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by Akihiko Shirota

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Studies on the Mouth Size of Fish in the Larval and Fry Stages

Akihiko SHIROTA*

(Received December 19, 1969)

Studies on the mouth size of larval fishes have not yet been fully made. The author measured the mouth size of various larval fishes which had absorbed yolk and just begin to take natural live food, and studied the relationship among mouth size, food size and growth of fish. Total body length of the material fishes ranged from 10 to 20 mm.

The results obtained are as follows.

1. No definite relationship was found between the mouth size and the total body length at the time of commencement of feeding.
2. The mouth size of various larval fishes at the time of commencement of feeding ranged from 200 μ to 1.000 μ and was observed to have a close relationship to the size of their natural foods: That is, larval fishes having small mouth sizes, such as *Hypomesus*, *Plecoglossus*, *Ammodytes*, *Sillago*, *Konosirus* and *Oplegnathus* take only phytoplankton, protozoa and the nauplii of small copepods, but larval fishes having big mouth sizes, such as *Thunnus*, *Katsuwonus*, *Seriola*, *Girella*, *Mugil*, *Lateolabrax* and *Clupea* were found to easily take large copepods at the time of commencement of feeding.
3. Although the body size at the time of commencement of feeding, in fishes of rapid growth such as *Thunnus*, *Katsuwonus*, *Seriola* and *Scomber*, was much smaller (about 1/2) than that of *Clupea*, their mouth size was equal to or larger than that of *Clupea*.
4. It was made clear that the quicker the growth of fish, the greater is the mouth size at the time of commencement of feeding.

In general, hatched larval fish begin to feed and grow from around the time when they have absorbed the yolk, and since their mouth size is very small, it is considered

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that the food which larval fish and fry can eat is related to their mouth size in addition to the quality or size of the food and their tastes.

In the production of cultured fish by egg rearing, research on the foods of the larval fish stage has mostly pertained to natural live foods, and much knowledge concerning kinds, sizes and quality of foods, conditions of providing food and control of water quality has been obtained. However, an investigation into the sizes of foods which can be fed considering the mouth size of larval fish and fry has not been undertaken. Moreover, with regard to the growth of fish in their natural habitat attention has been given to the feeding mechanism, the main subjects having been the gill raker and the amount of sea water it filters for plankton or how much energy fish need when taking food, but there has not been much study of the relation of growth to the mouth size at various stages, including those of larval fish or fry.

The present author measured the mouth size of various fish species in the larval or fry stages and investigated the differences among the species. He also investigated the size of food that the larval fish could take at the commencement of feeding and what kind of relationship there is between mouth size in the larval fish or fry period and the future growth of the various fish species.

As a result, it was learnt that the mouth size varies greatly according to the different fish species and it was possible to determine the size limit of foods which each larval fish can take at the commencement of feeding. Moreover, it was found that the larger the mouth size in the larval or fry stage, the faster the fish species grows. These results are reported below.

The author wishes to express his deep gratitude to 354
Dr. Nguyen-Hai, presently Associate Professor, Department of Physics, Faculty of Science, Saigon University, former Director of the Institute of Oceanography, Nhatrang, South Vietnam; Dr. Tran-ngoc-Loi, present Director of the Institute of Oceanography, Nhatrang and many other people in the Institute who gave helpful assistance in collecting data for this research. He is also very grateful to Dr. Shuzo Egusa, Associate Professor, Department of Fishery Science, Faculty of Agriculture, Tokyo University, who kindly reviewed this manuscript.

EXPERIMENTAL METHOD

Material

Some of the samples were obtained when the author was investigating planktons near the coast of South Vietnam including the South China Sea and the Gulf of Siam[1-3]; they were fixed with 5% formalin solution and the measurements were performed at the Institute of Oceanography, Nhatrang, South Vietnam. The larval and fry fish were identified according to Schaefer[4], Wade[5], Uchida[6], Matsumoto[7], Yabe[8] and Michizu[9]. Moreover, in order to compare with other fish in general, the measurements for the larval fish of the main fish species in which sufficient material was not obtained or which inhabit northern seas were made on diagrams from original texts.

