Occurrence and Abundance of Bregmacerotid Larvae in Kagoshima Bay, Southern Japan, with Descriptions of Ontogenetic Larval Characters

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Abstract Regular collections of ichthyoplankton were made with a larva net at 9–14 stations from Oct. 1983 to Dec. 1988 in Kagoshima Bay, totalling 817 collections from 66 cruises. A total of 2172 bregmacerotid larvae obtained from 195 collections of 33 cruises were identified as *B. atlanticus* (2001), *B. neonectabanus* (169), *B. macclellandii* (1) and *B. nectabanus* (1, tentative identification). The peaks of mean densities of larvae collected occurred in autumn for *B. atlanticus* and *B. neonectabanus*. The larvae of *B. atlanticus* occurred throughout the bay, and their densities and frequency of occurrence were lower in the northern part of the bay. In the southern part of the bay, stations in its southwest quadrant showed higher densities than the others. The larvae of *B. neonectabanus* occurred only in the southern part of the bay in which stations in the northwest quadrant showed higher densities than the others.

Bregmacerotids are small, gadiform fishes of pelagic habit found in neritic and oceanic waters of tropical and subtropical seas (Houde, 1984). The family contains only a single genus *Bregmaceros*. Species composition and species characters are far from complete. Based on worldwide specimens, D'Ancona and Cavinato (1965) recognized seven and Belyanina (1974) six species. From larval characters, Houde (1984) speculated on the existence of ten or more valid species. Recently, *B. cantori* by Milliken and Houde (1984), *B. houdei* by Saksena and Richards (1986) and *B. neonectabanus* by Masuda et al. (1986) were reported as new species, and the validity of *B. pescadorus* Shen and *B. lanceolatus* Shen was confirmed by Shen and Wang (1991). According to Okamura (1984) and Masuda et al. (1986), the following six species occur around Japan: *B. atlanticus* Goode et Bean, *B. arabicus* D'Ancona et Cavinato, *B. japonicus* Tanaka, *B. macclellandii* Thompson, *B. nectabanus* Whitley, and *B. neonectabanus* Masuda, Ozawa et Tabeta.

Bregmacerotid larvae are often among the ten most common families occurring in both oceanic and coastal ichthyoplankton surveys in subtropical and tropical waters (Houde, 1984). Early ontogeny has been studied by many authors such as D'Ancona and Cavinato (1965), Belyanina (1974), and Houde (1984), all of whom examined worldwide specimens. Irrespective of these reviews, larval species characters are still obscure partly because of systematic problems (e.g., Houde, 1984). Based on the literature such as Houde (1984), Kimura (1988) commented on the larval characters of six Japanese species. Except for distribution, the ecology of larvae has been seldom studied. Clancey (1956) reported the temporal occurrence, vertical distribution, and food of *B. atlanticus* larvae from the Florida Current. Houde (1981) analyzed the distribution and abundance of four types of larvae from the eastern Gulf of Mexico. Houde et al. (1986) studied the spatial and temporal occurrence of the larvae of three bregmacerotid species in the Arabian Gulf. There is no study on the ecology of the larvae of Japanese species.

From 1983 until present, ichthyoplankton surveys have been conducted in Kagoshima Bay by the Laboratory of Fisheries Resources, Faculty of Fisheries, Kagoshima University. During these surveys, bregmacerotid larvae have been commonly collected almost every year. This study reports on the occurrence and abundance of bregmacerotid larvae in Kagoshima Bay from 1983 to 1988.

Materials and methods

Kagoshima Bay (Fig. 1) is latitudinally elongated, opening to the south, and is divided into two parts by the narrow and shallow West Sakurajima Channel. It has a maximum depth of 230 m in the southern part and 200 m in the northern part.

