On the Records of a Leptocephalus and Catadromous Eels of *Anguilla japonica* in the Waters around Japan with a Presumption of their Spawning Places※

By

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1. Introduction

GRASSI and CALANDRUCCIO (1896) obtained proof that *Leptocephalus brevirostris* KAUP is the larva of an eel, and subsequently SCHMIDT (1906—1935) investigated its life history on the basis of many collections from larvae of Europeo-American, South-Pacific and Indo-Malayan eels by his various contributions and after his death, EGE (1939) and JESPERSEN (1942) pursued the collections secured in his expedition round the world during 1928—1930 for further researches.

The former reported "A Revision of the Genus *Anguilla* SHAW, a systematic phylogenetic and geographical study" and the latter reported "The Indo-Pacific Leptocephalids of the Genus *Anguilla*". On the other hand the first collection by UCHIDA (1925) concerning leptocephalus of *Anguilla japonica* was merely recorded and, although its earnest pursuit has been made until now, it has not yet been collected as evidence. Presumptions concerning the spawning places by MEEK (1916), SCHMIDT (1925), OSHIMA (1941), JESPERSEN (1942) and MATSUI (1952) have not yet been established as a theory. The author is in a position to define the leptocephalus of *Anguilla japonica* in Japan and has conducted a survey of the catadromous eels caught in the waters around Japan.

The author, from their probable spawning places, has made a report here based on the above-mentioned results. Before going further, the author wishes to acknowledge his indebtedness to Prof. Dr. K. UCHIDA of Kyushu University who had the kindness to lend him his valuable sample of leptocephalus with useful advice, to his colleagues Prof. T. CHIBA and Instructor H. MAEDA who submitted a leptocephalus to the author, to Mr. K. WATAUCHI of Miyazaki Prefecture Pelagic Fisheries Guidance Station, to Mr. T. ITO of Yamaguchi Prefectural Open Sea Fisheries Experimental Station, and to Mr. H. HIROTA of Nichiro Fisheries Co. for their great assistance in collecting samples of catadromous eels.

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Thanks are also due to Mr. S. NISHIKAWA of our college who helped the author in making the preparations of the genital gland.

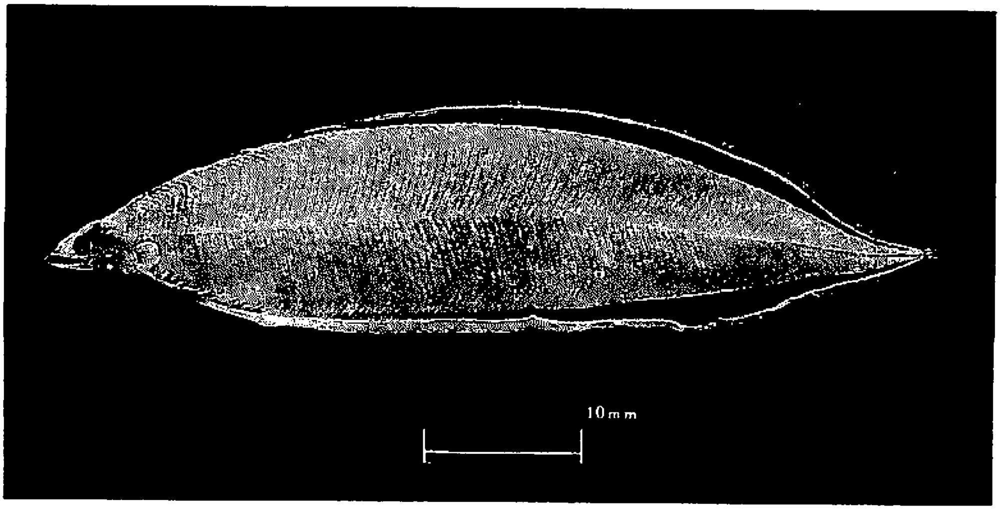

Fig. 2. Photograph of the leptocephalus of *Anguilla japonica*.

2. The diagnosis of the leptocephalus of *A. japonica*

While the survey of effect on radioactivity in the waters around the Bikini Atolls was being conducted by the "Shunkotsu Maru" during May—June, 1956, a specimen of leptocephalus of *Anguilla japonica* was collected by the collecting-net for macro-plankton, measuring 150cm in diameter, 450cm in length, bolting silk GG 56, and mesh $54\frac{1}{2}$. The collecting-net had a 3.5kg lead sinker attached to its lower part and a 170m rope tied to its upper part, and was put down into the sea over 4,000 m deep, while the vessel was sailing at a speed of 24—42.5 m/min, and pulled up vertically. It was June 25, 1956 when the fish was caught for specimen in the shallower sea about 150 m deep lying between the Uracas and the Volcano Islands, 142°40′E, 23°15′N.

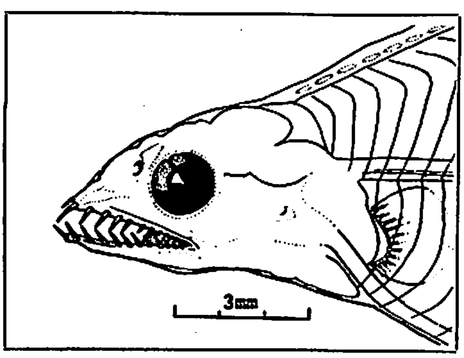

Fig. 3. Head region of the leptocephalus, especially showing the dentition.

The hydrographic conditions which were observed by HORI and SHIMANO(1956) at that time are given in Table 1 and Fig. 1. Water temperature was 20.63°C—29.4°C, Salinity 19.43—19.54% comparatively high temperature and salinity. The author has followed JESPERSEN (1942) in examining the specimen and the results obtained are given in Table 2. This specimen is 55.7mm in total length and, as shown in Fig. 2, looks like a small leaf, very broad for its length and very thin for its breadth, the total length being 3.8 times as long as the maximum height in the center of the body and narrowing roundly both in posteriority and anteriority.