Method of Measuring Mouth Size

Various methods of measuring the mouth size of larval fish can be considered such as the length of the front or the side or the distance between both sides (mouth width) or the area of the opened mouth, and it is difficult to determine a definite basis for measuring since the mouth size varies morphologically according to the different species or size of fish. The author used the side method and measured the portion from the front tip of the proboscis (A) to the end part where the upper and lower jaws meet (B) in the lateral view of the jaws under a microscope. Making the angle of the opened mouth (C) to be 90 degrees in all cases, the mouth size (D) was obtained as the upper jaw length $(A \sim B) \times \sqrt{2}$. The parts measured and the mouth size are shown in Figure 1. With regard to the degree of mouth opening, the case of an opened mouth angle of 90° was regarded as 100%, that of an opened mouth angle of 45° as 50%, and a closed mouth was regarded as a 0% opened mouth. The mean value of the mouth opening of larval fish and fry (to be called mouth angle in feeding) was considered to be an opened mouth percentage of 50 to 75% (the author's estimation). It is thought that there were some cases in which the opened mouth angle was more than or less than 90 degrees, however since relative problems and tendencies were mainly studied in this report, the close investigation of methods of measuring the mouth size of larval fish and fry, including the opened mouth angle, is hoped for in future studies.

Food Size Indication Method 356

With regard to the indication of natural food size, the size of animal food is usually shown only by body length, and that of vegetable food by cell width x cell length in most cases. In view of the feeding mechanisms of fish including larvae, the author modified the method so as to indicate the body width and diameter of food, since the body length indication does not necessarily represent the size of food that the fish can take.

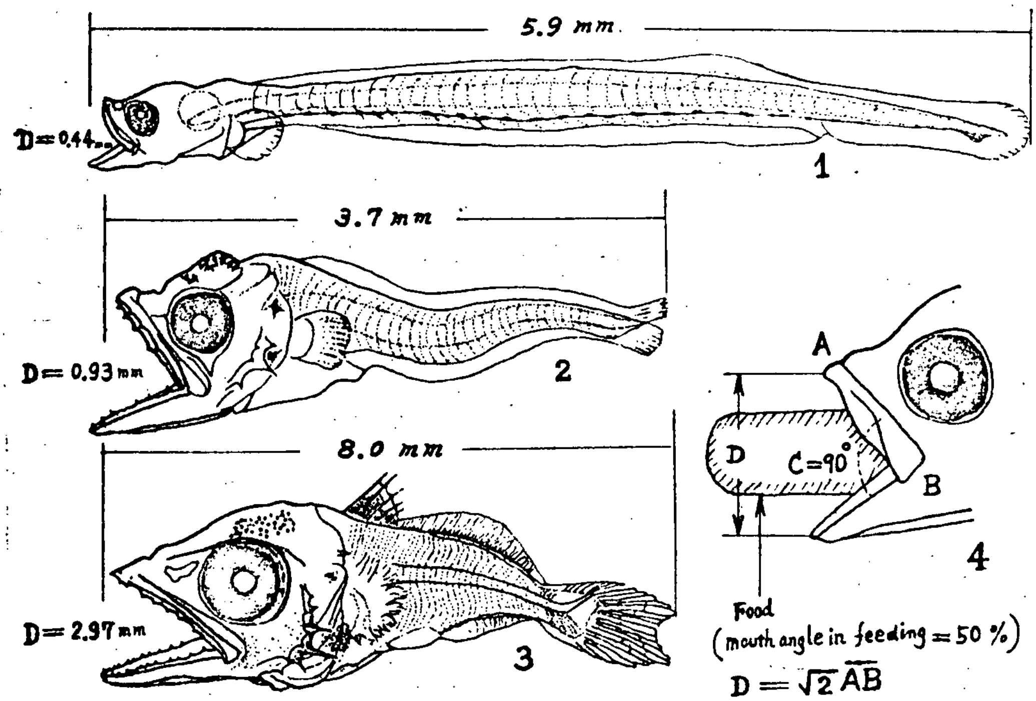

Fig. 1. Method for measurement of the mouth sizes of larval fishes.
1. *Sardinops melanosticta*. 2. *Katsuwonus pelamis*.
3. *Thunnus albacares*.
4. Measurement of the mouth size of fish.

Body Length of One-Year-Old Fish and the Growth During that Time

The body lengths of one-year-old fish and the growth of fish under one year old were all quoted from reports by other authors who studied each fish species, but in most of the fish species the results obtained varied according to the different fish habitat areas and different measuring methods or different age assumptions of the original authors. Moreover, the complete growth curves of large migratory fish such as tuna and bonito were not obtained due to the insufficient data on fish under one year old.