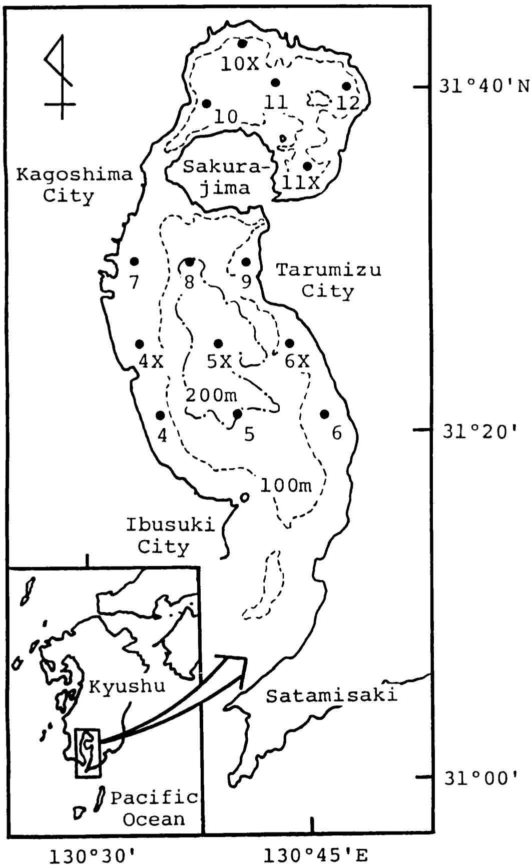

Fig. 1. Sampling stations of ichthyoplankton in Kagoshima Bay.

The specimens used in this study were collected regularly from October 1983 to December 1988 on board the research boat "Shiranami" (1.5 tons) principally at 14 fixed stations (Fig. 1). Stations marked X in Fig. 1 were not sampled in early collections: 4X and 6X before the beginning of February, 1984; 5X before the beginning of October, 1984; 10X and 11X before the latter half of February, 1984. Each collection in the southern and northern parts which usually took day, is called a cruise in this paper. Monthly cruises were made in daytime just after the middle of the month. In addition, from November 1983 to October 1984, an additional cruise was made just after the beginning of the month. Except in 1985, cruises in January were not made. Due to bad weather conditions, collections were sometimes impossible, though at least more than one station were sampled from both southern and northern parts in all cruises. In total, 817 collections from 66 cruises were available for the study.

The net of cylindrical-conical type (1.3 m in diameter, 4.5 m in length and 0.5 mm in mesh size) was towed in step hauls to depths of about 15 and 30 m with 50 and 100 m rope length for 5 min each at a speed of about 2 knots. A flowmeter was set at the center of the net mouth to calculate the volume of water filtered and allow estimation of the density ($/m^3$) of specimens collected. Sea surface temperature was measured simultaneously. The samples were fixed in about 5% buffered sea water formalin immediately after collection. The ichthyoplankton were sorted out and preserved in 70% ethyl alcohol in the laboratory. A total of 2172 bregmacerotid larvae from 195 samples of 33 cruises were identified to species and counted. Standard length (SL) of the smallest and largest specimens were measured. Meristics were counted when possible on large specimens stained with Alizarin Red S.

Results

Identification

The youngest bregmacerotid larvae are characterized by a short, depressed body, large head and mouth, and pedunculated pectoral fin. With growth the tail elongates, the pedunculated pectoral fin becomes higher in position and an occipital fin ray develops (Houde, 1984). These characters easily served to identify the bregmacerotid larvae from other ichthyoplankton of Kagoshima Bay.

Except *B. japonicus* and *B. nectabanus*, the larvae of other four Japanese species were decribed nearly completely by Houde (1984). The larvae attributed to *B. nectabanus* by Houde (1984) and Houde et al. (1986) can be considered to be *B. neonectabanus* because their collection locality is included within the range of *B. neonectabanus* (Kimura, 1988) and their dorsal and anal fin ray counts of 44–51 are more similar to those of *B. neonectabanus* (43–48) than to *B. nectabanus* (46–57) (Masuda et al., 1986). The larvae of *B. japonicus* were described from large specimens, 11.5–22.4 mm SL, by Munro (1950). The 11.2 mm TL larva described as *B. japonicus* by Mito (1966) seems to be *B. nectabanus*, judging from its close resemblance to larvae of the closely related *B. neonectabanus* (Masuda et al., 1986).

Bregmaceros atlanticus. The larvae of this species comprised 2001 (92.12%) individuals of size range 1.9 to 7.5 mm SL.