The top and tail are somewhat tapering, postanal length being 28.2% and myotomes numbering 120, with 79 at preanal portion, and 34 at ano-dorsal distance. The snout is moderately pointed, the lower jaw projects more slightly than the upper one, and the posterior maxilla attains towards far behind the center of the eye, but not towards the posterior margin of the eye. Eyes appear round. Tangue is distinct. A large grasping tooth is situated on

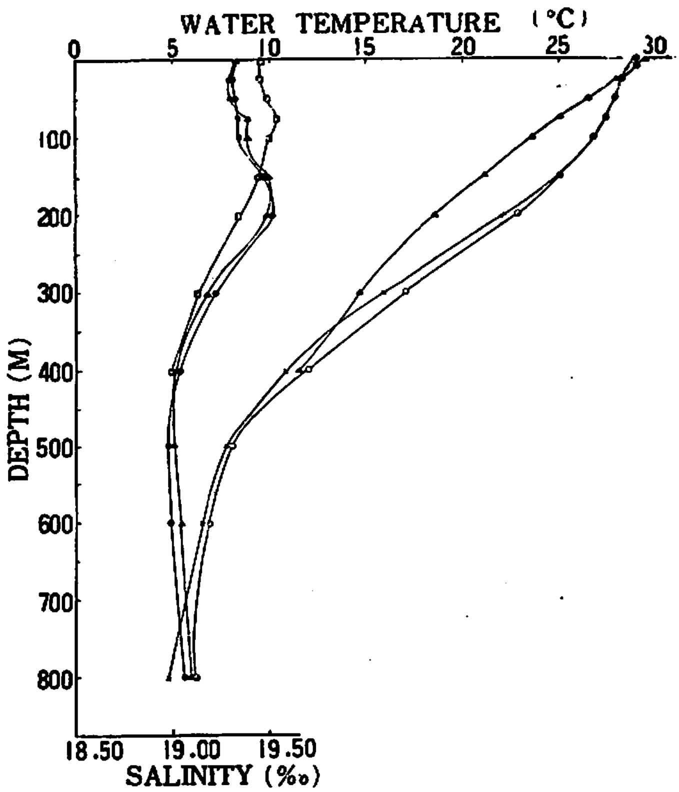

Fig. 1. Vertical distribution of temperature and salinity of the sea where the leptocephalus was caught.

Table 1. Oceanographical condition in the waters where the leptocephalus was collected (after HORI and SHIMANO 1956).

Date of observation	June 24, 1956. 19 h 20 m—21 h 00 m			
Locality	19°00′ N, 145°23′ E			
Depth (M)	Temperature (°C)	Cl (‰)	6 tD	Dynamic depth
0	29.4	19.46	22.07	0
10	29.04	19.45	22.23	9.783
25	27.93	19.45	22.63	24.454
50	26.42	19.49	23.30	48.893
75	25.09	19.54	23.90	73.317
100	23.56	19.50	24.39	97.727
160	20.63	19.43	25.23	146.517
206	18.22	19.32	25.99	195.268
302	14.58	19.12	27.04	292.685
400	11.43	18.99	27.99	390.007

Table 2. Morphometric measurements, counts of myotomes and proportional ratio of bodily parts for the leptocephalus of *Anguilla japonica*.

Total length	55.7mm
Standard length	54.9mm
Greatest depth	14.8mm
Length from tip of snout to origin of dorsal fin (D)	25.9mm
Length from tip of snout to origin of anal fin (A)	40.4mm
Ano-dorsal distance	14.5mm
Length of pectoral fin	1.8mm
Diameter of eye	1.3mm
Ano-dorsal distance/Total length	25.9
Number of myotomes	120
Number of preanal myotomes	79
Number of myotomes in ano-dorsal distance	34
Situation of vertical blood vessels	15,46,49,59
Dentition	1+4+8

each anteriority of the upper and lower jaws, and there is a row of 4 large teeth behind the grasping tooth in the upper jaw, behind which is another row of 8 smaller teeth (see Fig. 3).

In the lower jaw the teeth behind the grasping tooth are, more than eleven in number of uniform size, gradually decreasing in size posteriorly. The dental formula is 1+4+8. There is one comparatively large nostril and the pectoral fin appears oval in shape. Both dorsal and anal fins are emerged enough and the rays of the pectoral fin numbering 15 are also apparently seen. The pigment is wanting.

The specimen possesses the above-mentioned formal diagnois, which is discussed below in detail. The number of vertebrae, as seen from the researches by SCHMIDT (1909), (1925) and EGE (1939), is of the greatest importance in determining the species of the eel. JESPERSEN (1942) showed that it was a significant cause for the number of myotomes, which is closely related with vertebrae, in determining leptocephalus; it is estimated that on the average the number of vertebrae is one less than that of myotomes. Eight species of the eel widely distributed in the waters around the northern hemisphere of the Pacific Ocean, including the Banda Sea, the Celebes Sea, the South China Sea, the Sulu Sea, the Mindanao Sea, the Molucca Passage, north west of New Guinea, the Bay of Siam, Formosa and adjacent territories, the East China Sea, the Yellow Sea, the Pacific Ocean, and the Japan Sea, were reported by EGE (1939). Their numbers of vertebrae are given in Table 3. As to the number of vertebrae of the eight species, *A. japonica* can be apparently distinguished from the other seven species. *A. japonica* is the only species of which the number of vertebrae is more than 110. The Japanese eel may be divided in two species: temperate *A. japonica* and tropical *A. marmorata*, which are widely distributed in the South Pacific Ocean and the Indo-Pacific Ocean. The number of

Table 3. Ano-dorsal distance and number of vertebrae in species of *Anguilla* from Japan, Eastern Indo-Malaya and New Guinea.

