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Anguilliform Leptocephali from a Fixed Station in Sagami Bay, Central Japan

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The anguilliforms are currently represented by 21 families and 153 genera, with about 720 species (Castle, 1984). Their larvae, commonly known as leptocephali because of their slender heads and leaf-like bodies, are oceanic, being presumed to be spawned and hatched offshore in clean, warm, saline water, even those of adults that spend most of their lives in estuaries or fresh water (Smith, 1989b). Although numerous papers have dealt with "leptocephalus taxonomy" since the mid 19th century, due primarily to the distinctiveness of the larval forms (for review, see Smith, 1989b), there still remain a number of leptocephali that cannot be adequately identified to species. In general, the biology of leptocephali is poorly known, except for the spawning grounds and spatial and temporal distribution, for example, of several commercially important anguillid species (for review, see Smith, 1989a; Tsukamoto, 1992) and a few other abundant, easily identified species such as the moringuid, *Moringua edwardsi* (Castle, 1979). Apart from difficulties in identification, one factor that hinders further knowledge of their biology stems from the fact that although studies with wide geographic coverage have been numerous, few have been intensive and site-oriented, including repeated collections made in a consistent, quantitative manner.

Since 1968, a total of 134 deep-sea oblique-haul samples have been collected at a fixed station in Sagami Bay (35°00′N, 139°20′E, ca. 1,500 m depth; Fig. 1) over a twenty-year period, in which each month of the year was covered. The station was located near the center of Sagami Bay, where about 20 adult anguilliform species are so far known (Yamada, 1990; Kudo and Okabe, 1991; Yamada and Kudo, 1992; Miya, unpublished data), including several commercially important ones such as *Conger myriaster* (reliable catch statistics unavailable). Although the samples yielded only about 50 leptocephali, a number comparable with that from just several catches from more oceanic water adjacent to the bay (Miya, unpublished data) or from Kuroshio waters (Uematsu et al., 1990), information on the seasonal occurrences of relatively more abundant leptocephali, together with other "negative" data, will guide future studies on Sagami Bay leptocephali.

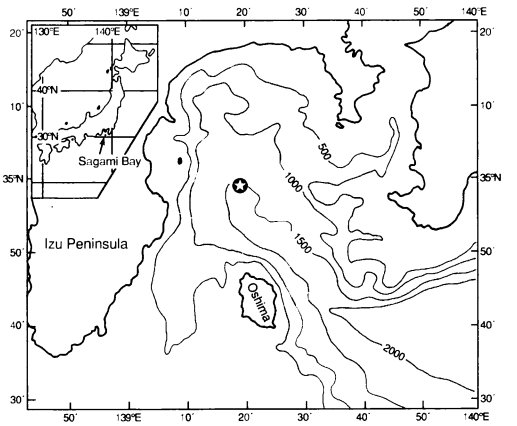

Fig. 1. Location of the fixed station in Sagami Bay (✪). Depth contours in meter.

Materials and Methods

Study site.—All samples were collected at a fixed station near the center of Sagami Bay (35°00′N, 139°20′E, ca. 1,500 m depth; Fig. 1) over a twenty-year period (1968–1988). Sagami Bay is located about mid-way along the length of Japan, its oceanographic features, particularly those of the surface, being greatly affected by the Kuroshio current, which flows northward along the eastern coast of Japan. A branch of the Kuroshio flows north-northeasterly into the bay, usually through the Oshima-West Channel and subsequently passes through the Oshima-East Channel on its return to the Pacific Ocean, thereby sweeping the southern half of the bay (Uda, 1937; Nakata et al., 1989). The surface temperatures vary considerably over a year, ranging from 15 to 25°C (see fig. 2 in Miya and Nemoto, 1991). The coolest surface temperatures are recorded during February and March, considerable vertical mixing occurring between the surface and 120 m depth, and the warmest, during August and September, when a clear, seasonal thermocline

develops between 20 and 50 m.

