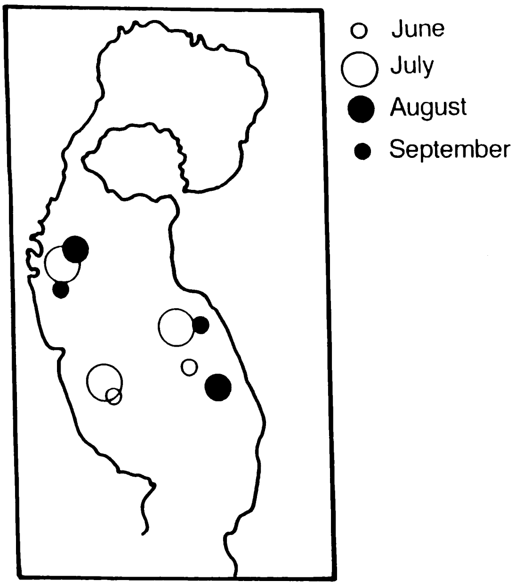

Fig. 4. Centers of *Leiognathus rivulatus* larval abundance in Kagoshima Bay.

along the east and west coasts of the southern bay. Of the four months, larval densities were the highest in July at almost all stations in the southern part. The sums of monthly average densities at the east line stations (6, 6X and 9), west line ones (4, 4X and 7), middle line ones (5, 5X and 8), and those in the northern part (10–12) were 0.17, 0.24, 0.09 and 0.003, respectively.

The centers of larval abundance are illustrated in Figure 4, the period of larval occurrence being partitioned into four months (Fig. 2): (i) June—initial occurrence, (ii) July—peak abundance period, (iii) August—between the peak abundance period and final occurrence, and (iv) September—final occurrence. According to rule 6 outlined above, the center of larval abundance for candidate station 7 and its two adjacent stations in June was not adopted because their average density was less than the overall cruise average.

In the present study, the centers of larval abundance were located at the east and west coastal areas (Fig. 4). Off the east coast, the center of larval abundance during the initial larval occurrence was between stations 5, 6 and 6X; during the peak abundance period it shifted a little northward to near station 6X; after the peak abundance period it shifted southward to near station 6; and during the final occurrence it was again located near station 6X. Off the west coast, the center of larval abundance during the initial occurrence was around station 4; during the peak abundance period it was located at two points around stations 4 and 7; after the peak abundance period and during the final occurrence it occurred near station 7. Along the east coast the centers of larval abundance were at the southern stations, but along the west coast were at two areas; early in the season near the southern station, and late in the season near the northern stations. However, an abundance area, which was not considered owing to rule 6, may be present around station 7 at the initial occurrence.

Despite the limited duration of the study, it appeared that three abundance areas existed for *L. rivulatus* larvae in Kagoshima Bay.

Discussion

During the 1991 study presented here and our unpublished studies from 1984 to 1990 in Kagoshima Bay, *Leiognathus rivulatus* larvae were collected over four or five months from May or June to September or October. They occurred from June to September in the Seto Inland Sea (Mito, 1966), from May to July in the East China Sea (Yamada, 1986) and from July to September in Tosa Bay (Kinoshita, 1988). Thus, *L. rivulatus* larvae appear around Japan over the summer period. Fujita (1960) reported the spawning season of *L. nuchalis* as being in northern Kyushu from the middle of May to the end of July. Ochiai and Kuwajima (1965), from gonadal development studies, described the spawning season of a leiognathid (species name not given) as being in Wakasa Bay from June to July, with a peak at the beginning of July, indicating that a number of *Leiognathus* species apparently spawn in summer around Japan.

Although peak abundance months have been regarded as the peak spawning season for ichthyoplankton surveyed at monthly intervals, because intensive spawning may not continue throughout the entire period, it may well be better to define the peak spawning season on a daily basis, rather than monthly, especially since spawning intensities are known to follow a normal distribution curve (Saville, 1956; Houde, 1977). On this basis, the peak spawning season can be defined statistically on a daily basis such as was done in the present study, in which the period of occurrence of the average$\pm$SD (68.26%)

number of larvae was defined as the peak spawning season. With this method, variations in number of peak spawning days and timing of such over the years can be examined. Using these principles, the spawning habits of fishes can be analyzed more precisely. The critical point of the method is to collect ichthyoplankton at adequate, frequent intervals, i.e., semi-monthly for fishes with a short spawning season, for the reason that the method works best for a fairly large number of samples (Sokal and Rohlf, 1969).

Mamhot et al. (1992) analyzed the areas of abundance of bregmacerotid larvae in Kagoshima Bay over six years, with regard to two criteria: frequency of occurrence, and slopes of the linear regressions between the cruise mean density and the difference of that from the station density. Their method seemed to be inappropriate for describing areas of higher density, because the frequencies of occurrence were not necessarily quantitative and the slopes of linear regressions obtained from six years data indicated only the average abundance during those years, since the intercepts of the linear regressions were zero (Mamhot et al., 1992). Moreover, the two criteria did not describe any spatial shift in larval abundance, either within a single spawning season or between years. Thus, their method can be said to have been static. To analyze changes in spatial occurrence of larvae, data should be examined cruise by cruise within a spawning season.

In order to establish the location of high density areas within a cruise, isometric lines of larval abundance should be determined. However, such a procedure requires many sampling stations (Sette and Ahlstrom, 1948; Saville, 1956; Sekiguchi et al., 1988; Davis et al., 1990). As did those of Mamhot et al. (1992), the sampling stations in this study numbered only nine in the southern part and five in the northern part of Kagoshima Bay. Hence the above method could not be applied. Comparing abundant stations cruise by cruise may aid in the description of spatial shifts of abundant areas, but no better than the method considering spatial expanse, i.e., the calculation of a center of larval abundance, utilizing stations having a larval density equal to or higher than the cruise average and the two adjacent stations. Used above, this method appeared to be satisfactory in that the abundant areas obtained agreed with known fishing grounds of *L. rivulatus* in Kagoshima Bay (Ozawa, 1993). However, because areas of high larval density were not found near the fishing ground in the northern part of the bay, as well as near a former fishing ground near Tarumizu City in the southern part, reported in Ozawa (1993), further investigations are planned.

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1991年鹿児島湾におけるオキヒイラギ仔魚の出現と分布

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1991年鹿児島湾の14定点での定期採集で得られたオキヒイラギ仔魚の出現と分布を研究した．体長1.1-5.6 mmの仔魚1036尾が6月から9月に採集された．それらは湾北部で極めて少なく，湾南部のほぼ全ての沿岸部定点で多量であった．出現期間における仔魚の密度は正規分布に従い，日の単位で統計的に分析された主出現期は6月30日から8月3日であった．仔魚の主分布域は航海毎に，航海平均密度よりも高い密度を示す定点とその周囲の他より高い密度の2定点を用いて重心を求める方法により解析した．オキヒイラギ仔魚の主分布は湾南部の3沿岸域に見いだされた．

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