Species	Ano-dorsal distance % in total length	Number of vertebrae	
		Variation	Average
Anguilla japonica	9.2	112—119	115.8
A. marmorata	16.3	103—109	105.5
A. borneensis	11.5	103—108	105.5
A. interioris	13.0	104—107	105.4
A. celebesensis	9.0	101—107	103.4
A. ancestralis	9.6	101—106	103.3
A. bicolor pacifica	0.2	103—110	107.2
A. obscura	3.6	102—107	104.0

vertebrae of *A. japonica* is as follows; 112—119, average 115.376 ± 0.062 by SCHMIDT; 111—119, average 115.65 by ISHIKAWA and TAKAHASHI; 112—119, average 115.888±0.404—116.111 ± 0.106 by MARUKAWA; 112—119, average 115.818±0.034 by EGE. As to that of *A. marmorata*; 110—107 by ISHIKAWA and TAKAHASHI; 99—107 by TAKAHASHI; 100—110, average 104.647±0.064—106.444±0.048 by EGE. It is apparent from the figures given above that we can tell the one from the other with 110 as the point of distinction. Vertebrae are numerous in *Apodes* except the eel. For example, the vertebral number of *Conger myriaster* amounts to 139—147, and that of *Rhynchocymba nystromi nystromi* to 113—124, *Oxyconger leptognathus* holds 111—119, but it can be easily distinguished from the pigmentary distribution, external characteristics, and especially from the anal position, body height and head length.

As the number of myotomes of the specimen is 120, the number of vertebrae in case of variation of this specimen indicates 119. The number of myotomes, according to UCHIDA's specimen (1935), coming to 118, the vertebral number amounts to 117, which indicates the approximate value, and is involved in the range of the variation of the vertebral number of the *Anguilla japonica*. BRUUN (1937) mentioned "that the figure and photograph of a leptocephalus which had been given by UCHIDA(1935) afford sufficient grounds for saying with certainty that it is not an *Anguilla*'s leptocephalus. One does not need to be able to read the Japanese text, the pigmentation above the brain and the characteristic, rounded tail show definitely that the larva must be referred to *Muraena* or its allied genus". And JESPERSEN (1942) agreeded with his opinion. The author has investigated this by using UCHIDA's specimen, and found that the part of the tail appears round in its photograph of his papers, though not so in the original specimen, and that the tail tapers off, as UCHIDA described in Japanese. As indicated by BRUUN, we can safely say that the number of myotomes is the safe way of determining definitely whether or not a leptocephalus will belong to that of *Muraena* and its genus, whose species have at least over 124 myotomes.

Another point of difference which the author has noticed is that the origin of dorsal fin is originated from the head in the adult fish and that the pectoral fin is laking. But the author is sure that UCHIDA's specimen corresponds to leptocephalus of *Anguilla japonica*. Comparisons between the author's specimen with UCHIDA's are given here to show how they differ in various points. In the total length, the former is about two times as large as the latter though they are fairly different in size, which shows the different degree of growth in them. The ratio of the height to the total length is 5.9 to 3.8, while the author's is fairly heavier than UCHIDA's. It is thought that in UCHIDA's specimen, the disappearance of the dorsal fin, the anal fin and some teeth is owing to different stages of development.

When the auther's specimen is compared with UCHIDA's one, the posterior end of the mouth cleft in the latter is located more behind than that of the former. The number of myotomes minus one is found in the range of variation of the vertebral number of *Anguilla japonica*, which does not make the numerical difference of vertebrae between these two specimens. But the number of myotomes at the postanal portion indicates the proportion of 79 to 70, the proportion of the total length and postanal portion corresponds each other. By SCHMIDT (1906) and STRUBBERG (1913), the leptocephalus of the eel was divided into six stages according to the degree of growth this specimen falls under 1st stage. Among the more temperate species of the Indo-Pacific, e. g. *Anguilla japonica*, *A. dieffenbachi* and *A. australis*, the length of the full-grown larvae is not known, but, judging from the length of the elvers, they are presumably somewhat larger than those of tropical eels in the corresponding stages and the average length of full-grown larvae of *A. anguilla* is about 75 mm and that of *A. rostrata* about 60—65 mm; hence this specimen is not a full-grown larva, being 55.7 mm in size by 1st stage, so it is presumed to be somewhat more grown than the 55.7 mm.

3. The collection of catadromous eels

It is generally accepted that the Japanese eel descends from the fresh water to the sea, suitable place for spawning towards the end of September until early in December. On January 20, 1954 HIRASAKA and HONMA (1954) caught catadromous eel in the sea at a depth of 250 meters off Awashima 139°11′E and 38°20′N. This is the only record in Japan concerning catadromous eels. The author has recently had eels sent by some fishermen who are interested in the eel which happened to be caught in the net mixed with other fish. The author has kept the eels as specimen, the records of which are given in Table 4.

A) The Period of catadromous migration

The catadromous eels in the sea, as seen from the records tabulated below were

Table 4. Records of the catadromous eels caught in the waters around Japan.

Date	Locality	Depth (m)	Depth caught	No. of specimen	Total length (cm)	Body weight (g)	Sex	Fishing gears	Remarks
Oct. 1939	Kumanonada	300		1			?	One boat medium trawl	
Sept. 24, 1952	NW 15 miles off Kawajiri, Yamaguchi	200	Surface	1	40.0	60	♂	Spoon net	School of 5 or 6 individuals
Dec. 5, 1952	NW 30 miles off Kochiga of Goto Is.	125	Surface	1	45.3	400	♂	Mackerels' pole and line	
Dec. 10, 1953	34°30′ N, 123°30′ E	80	80	2	80.7—79.5	880—900	♀	Otta trawl	
Dec. 15, 1953	28°30′ N, 124°40′ E	100	Surface	1	49.5	520	♂	Mackerels' pole and line	
Jan. 11, 1954	31°58′ N, 125°55′ E	70	0—70	1	75.5	770	♀	Otta trawl	
Jan. 20, 1954	38°20′ N, 139°11′ E	250	0—250	1	62.6		♀	One boat medium trawl	Hirasaka and Honma's report
Dec. 18, 1954	28°44′ N, 124°35′ E	88	Surface	3			♂ 2, ♀ 1	Mackerels' pole and line	Water temperature, 19.8°C
Dec. 20, 1954	28°45′ N, 124°37′ E	76	Surface	4	48.6—67.8	150—430	♂ 1, ♀ 3	Mackerels' pole and line	Water temperature, 19.2—19.6°C.
Jan. 10, 1956	27°35′ N, 124°15′ E	80	Surface	3	51.2	180	♀	Mackerels' pole and line	Water temperature, 18.8—19.0°C.
Dec. 22—Jan. 8, 1954—1956	27°50′ N—28°40′ N, 124°40′ E—125°02′ E.	70—80	Surface	8	47.2—74.5	143—540	♀	Mackerels' pole and line	Uchida's report