Monthly sampling.—A total of 104 oblique hauls were made during 31 cruises, from January 1968 to August 1984, using a large conical plankton net (ORI net: mesh size, 0.33–1.0 mm; mouth diameter, 160 cm; Omori, 1965) (for detailed sampling method and data, see Miya and Nemoto, 1986; Miya, 1994a). The maximum depth fished by the net varied from 310 to 1,500 m (average depth 930 m). A total of 30 oblique hauls were made during eight cruises, from December 1934 to July 1988, alternatively using an Isaacs-Kidd plankton trawl (IKPT; Loeb, 1979) with a mouth area of 7.32 m^2 and a mesh opening of 0.5 mm (for details, see Miya and Nemoto, 1986, 1987, 1991; Miya, 1994b). The IKPT was towed obliquely two to eight times during each cruise, from the surface to 730–1,410 m (average depth 1,110 m).

Sample processing.—The samples were fixed in 5–10% buffered formalin seawater immediately after collection, later transferred to 70% ethanol for preservation and eventually deposited at the Natural History Museum and Institute, Chiba, Japan. All leptocephali were separated from the plankton samples, being identified to species wherever possible (specimens and associated taxonomic data are available upon request to the senior author). They were later counted and standard length (SL) measured to the nearest 0.1 mm. Possible shrinkage after preservation with ethanol was not taken into account.

Data analyses.—Of the total 134 oblique-haul samples from the fixed station, 74 night-time samples (those taken between one hour after sunset to one hour before sunrise) were used for the present study, because of possible net avoidance during day-time tows. In fact, only seven leptocephali were collected from the 60 day-time samples. To investigate seasonality, all data were pooled for respective months, because of the scarcity of specimens. In addition, because leptocephali are concentrated principally in the upper 100-m layer at night (Kajihara et al., 1988; Smith, 1989b), their abundances were standardized to number per 1,000 m^3 in the upper 100-m layer by applying the following equation (the nets were assumed to have filtered equal volumes of water in successive layers during the oblique hauls):

$$\text{Abundance} = N \times \frac{100\ MD}{100\ VWF}$$

where N = number of fish caught, MD = maximum depth reached by net (m), and VWF = volume of water filtered by net (m^3).

In the following account, family names and arrangement follow Nelson (1984).

Results

Seventy-four night-time oblique hauls made at the fixed station in Sagami Bay yielded 42 leptocephali, representing five families with up to 15 species. Six individuals were unidentifiable to family, owing to their small size (Table 1). Apart from the latter, all leptocephali were separable on the basis of diagnostic features such as myomere counts and pigmentation, although only five (one synaphobranchid eel, *Dysomma anguillare*, and four congrid eels, *Gnathophis nystromi nystromi*, *Conger myriaster*, *C. japonicus*, *Muraenesox bagio*) could be definitely identified to species. The meristic and pigmentation characters of Ophichthinae sp. 2 (Table 1) agreed well with those of Ophichthinae sp. 3, previously described by Mochioka (1988b). Other unidentified species could not be referred to any previously described leptocephali, despite extensive literature surveys.

Leptocephali occurred in all months, except August (Table 1). Estimated mean abundances, indicated by the number of individuals per 1,000 m^3 in the upper 100-m layer, were apparently higher during the autumn and winter months (0.60–0.96; September–February) than during the spring and summer months (0–0.45; March–August) (Fig. 2), a significant difference being found between these two periods (Mann-Whitney U-test, $p < 0.01$). However, there was no significant difference among monthly abundances (Kruskal-Wallis test, $p = 0.340$), indicating that variations among tows from the same month were greater than between-month variations.