The larvae of this species are the most heavily

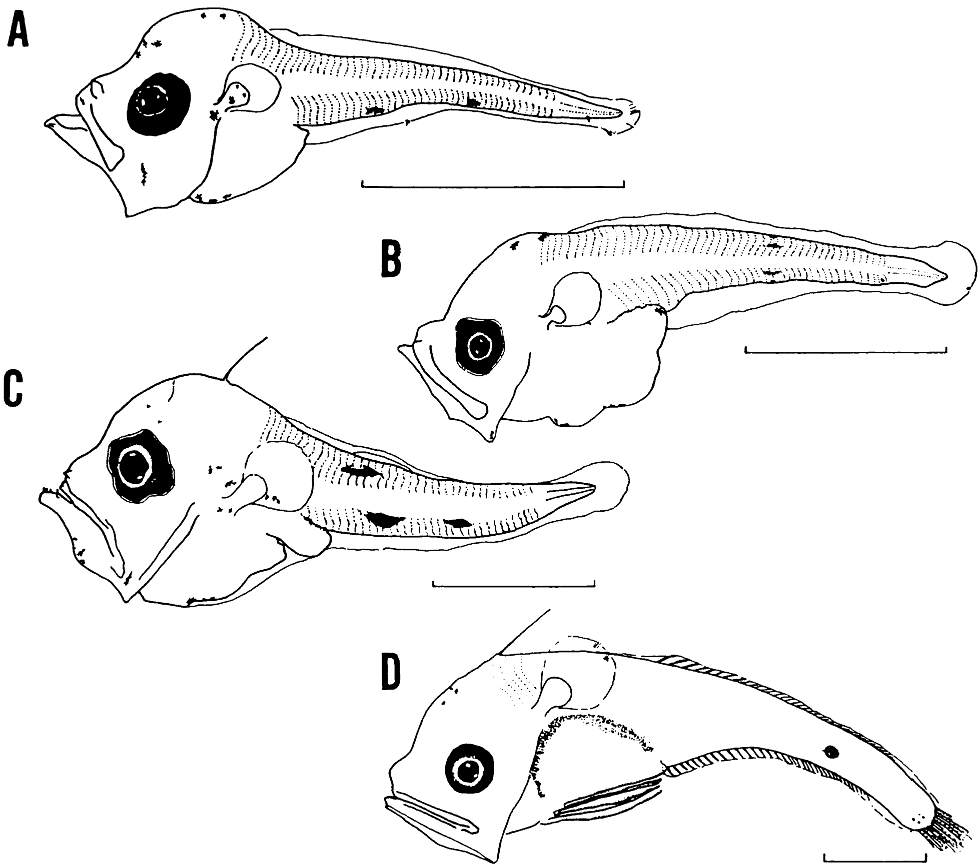

Fig. 2. Larvae of *Bregmaceros* species collected from Kagoshima Bay. A, *B. atlanticus*, 2.2 mm SL; B, *B. neonectabanus*, 2.8 mm SL; C, *B. macclellandii*, 3.2 mm SL; D, *B. nectabanus*, 5.2 mm SL. Scales indicate 1 mm.

pigmented among bregmacerotid species. Diagnostic melanophores are scattered on the head, over the midbrain and base to the peduncle of the pectoral fin in smaller larvae, and over most of the head and body including the dorsal, anal and caudal fins in larger larvae (Houde, 1984).

The above pigmentation was recognized in principle on all of the *B. atlanticus* larvae collected, together with the following changes with larval development. The smallest larvae (1.9–2.1 mm SL) show fewer melanophores on the head, over the midbrain, along the jaw and base to the peduncle of the pectoral fin, and on the body, only one large internal melanophore occurring on the ventral side at about the 35th myomere. At about 2.2 mm SL, a similar large melanophore appears on the ventral side of the body at about the 24th myomere, and a small dendritic melanophore at the ventral side just before the notochord end (Fig. 2A). The latter melanophore, which has never been previously reported (see the Discussion), moves to the lateral side of the caudal peduncle according to notochord flexion. Between 2.8–3.0 mm SL, two large internal melanophores appear on the dorsal side of the body opposite those on the ventral side. At more than 3.0 mm SL, the head and body become heavily pigmented, rendering the melanophore of the caudal peduncle inconspicuous.

In addition to melanophore patterns, a diagnostic character is the larval size at the time of development of the occipital ray, which is around 4.4 mm SL for the present larvae.

Two large individuals (6.9 and 7.5 mm SL) were stained for counting meristic characters (Table 1). Principal caudal fin rays could not be identified due to incomplete development of the caudal bones. The meristic counts compared well with those of *B. atlanticus* (D'Ancona and Cavinato, 1965; Belyanina 1974; Houde, 1984; Masuda, 1986).

Bregmaceros neonectabanus. The larvae described as *B. nectabanus* by Houde (1984) and Houde et al. (1986), which were from the Arabian Gulf, are considered to have been *B. neonectabanus*, based upon descriptions and distribution data analyzed by Masuda et al. (1986). Larvae of *B. neonectabanus* occurred in Kagoshima Bay. One hundred and sixty nine larvae (1.6–7.9 mm SL) or 7.8% of the total were identified as this species in the present study.