caught during the period between September 24 and January 20. As the oceanic conditions vary every year, they may descend to the sea for about a month from September 24 to December 5, or from December 18 to January 11. The first period of migration is about the end of September, but in the northern district of Japan early in September, silver eels leave the pool and water-course in the interior and descend by degrees towards the mouths of rivers, or those which live in the littoral lagoons and estuaries also reach the sea water. In the southern region down to the middle of Japan, they gradually descend slowly from the north to the sea and their downstream migration comes to an end.

Thus catadromous eels captured in the sea from the end of December to the middle of January may have descended from fresh water to the sea much earlier. HIRASAKA and HONMA's joint records have it that catadromous eels were caught in the northern waters of Japan on January 20, which shows that the fish descend from fresh water to the sea, extending over a long period of time and that their spawning also extends over a long time. On the other hand, though *A. japonica* is distributed fairly wide, it is presumed that catadromous eels captured in the East China Sea migrate downstream from the coast along the East China, especially along the northern coast of Korea, the continent of China, and the Japan Sea. Therefore, local temperature and salinity, alternation of day and night in particular, may make the period of migration different, compelling eels to make detours or to stop in their course, thus retarding their migration.

B) The locality of collection

The author's record of catadromous eels captured in the sea is given in Table 4, Fig. 4. According to these, a vast range of variations are found in the area between the sea 15—30 miles off the coast and the mid-East China Sea.

The locality where eels have recently been caught in plenty is the East China Sea off about 270 miles west of the Amami Oshima, where various fishing vessels operate during December and February as it has proved to be a good fishing ground for mackerel. Fishermen in their fishing boats can not only see with gathering lamps eels swimming in the surface water layer in several schools, but also catch them easily with the spoon net or a dip net. It is impossible for us to know the depth of the sea where the specimens were collected by the otta trawl or the two boat trawl net. However as seen from many other demonstrations, they seem to swim near the surface layer. CLIGNY (1912) explained the fact that they habitually swim well off the bottom, and are out of reach of the trawls. As to the relation of the current to the location where catadromous eels are found in abundance, the location does not lie in the main stream of the main currents, such as the Tsushima Warm Current, Kuroshio, and cold water of the Yellow Sea, but in the current rip between the Tsushima Warm Current and coastal current or between the Kuroshio and Cold Water of the Yellow Sea. ROULE (1937) showed that from rivers or littoral pools, eels are led to the sea by the out-going water, and FONTAINE and CALLAMAND (1943) and FONTAINE (1945) determined that they are less active by a rapid fall of the water temperature, and besides, eels' muscular strength slightly diminishes because their migration is made passive by the current due to the want of nutrition caused by their fasting, all this being responsible for their negative rheotaxis.

These facts show that catadromous eels in the sea travel round their spawning places through these current rip instead of following the strong current, such as the Japan Current and the Tsushima Warm Current. It is not due to the phototaxis, but to the ceasing of the movement caused by the powerful light that they are considerably caught under the gathering lamp in the mackerel pole and line fishing ground in the East China Sea. This is based on the fact that catadromous eels are more active by night than by day. The water temperature in fishing points out 18.8°C—19.8°C. Eels move with greater activity in high temperature than in low temperature, and catadromous eels seem to travel in pursuit of high temperature. The measurement of the collected eels is shown in Table 5. Judging from the vertebral number and the external morphological characteristics, each specimen seems to belong to *Anguilla japonica*. Its body length is 40.0 cm in minimum, 40.0—49.5 cm in male, 51.2—79.5 cm in female, its weight being 60g in minimum, 880g in maximum. The author (1952) examined the sexes of 11,097 Japanese eels, and

Table 5. Morphometric measurements (mm) and proportional ratios of bodily parts for the catadromous eels.

Date of collection	Dec. 20, 1954				Sept.24, 1952	Dec. 10, 1953	Jan. 10, 1956
No. of specimen	1	2	3	4	5	6	7
Total length	62.6	67.8	60.8	48.6	40.00	79.5	51.2
Weight (g)	371	430	340	150	60	880	180
Head length	7.5	7.6	6.6	6.1	5.0	8.6	6.3
Length from tip of snout to origin of dorsal fin	19.1	20.2	7.8	14.7	12.4	23.2	15.6
Length from tip of snout to origin of anal fin	25.9	27.1	24.7	20.6	16.4	31.0	20.2
Greatest depth	3.7	3.8	3.6	2.8	1.8	5.0	3.1
Length of pectoral fin	3.0	3.6	3.1	2.8	2.2	4.0	2.7
Height of dorsal fin	1.7	1.8	1.5	0.8	0.3	1.2	0.7
Length of snout	1.55	1.45	1.32	1.25	0.82	1.97	1.27
Diameter of eye	0.74	0.70	0.67	0.70	0.54	0.79	0.56
Interorbital space	1.4	1.4	1.2	1.1	0.9	1.7	1.3
Girth of body	10.4	11.5	11.1	7.9	5.5	15.1	9.6
Width of body	3.3	2.9	3.1	2.2	1.6	4.2	2.6
Ano-dorsal distance	6.9	7.0	6.9	5.9	4.0	7.8	4.6
$\frac{\text{Ano-dorsal distance}}{\text{Total length}}$	11.0	10.3	11.3	12.1	7.4	9.8	9.0
Sex	♀	♀	♀	♂	♂	♀	♀

reported his results as follows: the percentage of emergence in the body length above 50 cm is 15 % in female, which has the range from 32 cm to 129.7 cm and 47 % in male which has the range from 32 cm to 57.5 cm. The *Anguilla japonica* is in the range of this variation. Its body is black in color, tinged with blue in the dorsal part and emitting some metalic luster in the lateral part, or at dorsal portion with bronzed black, its side part with golden color at both upper and lower portions from lateral line and ventral part with plain crimsom. The origin of pectoral fin is colored with golden luster, and greynish black with a purple sheen or bronzed black in the top portion and also in lip and snout, or some eels are colored black in opercula.