There were some indications of seasonality among the three most abundant species, *Gnathophis n. nystromi*, *Conger myriaster* and *C. japonicus*, all congrid eels (Table 1). Ten *G. n. nystromi* leptocephali were collected, their occurrence being restricted to between September and March. They were smaller during September–November (11–35 mm SL) than during December–March (34–79 mm SL, including one transforming individual), suggesting that spawning occurred before the September–November period. The occurrences of the other two species were also restricted, to several months between February and June (except April) for *C. myriaster* and between October and November for *C. japonicus*. Seasonality in the other, less abundant leptocephali, was not discernible because of the scarcity of specimens.

Table 1. Monthly pooled catch data of anguilliform leptocephali from a fixed station in Sagami Bay. Numerals indicate the number of individuals collected during respective months; SL measurements (mm) are given in parentheses

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
VWF100* (No. tows)	4,150(4)	5,110(7)	6,813(8)	3,401(3)	4,110(4)	8,226(9)	12,578(6)	2,492(3)	8,932(5)	10,605(7)	30,832(17)	1,039(1)	Total
No. of leptocephali	2	3	3	1	1	2	1	——	6	5	17	1	42
Muraenidae ($n=3$)													
Muraenidae sp. 1	——	——	——	——	——	——	——	——	——	——	1(60)	——	1(60)
Muraenidae sp. 2	1(68)	——	——	——	——	——	——	——	——	——	——	——	1(68)
Cyematidae ($n=1$)													
Unidentified	——	——	1(12)	——	——	——	——	——	——	——	——	——	1(12)
Synaphobranchidae ($n=1$)													
Dysomma anguillare	——	——	——	——	——	——	——	——	——	——	1(56)	——	1(56)
Ophichthidae ($n=7$)													
Myrophinae sp. 1	——	——	——	——	——	——	——	——	1(39)	——	——	——	1(39)
Ophichthinae sp. 1	——	——	——	——	——	——	——	——	——	——	2(38–47)	——	2(38–47)
Ophichthinae sp. 2[a]	——	——	——	——	——	1(86)	——	——	——	——	2(66–69)	——	3(66–86)
Unidentified	——	——	——	——	——	——	——	——	——	——	1(19)	——	1(19)
Congridae ($n=32$)													
Ariosoma sp.	——	——	——	——	——	——	——	——	——	——	1(61)	——	1(61)
Gnathophis nystromi subsp.	1(34)	1(75)	1(79)	——	——	——	——	——	1(11)	3(29–35)	2(26–28)	1(78)†	10(11–79)
Gnathophis sp.	——	——	——	1(96)†	——	——	——	——	——	——	1(53)	——	2(53–96)
Conger myriaster	——	2(101–103)	1(112)	——	1(102)	1(84)	——	——	——	——	——	——	5(84–112)
Conger japonicus	——	——	——	——	——	——	——	——	——	1(71)	4(65–83)	——	5(65–83)
Congrinae sp.	——	——	——	——	——	——	——	——	——	1(132)	——	——	1(132)
Muraenesox bagio	——	——	——	——	——	——	1(58)	——	——	——	——	——	1(58)
Unidentified	——	——	——	——	——	——	——	——	4(6.8–14)	——	2(10–17)	——	6(6.8–17)

*Calculated total volume of water filtered (m^3) by night-time oblique tows in the upper 100-m layer the method for calculation, see text; †metamorphosing leptocephali; [a]cf. Ophichthinae sp. 3 in Mochioka (1988b).

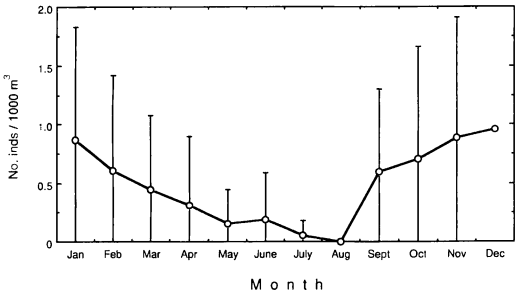

Fig. 2. Monthly changes of mean abundance of leptocephali from the fixed station in Sagami Bay. Vertical bars indicate ±standard deviations.