The larvae of *B. neonectabanus* belong to the lightly pigmented group of bregmacerotid larvae, and can be distinguished with the following melanophores (Houde, 1984): for small larvae, a single melanophore at the jaw angle, over the hindbrain, on the nape, on the dorsal surface of the intestine just anterior to the anus, and on the ventral side of the tail just anterior to the tip of the notochord, and diffuse melanophores in a short, double row on the side of the tail, on the dorsal and ventral finfolds directly above and below the double row, and along the midventral line of the abdomen; for large larvae, a single melanophore at the jaw angle, a few melanophores on the tail just anterior to its tip, at the base of the caudal fin, and along the midventral line of the abdomen, and internal melanophores on the side of the body between the origins of the dorsal and anal fins, and in the tail midway between the origins of these fins and tip of tail (Houde, 1984; Houde et al., 1986). Those along the midventral line of the abdomen were illustrated but not mentioned by Houde (1984: figs. 154 (A) and 156 (A); table 84) and Houde et al. (1986: fig. 6). They seem to be one of the distinctive characters to distinguish the larvae of this species from those of *B. nectabanus* (see below).

Table 1. Meristic counts of *Bregmaceros atlanticus* and *B. neonectabanus* larvae collected from Kagoshima Bay. SL, standard length (mm); TV, total vertebrae; AV, abdominal vertebrae; CV, caudal vertebrae; D, dorsal fin rays; A, anal fin rays; br, broken.

	SL	TV	AV	CV	D	A
B. atlanticus	6.9	53	14	39	51	51
	7.5	53	14	39	51	51
B. neonectabanus	7.8	51	14	37	br	br
	7.9	51	14	37	48	45

The change of melanophores with development was recognized in this study as follows. The smallest larvae (1.6–2.2 mm SL) show all the above characteristics except the melanophore near the tip of the tail, which appears at about 2.3 mm SL (Fig. 2B). At about 3.0 mm SL, the melanophores on the finfolds locate on the dorsal and ventral sides of the body. At more than 4.0 mm SL, the melanophore near the tip of the tail moves to the lateral side according to notochord flexion, and increases in number anteriorly. At about 5.0 mm SL, the double row of melanophores on the body is apparently internal, joining together at the midline of the body, and an internal melanophore on the midline between the dorsal and anal fin origins is present. The melanophores on the head, which increase in number with development, and those on the midventral line of the abdomen are distinct in the largest specimen examined (7.9 mm SL).

The two largest individuals in the present study (7.8 and 7.9 mm SL) were stained to count meristics. The principal caudal fin rays could not be identified because of the undeveloped caudal bones. The meristics presented in Table 1 are within the range for the species (Masuda et al., 1986).

Bregmaceros macclellandii. In this study, one larva of 3.2 mm SL (Fig. 2C) was identified to this species, which showed the same melanophore pattern and early formed occipital ray as those described by Houde (1984). It was collected at Stn. 6 on October 1, 1984.

Bregmaceros nectabanus. Under the name *B. nectabanus* larvae were described erroneously by Munro (1950) and Belyanina (1974). Those of Munro seem to have been *B. neonectabanus* because they have similar numbers of dorsal and anal fin rays to that species (Munro, 1950: p. 45). Those of Belyanina (1974) were regarded as *B. cantori* by Milliken and Houde (1984). As stated above, a larva of 11.2 mm TL described as *B. japonicus* by Mito (1966) seems to have been *B. nectabanus..*

In this study, one specimen of 5.2 mm SL, collected at Stn. 8 on December 17, 1986 (Fig. 2D) was tentatively identified as *B. nectabanus.*

The larva is lightly pigmented, with melanophores over the midbrain and on the dorsal surface of the abdomen, a mass of internal melanophores on the posterior part of the body, and about four melanophores near the base of caudal fin. The dorsal and anal fin rays seemed not completed posteriorly. The number of myomeres was about 52 but not decisive