C) Maturity

The author (1952) examined the maturity of gonad of downstream eels of *Anguilla japonica*, and got the following results; diameter of eggs above 0.2 mm in the stage of ooplasma is 16.3 %, the width of testis above 3.0 mm is 18 %, on the other hand, diameter of eggs above 0.1 mm, yolk-granules are very little, and few or undeveloped is 30.6 %, the width of testis from 2.0 mm to 3.0 mm is 39.6%, diameter of eggs below 0.1 mm is 53.1 %, and the width of testis below 2.0 mm is 41.2 %; from these the author has mentioned that the catadromous group with the comparative matured stage in the fresh water occupies 17.3 %, and the catadromous

Table 6. Size of the ovarian egg (mm) for the catadromous eels.

Date of collection	Diameter of ovum (O)		Diameter of nucleus (N)		$\frac{O}{N}$	Number of nucleoli
	Maximum	Minimum	Maximum	Minimum		
Dec. 20, 1954	0.22	0.19	0.080	0.061	2.75	9—14
〃	0.21	0.17	0.068	0.057	3.08	9—22
〃	0.18	0.17	0.070	0.056	2.57	9—17
Jan. 10, 1956	0.27	0.23	0.084	0.065	3.22	15—32

migration group with the immature stage is 47.3 %, to which most of the fish belong.

The results obtained from the author's examination of the gonad are shown in Table 6. The egg is 0.17—0.27 mm in diameter with the mean diameter of 0.22 mm, the testis measuring 0.2 mm in width, which shows it to be in a stage of sexual maturity. (See PL. 1). But the author does not think that eels will rapidly mature for their transportation from fresh water to the sea and a sudden change of living during its catadromous migration with fasting. They differ in the developmental stage of sexual maturation even in the same district and local distribution.

D) Contents of the alimentary canal

As to the alimentary canal, nothing has been found but some debris in its inner wall, which shows us that catadromous eels will not eat during their downstream migration. Considerable changes must have been brought about in their digestive apparatus, as they cease eating from the beginning of their sexual maturation till the time of their migration.

SCHNAKENBECK (1943) and BERNDT (1938) have closely studied the consequent regression in various parts of the digestive apparatus. First of all, the intestine shrinks and loses some sinuosity which is found in the yellow eel. Its lining diminishes in thickness, and, becoming flaccid, sticks together in many places, which further diminishes the internal diameter. All the tissues become thinner and the cells as well as their nuclei diminish in volume.

4. Consideration on the spawning places

MEEK (1916) included the Japanese eel in the South Pacific Ocean eels as the same species, about the spawning places of which he stated that the currents would lead us to discover the spawning regions in the Indian and Pacific Oceans from the distribution of larvae and a text figure showing the spawning regions which he presumed. The spawning places are located somewhere in the vicinity of the waters 5°—10°S, 160°—170°E in the south hemisphire. SCHMIDT (1925) and JESPERSEN (1942) presumed the spawning regions of *Anguilla japonica* as follows: in the south of Japan there is an area with specially high temperature in the intermediate water layer. The "Dana" found a temperature as high as 26.4°C at a depth of 100 meters; 23.4°C at 200 m ; and 18°C at 300 m at a station south-east of Formosa.

It is the northern branch of the North Equatorial Current which runs up along the south coast of Japan under the name of "Kuroshio," corresponding to some extent to the Atlantic Gulf Stream. SCHMIDT (1925) already called our attention to the fact that this warm, more salt water in the south of Japan is the most likely spawning place of the Japanese fresh water eel, *A. japonica*. But the specimen of eel larvae collected from the "Dana" does not contain larvae of this species, and we are unfortunately unable to confirm this theory.

OSHIMA (1941) mentioned that the spawning places may be situated somewhere in the Celebes Sea or the Philippines Trough.

And, the author (1952) presumed as follows: the distribution of *Anguilla japonica* is closely related with the movements of ocean currents, and the spawning places must exist in the sea area, directly or indirectly influenced by the Japan Current. If the Japan Current originates near lat. 20°N., the spawning places must be situated in lat. 20°N. or a little northwards. But according to the distribution they seem to be situated south of lat. 30°N. If I were to determine the spawning places of the *Anguilla japonica*, taking into consideration the ocean currents, the depth of the sea, water temperature, salinity, etc., I would come to the conclusion that the most favorable water conditions for the fish are found south of lat. 30°N, not far from the land : hence the sea area, west of the Bonin Islands and near the Satsunan waters, which can easily be reached and in which the main Japan Current does not run, is the likeliest spawning places of the fish.