Discussion

Although the above sampling programs were not originally designed to specifically collect leptocephali, there have been no comparable intensive site-oriented studies that included repeated collections made in such a consistent, quantitative manner except for that made by Brache (1977) in Gulf of Guinea. Smith (1989b: 666–667) outlined sampling programs in the western Gulf of Mexico that had been conducted at 10–13 stations during each seasons, in order to determine which leptocephali were present and to gain some idea of seasonal and spatial distributions. While the collections have provided a basis for taxonomic studies of leptocephali from the western North Atlantic (see Bölke, 1989), the results have not been published in terms of species' composition, seasonal occurrence, or abundance. Meaningful reports of the latter aspects cannot be entertained unless a large proportion of leptocephali can be adequately identified to species, concurrent with sound development of adult taxonomy. Actually, of the 15 types (species?) of leptocephali recognized in the present study, only six could be definitely identified, because of their unique diagnostic features.

Some indications of seasonality were observed in the occurrences of the three congrid leptocephali (*Gnathophis n. nystromi*, *Conger myriaster* and *C. japonicus*). Although reliable information is lacking, the data agree well with previous observations. Uematsu et al. (1990) reported catches of 33 *G. n. nystromi* leptocephali from Kuroshio waters in January, which falls within the period observed in the present study (September–March). Numerous *C. myriaster* leptocephali, in late developmental stages (≥84 mm SL), reportedly occur along the Pacific coast of Japan during December–July (Mochioka, 1988a), the size and period being consistent with the present observations (84–112 mm SL; February–June). Mochioka et al. (1988) reported the November capture of a single preleptocephalus of this species (16 mm in total length) from Suruga Bay, an adjacent water across the Izu Peninsula, suggesting that spawning may take place near the bay during autumn months. This suggestion, however, was not substantiated, because of the lack of comparable *C. myriaster* in the present samples. Ochiai et al. (1978) reported numerous *C. japonicus* leptocephali from inshore waters of Tosa Bay, Shikoku Island, from October to March, peaking in December, this also being consistent with the present results (October–November).

The total of 42 leptocephali caught was very low, compared with that from only several tows made in the more oceanic waters adjacent to the bay, which yielded a comparable number of leptocephali (Miya, unpublished data), and considerring the number of anguilliforms species known from Sagami Bay (>20; Yamada, 1990; Kudo and Okabe, 1991; Yamada and Kudo, 1992; Miya, unpublished data). It should be noted that Uematsu et al. (1990) collected 41 leptocephali at six stations from Kuroshio waters off Shikoku Island, southern Japan, during a single cruise in January 1990.

It might be possible that the fixed station was not located on the major inshore migration routes of anguilliform leptocephali in Sagami Bay, because the station was just north of Oshima Island (see Fig. 1), which is positioned so as to form the Oshima-West and East channels, through which oceanic waters enter the bay. If so, seasonal extensive grid surveys should be conducted, if basic biological information, such as species composition and spatial and temporal distribution patterns, is sought.

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相模湾の定点から採集されたウナギ目の葉形幼生

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相模湾のほぼ中央に位置する定点（35°00′N, 139°20′E, 水深約1,500 m）で過去20年間に行われた計74回の大型プランクトンネットを用いた月別夜間傾斜曳きにより，5科，15タイプ（種まで同定された5種を含む）からなる42個体のウナギ目の葉形幼生が採集された．葉形幼生の出現個体数は秋から冬（9月–2月）にかけて多く，春から夏（3月–8月）にかけて少なかった．最も多く出現した3種（*Gnathophis nystromi nystromi* ギンアナゴ，*Conger myriaster* アナゴ，*C. japonicus* クロアナゴ）の出現は季節的で1年のうちの数カ月に限られていたが，他の種では，採集個体数が少なかったためもあり，そのような季節的な出現は認められなかった．

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