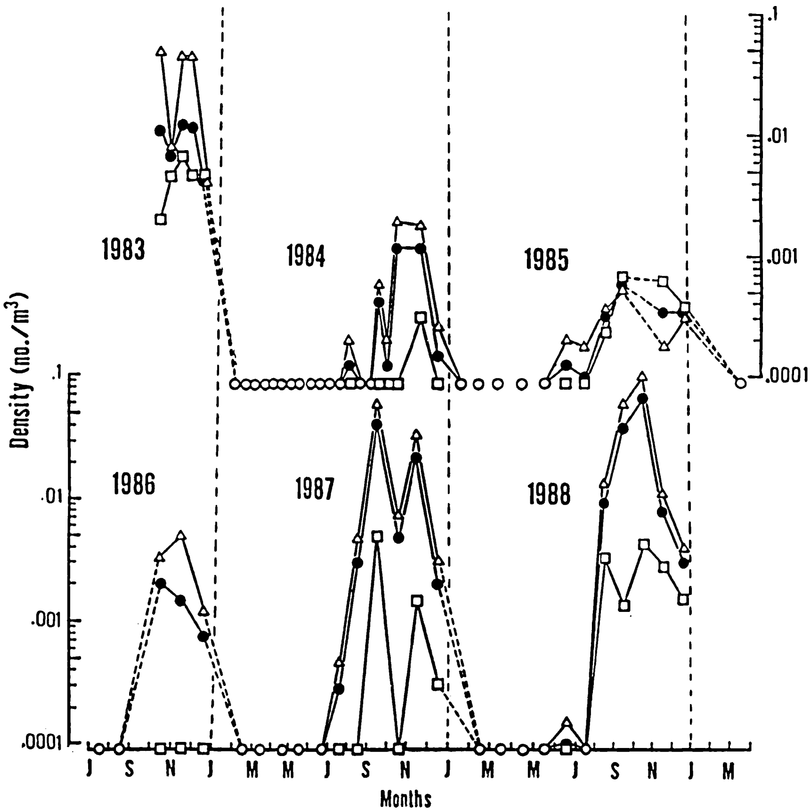

Fig. 3. Average cruise densities (no./m^3) of *B. atlanticus* larvae. Triangles, squares, black circles, and white circles indicate average cruise densities in the southern part, northern part and overall, and no larvae in cruise, respectively.

due to difficulty of counting.

The larva is very similar to *B. neonectabanus*, but some clear differences can be discerned; viz the melanophores on the head are located over midbrain in the present specimen vs hindbrain (base of occipital ray) in *B. neonectabanus*, a melanophore on the angle of the lower jaw is absent vs present, and melanophores along the midventral line of the abdomen are absent vs present.

Among the Japanese species, the larvae of *B. japonicus* and *B. nectabanus* have been incompletely described. The present larva has about 52 myomeres, and therefore is not *B. japonicus* which has more than 56 vertebrae (Okamura, 1984). Because of the uncertainty in counting meristics, the larvae was only tentatively identified as *B. nectabanus* in this study.

Temporal occurrence and abundance of the larvae

Temporal occurrence and abundance were analysed only for larvae of *B. atlanticus* and *B. neonectabanus*, because the other two species comprised only one specimen each in the samples.

Bregmaceros atlanticus. Fig. 3 shows the average densities (/m^3) of the larvae in collections from the northern and southern parts of Kagoshima Bay, and the overall total. The first appearance of the larvae in collections each year (not available in 1983) ranged from June (1985 and 1988) to possibly September (1986: no cruise in October). The last appearance (not available in 1988) was December in 1983 to 1987, although cruises in the following month, January, were not made except in 1985. The duration of occurrence (not available in 1983) lasted from three (1986) to seven months (1988), and showed no correlation with larval densities of the larvae. Peak densities (perhaps not sampled in 1983) occurred from September (1985 and 1987) to November (1984 and 1988). Densities in the southern