Concerning the spawning places of the *Anguilla japonica*, we have had no other contribution than the ones mentioned above. The author has tried again to examine those based on the records of the leptocephalus and catadromous eels captured in the sea. Localities where leptocephalus and catadromous eels of *Anguilla japonica* have been collected are given in Fig. 4. As to leptocephalus, UCHIDA's specimen was found in the Kuroshio, while MATSUI's specimen, to the south-east of the place where UCHIDA's was collected, and in the waters where the branch of the North Equatorial Current turns to the north-east. The two specimens are remarkably different in size as follows: UCHIDA's sample 24.8 mm and MATSUI's 55.7 mm. It is not proper to compare the two specimens about their size, for they were not collected in the same year. It is not thought that their variation in size, as in the spawning places of the Europeo-American eel, is proportional to the distance from the spawning regions. On the contrary, Indo-Pacific larvae collected at the same time and in the same place vary considerably in size. JESPERSEN (1942) pointed out that this fact was due to the following three viewpoints ; the different rate of growth of larvae, the different distance from the shore of the spawning areas and the different period of the spawning time. As to *Anguilla japonica*, the

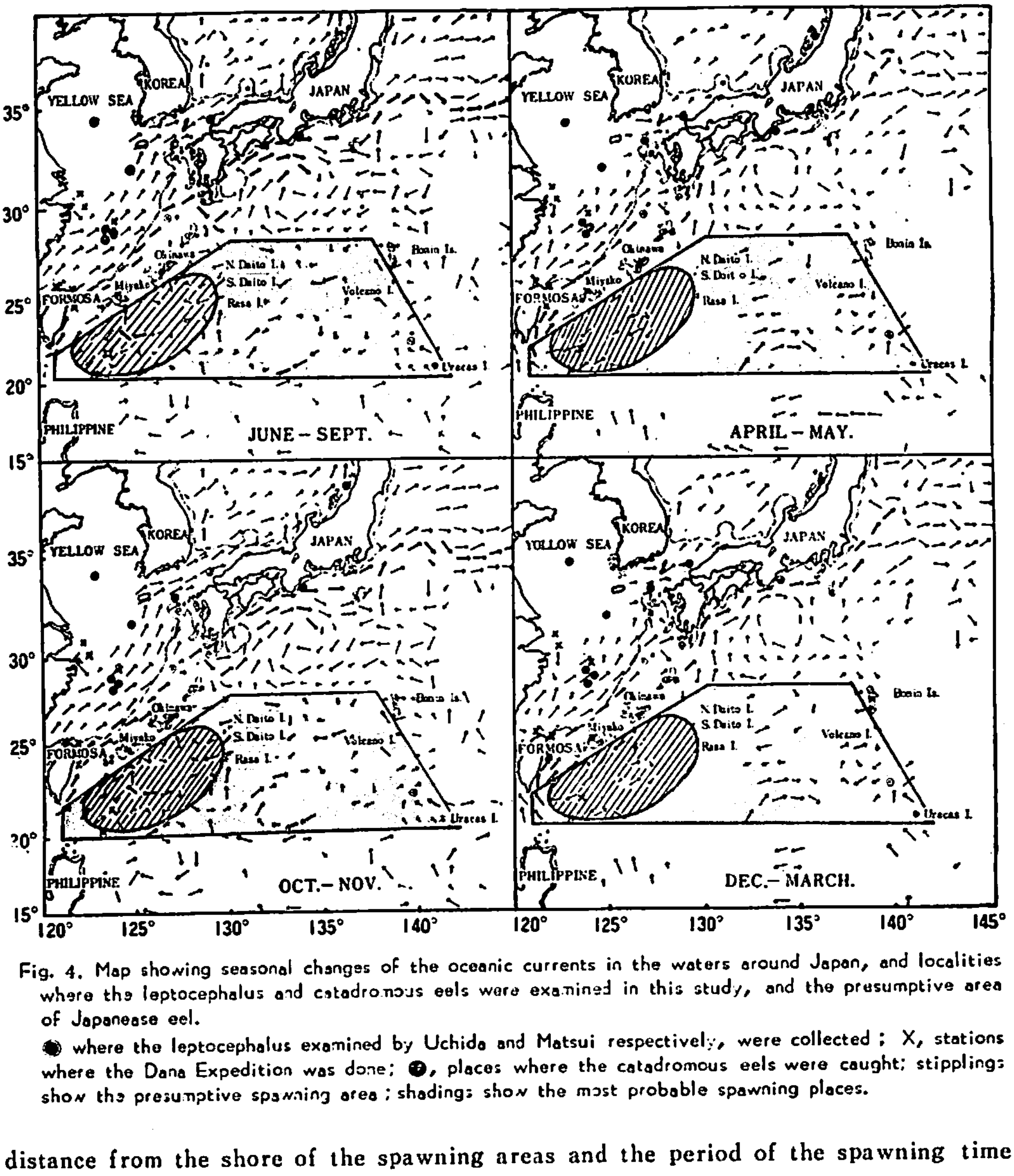

Fig. 4. Map showing seasonal changes of the oceanic currents in the waters around Japan, and localities where the leptocephalus and catadromous eels were examined in this study, and the presumptive area of Japanease eel.
● where the leptocephalus examined by Uchida and Matsui respectively, were collected ; X, stations where the Dana Expedition was done; ●, places where the catadromous eels were caught; stipplings show the presumptive spawning area ; shadings show the most probable spawning places.

distance from the shore of the spawning areas and the period of the spawning time are important factors.

The author (1952) mentioned as follows : The upstream period of the glass eels begins early in October and ends in the latter part of May, the size of glass eels during the period showing 56.73±0.17 mm—58.75±0.14 mm, and the upstream period extending to the long term is due to the long term of spawning time. This is one of the proofs that the spawning places are in the sea close by Japan proper. The upstream period of Japanese eels begins earlier than that of European eels. JESPERSEN (1942) mentioned that the spawning period of the tropical species covers the greater part of the year, or possibly the whole year, while for the more temperate species in the Indo-Pacific as the Atlantic it depends on the season. The upstream period of glass eels is long, but no visible difference is noticed in their size during that period. From this, the author has presumed that the spawning time of *Anguilla japonica* is between that of the Europeo-American and that of the tropical eels. According to SCHMIDT (1925) it is apparent that, so far as the spawning area is concerned, very young leptocephali cannot be caught except in the period between March and July. They are not caught in autumn or winter, so the spawning of eels must begin in spring and continue for about five months until the middle of summer.