RESULTS

Relationship Between the Total Length of Larval Fish at the Commencement of Feeding and the Egg Size, Total Length of the Newly Hatched Larva, or the Mouth Size

After fish eggs hatch, it normally takes several days for the yolk to be absorbed, and the larval fish commence oral feeding just before or after the complete absorption of the yolk. Table 1 shows egg size, size of larva immediately after hatching, number of days required for yolk to be absorbed, and body and mouth size of larvae at the commencement of feeding.

Although the egg size is generally around 1 mm,
in *Sillago sihama* and *Siganus fuscescens* it is 0.5 to 0.7 mm; 357
in *Mugil cephalus* or in *Chrysophrys major*, *Mylio macrocephalus* and *Oplegnathus fasciatus* of Sparidae it is less than 1 mm; in *Cyprinus carpio* and *Carassius auratus* it is 0.7 to 2.0 mm; in *Plecoglossus altivelis* or *Katsuwonus pelamis* it is about 1 mm; in *Seriola quinqueradiata*, *Gadus macrocephalus*, *Chelidonichthys kumu* or in the bottom fish *Eopsetta grigorjewi*, *Tanakius kitaharai* and *Pleuronichthys cornutus* it is 1.1 to 1.3 mm; in *Sardinops melanosticta*, *Engraulis japonica*, *Clupea pallasi* of Clupeidae and *Prognichthys agoo* it is about 1.5 mm; in *Cololabis saira* it is 1.5 to 2.0 mm; in *Ilisha elongata* and *Hemiramphus sajori* it is 2.0 to 2.5 mm,

Table 1. The total length and the mouth size of larval fishes in the time of commencement of feeding.

No.	Species of fish	Egg size (mm)	Size of hatched larva (mm)	Time from hatch to absorption of yolk (days)	Body size of larval fish in the time of commencement of feeding	
					Total length (mm)	Mouth size (μ)
1	*Cyprinus carpio*	1.2~2.0	5.1~6.5	2~3	6.6	570
2	*Carassius auratus*	0.7~1.2	4.5	2	5.2	400
3	*Hypomesus olidus*	0.5~0.8	4.2	4	5.0~6.2	226
4	*Salmo gairdneri-irideus*	4.0~6.4	13.3~18.3	50	17.4~25.1	—
5	*Plecoglossus altivelis*	0.9~1.1	4.3	1	6.6	375
6	*Rhinogobius similis*	1.4~2.1	7.5	2	7.9~8.3	509
7	*Mugil cephalus*	0.9~1.0	—	—	5.2	636~882
8	*Lateolabrax japonicus*	1.22~1.45	3.0~4.6	3~5	—	—
9	*Oncorhynchus kisutch*	6.0~8.0	—	100~150	—	—
10	*Ammodytes personatus*	0.85~0.95	3.3~4.0	2	4.4~5.0	226
11	*Konosirus punctatus*	1.4~1.6	3.2~3.4	4	4.8~5.2	264
12	*Etrumeus micropus*	1.2~1.4	3.8	3	6.0~6.9	690
13	*Engraulis japonica*	0.7~1.6	2.6	3	3.7	233~283
14	*Sardinops melanosticta*	1.5~1.75	3.0~3.8	3	5.0	426
15	*Spratelloides japonicus*	0.93~1.29	4.6~4.7	1	4.8~5.2	276
16	*Clupea pallasi*	1.3~1.6	6.8~7.6	7	9.0~10.5	728
17	*Harengula zunasi*	—	—	—	4.4	291
18	*Ilisha elongata*	2.2~2.5	5.1	4~5	6.8	496
19	*Tylosurus melanotus*	3.22~3.52	.16	2	12.8~14.0	1450
20	*Cololabis saira*	1.51~1.98	6.2~6.7	2	7.2~7.4	546
21	*Hemiramphus sajori*	2.1~2.3	7.7	2	9.2	550
22	*Trachurus japonicus*	—	—	—	3.6	298~481
23	*Scomber japonicus*	0.9~1.3	3.0	3	3.7~4.0	622
24	*Seriola aureovittata*	—	—	—	5.5	1004
25	*Seriola quinqueradiata*	1.25	3.45~3.5	4	5.1	994
26	*Seriola purpurascens*	—	—	—	5.5	984
27	*Sillago sihama*	0.61~0.71	1.31	3~4	2.6~3.0	255~311
28	*Girella punctata*	1.01~1.05	2.27~2.35	—	6.6	882
29	*Siganus fuscescens*	0.62~0.66	2.6	3	3.0~3.3	287
30	*Oplegnathus fasciatus*	0.86~0.95	2.1~2.3	4	3.0	259
31	*Mylio macrocepoalus*	0.74~0.94	1.70~2.18	2~3	2.3~2.7	—
32	*Chrysophrys major*	0.9~1.0	2.0	3	3.1~3.5	—
33	*Katsuwonus pelamis*	0.80~1.17	2.44~3.04	4	3.7~4.0	930
34	*Thunnus albacares*	1.0	2.6	—	—	—
35	*Thunnus thynnus*	0.6~1.0	2.6	4	3.7	—
36	*Fugu rublipes*	1.35~1.45	2.9	6	3.6	303
37	*Platycephalus indicus*	0.88~0.91	1.78	4	2.84	223
38	*Chelidonichthys kumu*	1.20~1.27	3.21~3.26	4	4.05~4.20	594
39	*Gadus macrocephalus*	1.25~1.30	3.6	3~4	4.3	424
40	*Eopsitta grigorjewi*	1.10~1.20	3.0~3.2	5~6	4.5~4.6	368