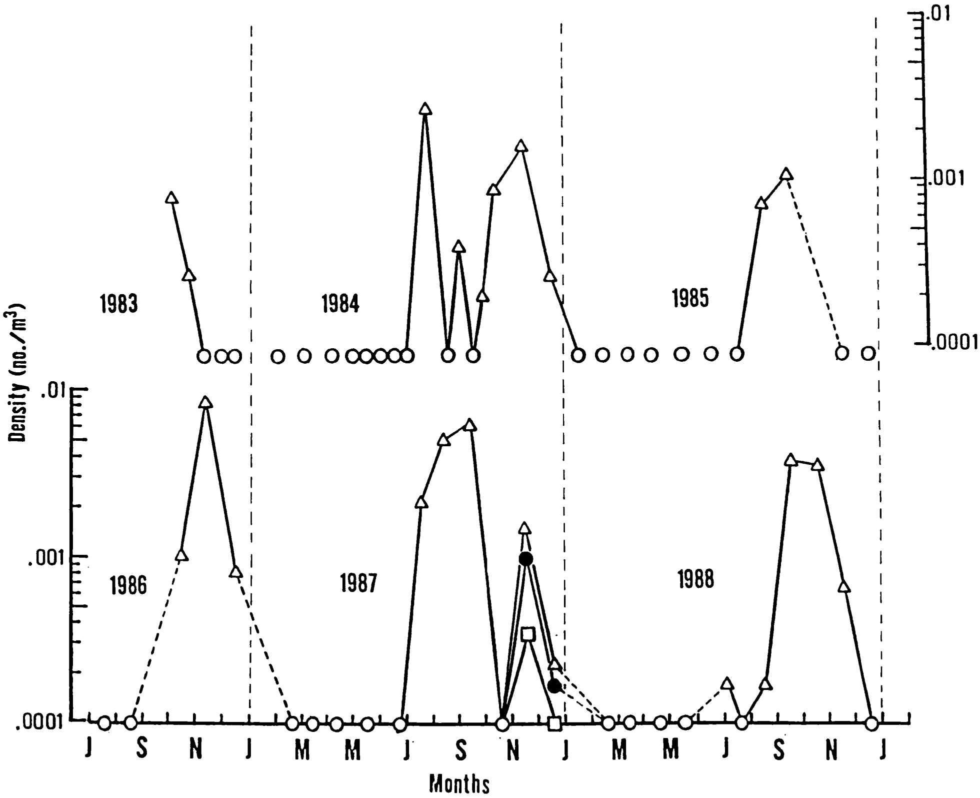

Fig. 4. Average cruise densities (no./m^3) of *B. neonectabanus* larvae in the southern part of the bay. For the symbol see the explanation of Fig. 3.

part of the bay conformed to the overall density pattern each year. Densities in the northern part showed nearly the same trend with the total in 1985, 1987 and 1988, but did not in 1984 and 1986 due to an almost complete or complete absence of the larvae.

The average annual densities fluctuated remarkably (Table 2). Overall densities were high in 1983, 1987 and 1988, and very low in 1984 to 1986. The highest estimate was in 1988 (1.781/100 m^3), which was 59 times higher than the lowest in 1985 (0.030). The low densities in 1984–1986 were slightly lower than those of *B. neonectabanus* (Fig. 4), but the high densities of other years were more than ten times those of *B. neonectabanus.* The density trend in the southern part followed closely that of the overall pattern. The highest southern bay density in 1988 (2.783) was 96 times that of the lowest in 1985 (0.029). The average annual densities in the northern part, apparently lower than those of the southern part, also showed largely the same trend as the overall pattern, although the average density was highest in 1983 (0.458), lowest in 1986 (0), and slightly exceeded that of the southern part in 1985 (0.032 vs 0.029).

Table 2. Average annual densities (no./100 m^3) of the larvae of *B. atlanticus* (upper three lines) and *B. neonectabanus* (lowest line). T, S, and N indicate overall sampling, southern, and northern parts, respectively.

	1983	1984	1985	1986	1987	1988
T	0.891	0.043	0.030	0.135	1.219	1.781
S	1.108	0.066	0.029	0.237	1.835	2.783
N	0.458	0.004	0.032	0	0.118	0.178
S	0.052	0.074	0.090	0.151	0.240	0.137

In summary, large fluctuations were observed both in temporal occurrence and abundance; first larval appearance was from June to possibly September, peak occurrence was from September to November, and the highest densities were more than 60 times