The leptocephalus of *Anguilla japonica* is collected from the end of May to that of June, as is the case with Atlantic eels. From the above account and the upstream period of glass eels, the spawning time begins early in spring and continues until early in summer. SCHMIDT (1925) and JESPERSEN (1942) gave the following as the favorable conditions for eels' spawning places: the depth of water is at least above 4,000 meters and, though the eggs are fertilized at a depth of 400—500 meters, very young larvae just hatching from them rise to the surface without delay. Those which measure 5 to 15 mm are mostly caught at the sea 300 and 100 meters deep. A little bigger ones, or a little grown-up ones, are caught still nearer to the surface, generally at a depth of 50 meters or so with a temperature of less than 15°C. It does not seem possible that eels find the favorable place for spawning. That part of the sea which is above 4,000 meters deep and the temperature of which is above 15°C during the period between February and June may be considered to be a favorable place for eels' spawning.

Thus the author has observed the high temperature in the sea around Japan, especially along the Pacific coast in the above period. SCHMIDT (1925) presumed that the spawning ground of *Anguilla japonica* is distributed in the high temperature waters of the Pacific Ocean, because the high temperature waters of 13°C at a depth of 400 meters are found in the Pacific Ocean near Japan and there exist the

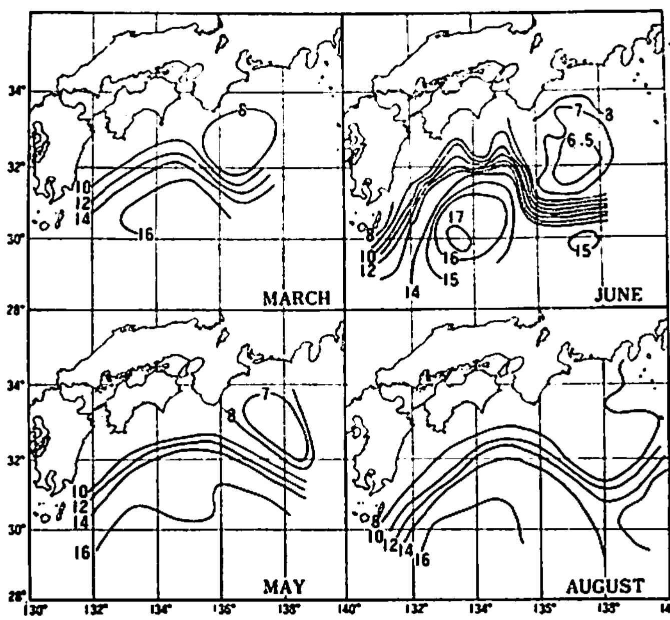

Fig. 5. Map showing the distribution of temperature at 400 meters depth in the water off south Japan.

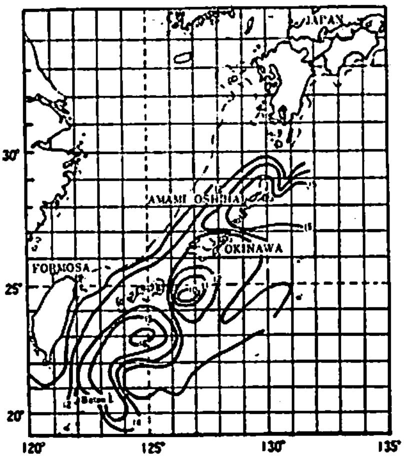

Fig. 6. Map showing the distribution of temperature at 400 meters depth in the water around the Loochoo Islands.

isothermal waters of 17°C in the Atlantic Ocean of America and its vicinity, analogous to the spawning place of *A. rostrata*. According to the recent report of the oceanographical investigation of Japan conducted in the southern waters, the isothermal layer of 16°C extends from the southward to the waters near lat. 34°N, where the cold water mass exists discontinuously (Fig. 5,6). It is recorded from the "Dana" expedition that the high temperature station exists in the southern extremity of Formosa. UDA (1940,'41) observed that the high temperature waters exist to the east of the Okinawa Islands outside the Kuroshio main stream. According to the investigations of IIDA et al. of Kobe Marine Observatory (1955), the isothermal layer of 16°C at a depth of 400 meters is distributed in the sea south of Japan all the year round. So far as the water temperature is concerned, the spawning place of *A. rostrata* covers the sea of high temperature above 16°C, as discovered by SCHMIDT (1925).

Though there is a water layer with a temperature of above 16°C at a depth of 400 m near the Pacific coast of Japan, the water temperature is not the only condition necessary for eels' spawning places, because eels have to depend presumably upon the ocean current for their distribution. In the northern waters around 28°N. and 29°N., where the Tsushima Current bifurcates and a branch stream of the Japan Current turns up to the Yellow Sea, eels may find their spawning places, but it is rather difficult for them to get distributed off the coasts of China, Korea and the Japan Sea. If the spawning place of *Anguilla japonica* has the water temperature above 16°C, as is the case with that of *A. rostrata*, they must be distributed in the southern waters between 28°N and 30°N.

As to the Europeo-American eel, the larvae, on being hatched, ascend towards the surface and are taken at an average depth of 50 meters in the daytime, and at a depth of 20—30 meters at night. The Kuroshio main stream runs at a velocity of 30—50 miles per day, so they can reach the coast of Japan from the spawning places in a short time. But the spawning places cannot be in the Kuroshio main stream, but necessarily in the waters accessible to it. The counter current and the maelstrom of the Kuroshio between the Japan Current and the North Equatorial Current are strengthened and a fairly complex tidal current exists, and the waters in the vicinity of this area, as seen in the above account, are high both in temperature and salinity. Consequently that part of the sea may be considered suitable for the eels' spawning places. Under these oceanic conditions, UCHIDA's specimen was collected in the Kuroshio, while MATSUI's specimen, in some part of the Counter Japan Current, what is called the "Ogasawara Current".