and in Tylosurus melanotus it is more than 3 mm. Salmonidae have the largest egg size, the egg size of Salmo gairdneri-irideus being 4 to 6.5 mm and that of Oncorhynchus kisutch 6 to 8 mm.

Although normally it takes several days after hatching for the egg yolk to be absorbed, it takes only one day in Plecoglossus altivelis and Spratelloides japonicus, 7 days in Clupea pallasi, and Salmonidae take the longest, Salmo gairdneri-irideus taking 50 days, Oncorhynchus kisutch taking 100 to 150 days.

Larvae begin feeding around the time when they finish absorbing the yolk. When the relationship between the fish-egg size and the body size (total length is shown) at the commencement of feeding was investigated, it was learnt that the larger the egg size (x mm), the longer the body length (y mm) was at the commencement of feeding as shown in Figure 2, the relation being displayed approximately as the straight line $y = 4.0x$. Moreover, as shown in Figure 3 the relationship between the total length of the newly hatched larva and the total length of the fish at the commencement of feeding became a linear relation, and if the total length at the time of hatching is x and the fish body length (total length) at the time when they have absorbed the yolk and commenced feeding is y,

$$y = 1.357x$$

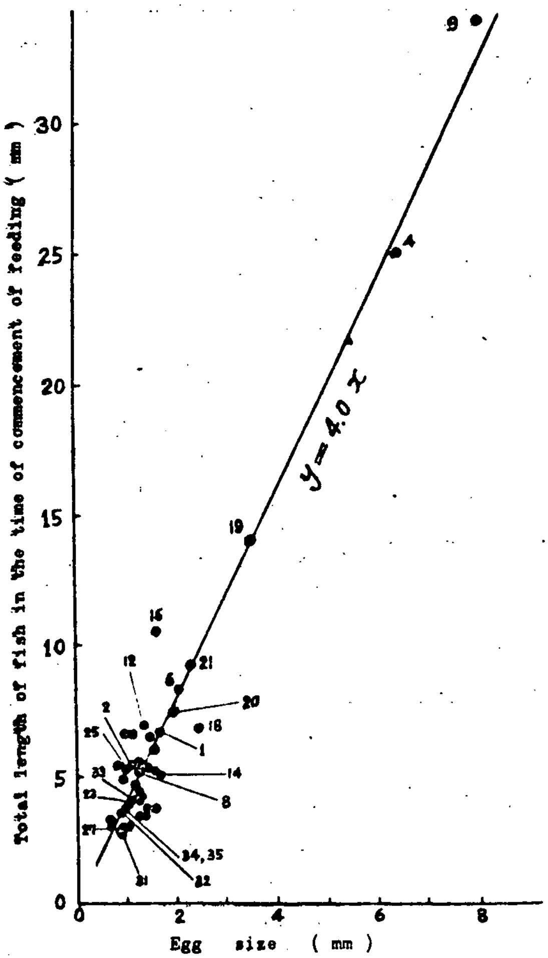

Fig. 2. The relationship between the egg size and the total length of fish in the time of commencement of feeding. Figures indicate the species of the fishes given in Table 1.