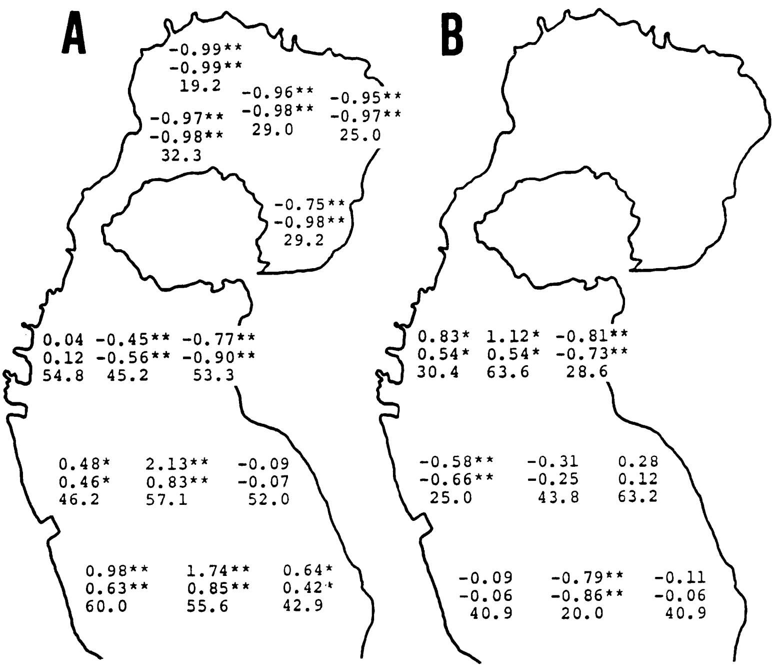

Fig. 5. Frequency of occurrence (lower figure), and slope (upper figure) and correlation coefficient (middle figure) of the linear regression between average cruise density (x) and difference (y) of station density from average cruise density at each collection station for *B. atlanticus* (A) and *B. neonectabanus* (B). Statistical significance of b and r is indicated by one (P=0.05) or two (P=0.01) asterisks.

those of the lowest ones, including absolute absence throughout the year (1986) in the northern part of the bay.

Bregmaceros neonectabanus. Fig. 4 shows the average densities ($/m^3$) of the larvae for cruise collections in the southern part of Kagoshima Bay only, except November 1987 when one specimen was collected at Stn. 10 in the northern part. Clearly, occurrence in the northern part was negligible for the species. The first appearance of larvae (not available in 1983) ranged from July (1987 and 1988) to possibly September (1986: no cruise on this month). The last occurrence ranged possibly from October (1985: no cruise on this month) to December (1984, 1986, and 1987). The duration of occurrence (not available in 1983) lasted from two (1985: no cruise in October) to six months (1987) and showed no correlation with the densities of larvae. The peak density (perhaps not sampled in 1983) was observed from August (1984) to November (1986).

The average annual densities in the southern part (Table 2) were low from 1983 to 1985 (0.052–0.090/$100\,m^3$), and high from 1986 to 1988 (0.137–0.240). There was a difference of only 3.2 times between the highest density in 1987 and the lowest one in 1984 (0.074) (the cruises in 1983 possibly did not cover peak occurrence).

The occurrence of larvae was nearly the same between the two species: first appearance from June to September for *B. atlanticus* and from July to September for *B. neonectabanus*; peak density from September to November for both species; and final occurrence in December for *B. atlanticus* and October to December for *B. neonectabanus.* However, average annual densities. Those of *B. atlanticus* fluctuated more than 60 times, inclusive of complete absence in the northern part. Those of *B. neonectabanus* were very low compared with *B. atlanticus*, and fluctuated within a range of only 3.2 times. In addition, the larvae of this species were completely absent from the northern part of the bay throughout the study.

Spatial occurrence and abundance of the larvae

Spatial occurrence was compared among stations with the ratio of positive collections to total collections limited to positive cruises. The results are shown in Fig. 5. For comparison of larval densities among stations, linear regressions $y=a+bx$ were computed between cruise mean density (x) and difference (y) of station density from cruise mean density. The significance of the constants a and b was tested statistically. In Fig. 5, the values of b and the correlation coefficient r are shown. Values of a, the intercept, were omitted because none differed statistically from zero.

Bregmaceros atlanticus. The ratios of positive collections, showing a relatively small range in each part, were apparently higher in the southern part of the bay (42.9–60.0%, average 51.9%) than in the northern part (19.2–32.3%, average 26.9%). The values of b showed the local difference in the southern part. They were positive ($P>0.95$) at the western south stations (4, 4X, 5, 5X and 6), and negative at the eastern north stations (6X, 8 and 9). They especially were high at Stn. 5 (1.74) and 5X (2.13). In the northern part, all the values of b were lower than zero ($P>0.99$) and were similar among stations.

In summary, the southern part showed local differences in density, the western south stations having higher densities and the eastern north stations lower ones. The northern part showed a frequency of occurrence half of that of the southern part, and lower densities.

Bregmaceros neonectabanus. Due to nearly complete absence of the larvae in the northern part, the analyses were restricted to the southern part. The ratios of positive collections showed a wide range of 20.0 to 63.6% (average 39.6%), and were scattered randomly. The values of b were more than zero ($P>0.95$) at the two western north stations (7 and 8), and less than zero at the other six stations except 6X which had an insignificant positive value.