Leptocephali are carried by the surface currents and the larvae are spread in all directions around the spawning area. But if leptocephali were to drift in the waters of low temperature and salinity unsuitable for inhabitation, they would die. But they manage to find suitable waters for inhabitation, and travel around the coasts of Japan and China. So we can safely say that the distribution depends on the waters adjacent to the Japan Current. The ocean current in that part of the sea lying between lat. 20°N. and lat. 28°N. has much to do with the author's presumption of the spawning place of Japanese eels, particularly so during the period between April and November, when the leptocephali approach the sea-shore after they are hatched. The spot where my specimen of the leptocephalus was caught was a little far away to the east of the above-mentioned area. Our sea examination conducted when the specimen was caught showed that a weak ocean current was heading north-east to join the Counter Japan Current and finally the Japan Current near the Loochoo Islands. Elvers can presumably migrate from place to place by means of these currents. Those catadromous eels which have often been caught in the fishing ground for mackerel in the East China Sea to the west of the Loochoo Islands in December and January have easy access to their presumable spawning places, taking advantage of the weak ocean current heading south between Okinawa Island and Miyako Island of the Loochoo Islands. Taking all these into consideration, presumable spawning places of Japanese eels may be in the range lying between lat. 20°N. and lat. 28°N. and between the Loochoo Islands (long. 125°E) and the Bonin Islands (long. 140°E). The most probable spawning places of the eel in this range may be in the sea, oval in shape, bounded on the west by Formosa and the Loochoo Islands with their Trench and bounded on the east by an imaginary line extending downwards from North Daito Island to Lat. 20°N. with South Daito Island and Rasa Island on its way.

Acting on this presumption, the author is planning to determine the spawning places of Japanese eels, investigating the sea on board the training ship of our college. In the event of this plan being put into practice, the spawning places of Japanese eels will be made clear, it is hoped.

(The author wishes to heartily acknowledge his assistance rendered in the studies on the vertebral number of Apods except the eel (See 155 p.), which has been investigated by Ass. Prof. T. Takai.)

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PLATE

Explanation of Plate I.

Fig. 1. Section through the ovary of 62.6 cm in body length was caught on Dec. 20, 1954, ovum is 0.17--0.19mm in diameter.

Fig. 2. Section through the ovary of 51.2 cm in body length was caught on Jan. 10, 1956, ovum is 0.17—0.21 mm in diameter.

Fig. 3. Section through the ovary of 67.8 cm in body length was caught on Dec. 20, 1954, ovum is 0.23--0.27 mm in diameter, showing a stage of comparatively mature.

Fig. 4. Section through the ovary of 60.8 cm in body length was caught on Dec. 20, 1954, ovum is 0.19--0.22 mm in diameter.

Fig. 5. Section through the testis of 48.6 cm in body length was caught on Sept. 24, 1952.

Fig. 6. Section through the testis of 40.0 cm in body length was caught on Dec. 20, 1954.

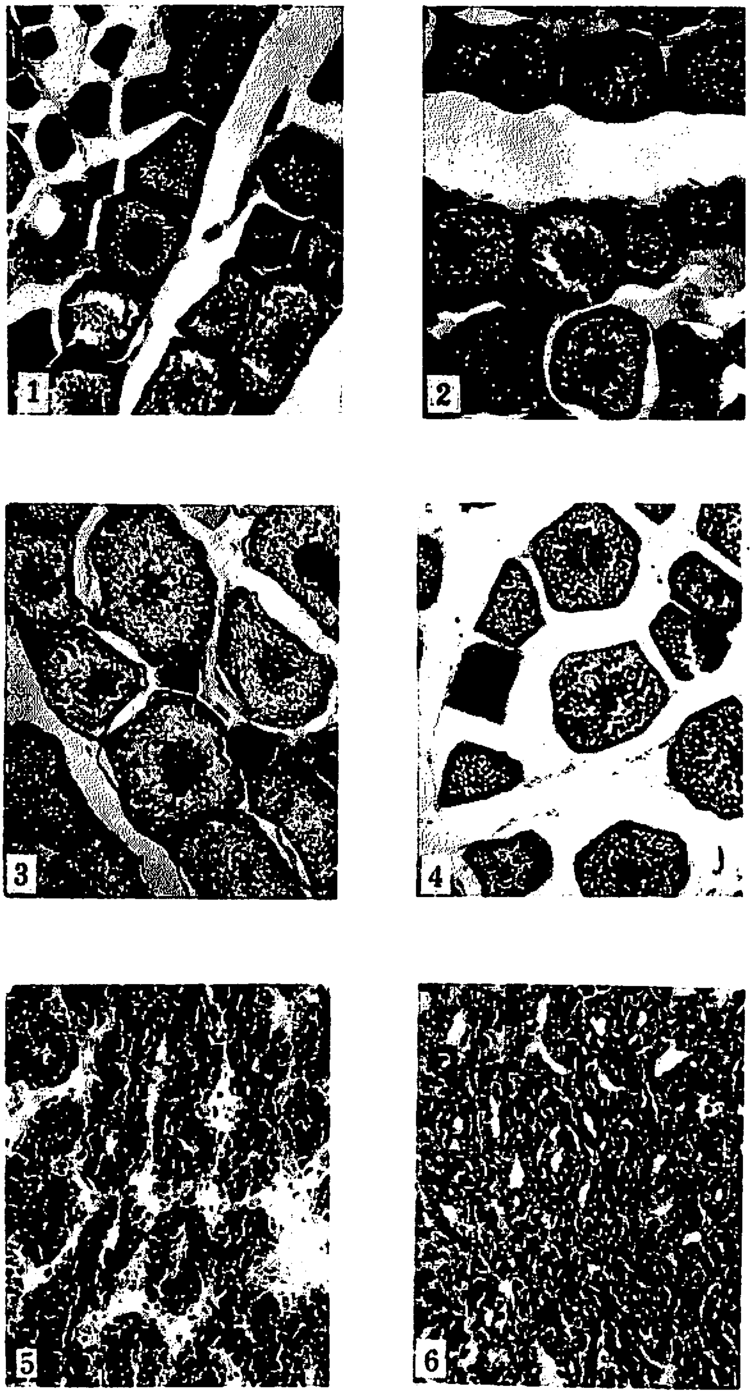

Photo. NISHIKAWA