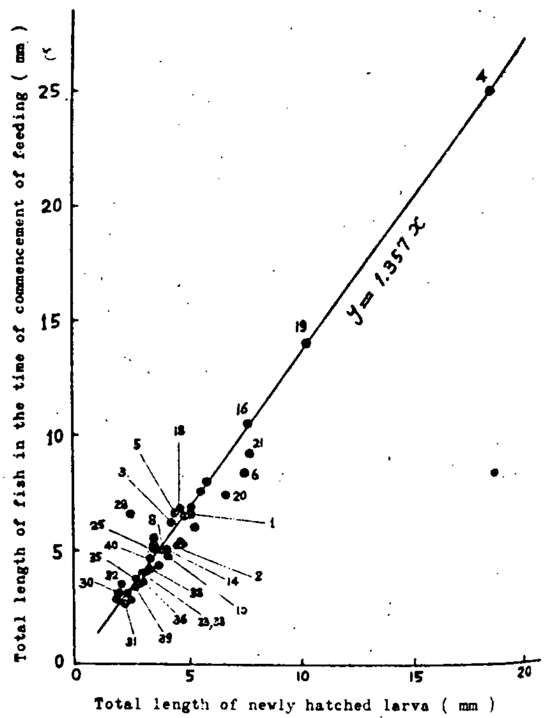

Fig. 3. The relationship between the total length of newly hatched larva and the total length of fish in the time of commencement of feeding. Figures indicate the species of the fishes given in Table 1.

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is established between the two. Incidentally, the units 358
are mm.

Therefore, it is possible to estimate the fish total length at the commencement of feeding if the total length of the newly-hatched larva is known. At the time of commencing feeding Salmonidae had the longest total length, being about 25 to 35 mm, followed by *Tylosurus melanotus*, *Clupea pallasi*, *Ctenopharyngodon idellus*, *Hypophthalmichthys molitrix*, *Cololabis saira* and *Hemiramphus sajori*, and at the times of hatching or of commencing feeding the larvae of *Katsuwonus pelamis*, *Scomber japonicus* and *Seriola quinqueradiata* and of the tunas *Thunnus thynnus* and *Thunnus albacares* (the sizes in tuna were assumed from the egg sizes and the sizes of newly-hatched larvae) which are all considered to grow quickly were less than half those of *Clupea pallasi* in length. Moreover, it was found that *Oplegnathus fasciatus*, *Mylio macrocepoalus* and *Chrysophrys major* in Sparidae and also *Gadus macrocephalus* were fairly small at the times of hatching and commencing feeding.

Figure 4 shows the relationship between the mouth size and the total fish length at the time of commencing feeding. It was learnt that in Salmonidae and *Tylosurus melanotus* the mouth size and body length at the time of commencing feeding are both large, but that in *Katsuwonus pelamis*, *Seriola aureovittata*, *Seriola purpurascens*, *Scomber japonicus*, *Seriola quinqueradiata*, *Lateolabrax japonicus* and *Mugil cephalus*, although the body length at the time of commencing feeding is small, the mouth size was very large. The mouth size of *Clupea pallasi* is small for its long body length at the commencement of feeding,

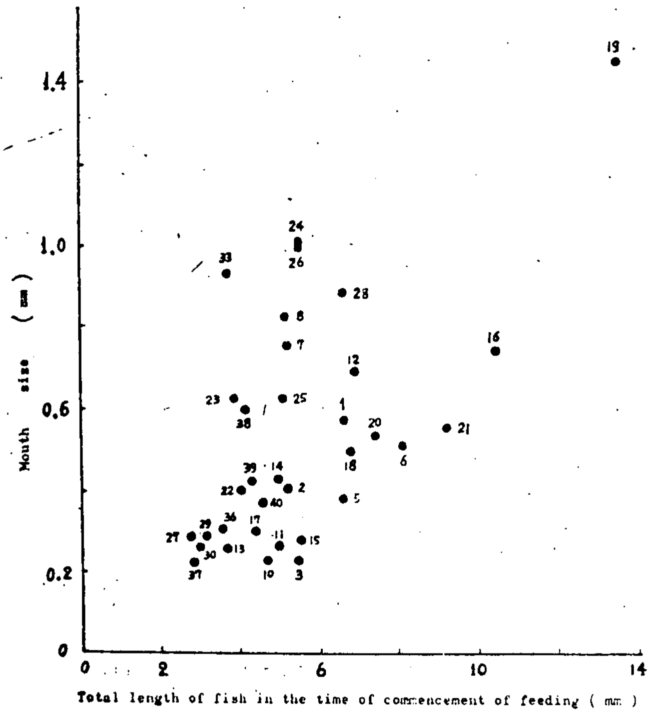

Fig. 4. The relationship between the total length of fish in the time of commencement of feeding and the mouth size. Figures indicate the species of the fishes given in Table 1.