The larvae of *B. neonectabanus* showed quite different spatial occurrence to *B. atlanticus.* First, they were limited to the southern part. Second, the densities of the larvae were high at the western north stations for *B. neonectabanus* but at the western south stations for *B. atlanticus.*

Discussion

There are many records of *B. atlanticus* worldwide (e. g., D'Ancona and Cavinato, 1965; Belyanina, 1974). However, the identity of the species still remains doubtful. D'Ancona and Cavinato (1965) recognized three regional forms with varied coloration: northern and central Atlantic, southern Atlantic and Indian Ocean, and Gulf of Panama forms. Houde (1984) noted differences in larval melanophores between eastern Pacific and Atlantic specimens. Masuda (1986) considered *B. atlanticus* from Kagoshima Bay to resemble the southern Atlantic and Indian Ocean form of D'Ancona and Cavinato (1965) in coloration, but remarked that his specimens had a higher number (14–15) of transverse scales than reported (11–13) by D'Ancona and Cavinato (1965). The larval specimens examined here showed unique tail melanophores which have not been described previously, and their autumn peak in densities differed from the spring to early summer peak recorded in the Gulf of Mexico (Houde, 1981). It is possible that *B. atlanticus* comprises a species complex that includes undescribed species.

Judging from both the oceanography (Sakurai and Maeda, 1980) and submarine topography and distribution pattern of bottom sediments (Ōki and Hayasaka, 1983), it is suggested that the predominant current movement in Kagoshima Bay is northward along the coast of Ōsumi Peninsula and southward along that of Satsuma Peninsula. According to Takahashi (1977), the exchange of water through the West Sakurajima Channel is caused by a difference in water densities (σt) between the southern and northern parts.

Among the four species identified in this study, *B. macclellandii* and *B. nectabanus* were probably immigrants from outside the bay because of their rarity in the samples. Immigration of *B. atlanticus* and *B. neonectabanus* into the bay seems unlikely since the densities of the larvae of both species were not high along the east coast compared with the other stations (Fig. 5). Exchange of populations through the West Sakurajima Channel may be unusual because only one specimen of *B. neonectabanus* was collected in the northern bay in spite of the high abundance of the species in the area south of the channel.

B. atlanticus and *B. neonectabanus* differed in spatial distribution. The former occurred throughout the bay with highest densities at the western south stations. On the other hand, *B. neonectabanus* larvae were almost absent from the northern part and showed their highest densities at the western north stations in the southern part of the bay. This difference seems to correspond to bottom sediments, especially clay content (Ōki, 1989; figs. 13 and 15), *B. atlanticus* occurring over bottoms comprising more than 20% clay and *B. neonectabanus* less than 20%. Bregmacerotids are considered pelagic, but owing to diel vertical migration (Milliken and Houde, 1984), can reach the bottom in shallow waters. In Kagoshima Bay, bregmacerotids have been caught with commercial bottom trawls (Masuda, 1986). Accordingly, the difference in distribution between the two species may be a reflection of their preference for different bottom sediments.

B. atlanticus showed large annual variations in densities (Fig. 3), a complete absence in 1986, and high abundance the following year in the northern part of the bay. As an exchange of populations is considered uncommon between the southern and northern parts of the bay, the absence in 1986 may have been caused by a cessation of spawning or simply reflected the small number of collections made during positive cruises compared with the other years (fifteen collections made in 1986 vs twenty-eight to thirty-seven in other years).

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鹿児島湾におけるサイウオ科仔魚の分布と出現量について

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1983年10月から1988年12月まで66航海817回の稚魚ネット定期採集を鹿児島湾内9–14定点で行った．33航海195回の採集に出現した2172尾のサイウオ科仔魚はセイヨウサイウオ2001尾，クロハラサイウオ169尾，そしてミナミサイウオと確

定的ではないがトヤマサイウオ各々1尾に同定された．セイヨウサイウオは湾全体に出現し，湾北部での密度と出現頻度は湾南部と比べ低かった．湾南部ではより高い密度が南西の定点でみられた．時期的に密度のピークは秋にみられ，また年平均密度の変動は60倍以上であった．クロハラサイウオは湾南部にのみ出現し，その中で北西の定点でより高い密度を示した．密度のピークは秋で，年平均密度の変動はわずか3.2倍であった．

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