that is, the fish body is long and slender. Moreover, the same tendencies were observed in Cololabis saira, Hemiramphus sajori and Rhinogobius similis. Furthermore, if the ratio of mouth size to total length at the time of commencing feeding is examined, it is as shown in Figure 5, and it is possible to compare the ratio among different fish species.

As a percentage of total length, the mouth size in Katsuwonus pelamis is 25% which is very large, being about 1/4 of the total length (The percentage in tuna is presumed to be about the same). The percentages in Cyprinus carpio

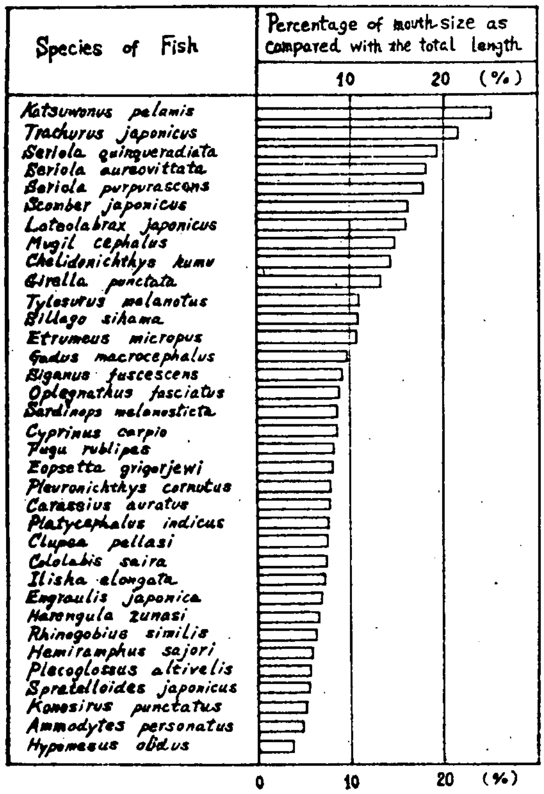

Fig. 5. The relationship between the mouth size and the total length of larval fishes in the time of commencement of feeding.

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and Carassius auratus which are very well known to us are 8.6% and 7.7% respectively, their mouth sizes being 1/12 to 1/13 of their total lengths, that is the mean value for the goldfish species is slightly smaller. Moreover, the ratio in Plecoglossus altivelis is 1/17, and that of Hypomesus olidus is the smallest, being about 1/25.

Change in Mouth Size with Growth in the Larval Stage

When larval fish begin to feed and grow, the head length and mouth size also become larger with the growth. Figure 6 shows the changes in mouth size with growth in the larval stage.

Fish species in which the total length of the larval stage was less than 20 mm are listed below in order of mouth size, large to small: Thunnus albacares, Katsuwonus pelamis, Seriola quinqueradiata, Gadus macrocephalus, Lateolabrax japonicus, Scomber japonicus, Mylio macrocepoalus, Seriola purpurascens, Engraulis japonica. In cases in which the larval body length exceeded 20 mm, such as Engraulis japonica, Sardinops melanosticta, Clupea pallasi, Gadus macrocephalus, Konosirus punctatus, Harengula zunasi and Seriola purpurascens, a tendency was observed for the mouth size to increase remarkably compared with the body length. The mouth sizes of the fish species in which the body length was more than 20 mm extended from 1.5 to 4.0 mm in most cases. When their mouth size was more than 2 mm, it is presumed that they could eat most of the species of Copepoda[1,3] which are the main animal foods present in the natural habitat.

When the mouth sizes of various species of larval fish were compared at total lengths of 10 mm, 15 mm and 20 mm, Thunnus albacares gave the highest value in each case as shown in Table 2.

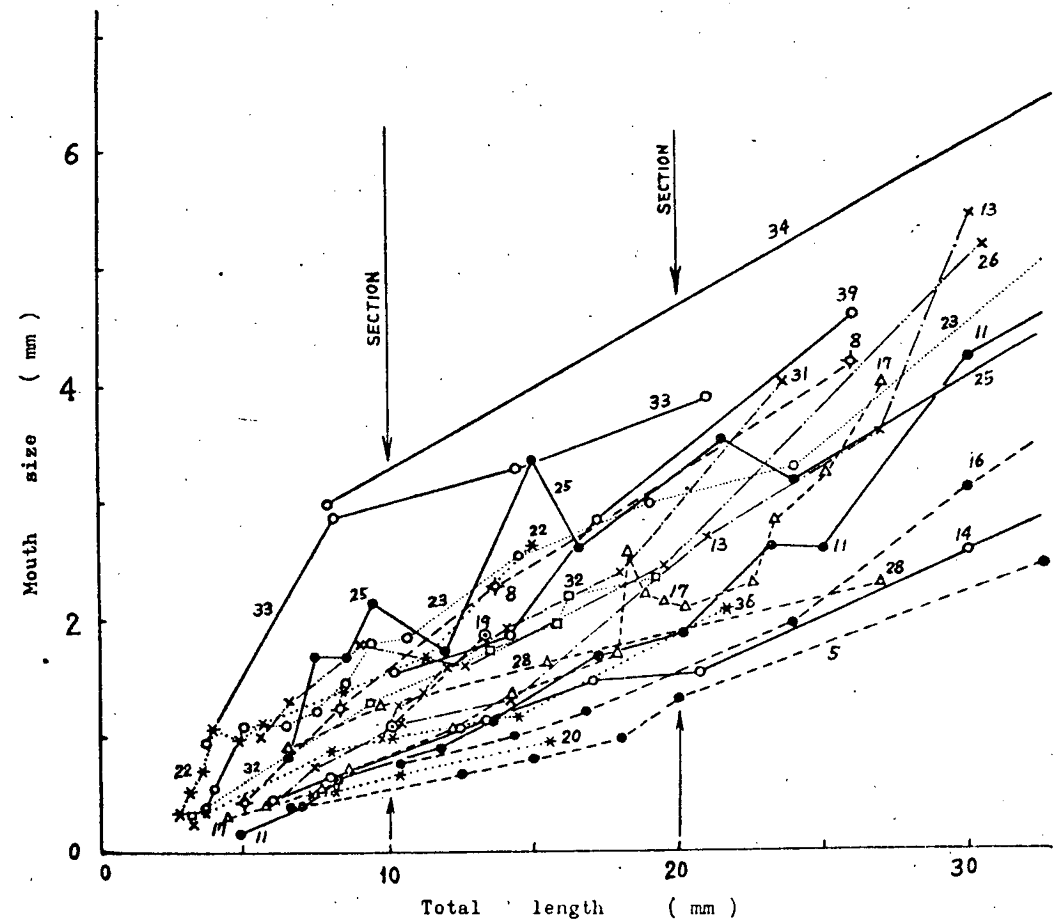

Fig. 6. Relationship between the total length of larval fishes and the mouth sizes. Figures indicate the species of the fishes given in Table 1.

Since there are very few reports on the growth of 359
Thunnus albacares in the larval and fry stage, the growth was examined by connecting the two actual total length points, 8 mm (Yabe[8]) and 53.1 mm (Marchal)*(Figure 6).

*Since generally speaking the growth is shown as a sigmoid curve, it is considered that a slightly catenary curve would be drawn in actuality. However, the author used the actual points as they were and calculated the mouth size of Thunnus albacares on the straight line by proportion.

Table 2. The mouth size of larval fish at different body sizes.

Total length of fish		*	10 mm	15 mm		20 mm	
No.	Species of fish	Mouth size (μ)	Mouth size (mm)	Species of fish	Mouth size (mm)	Species of fish	Mouth size (mm)
1	*Thunnus albacares*	—	3.3	1	4.0	1	4.7
2	*Katsuwonus pelamis*	930	3.0	2	3.3	2	3.9
3	*Seriola quinqueradiata*	994	2.1	3	2.8	8	3.4
4	*Scomber japonicus*	622	1.8	7	2.6	3	3.3
5	*Seriola purpurascens*	984	1.7	4	2.6	6	3.2
6	*Lateolabrax japonicus*	—	1.6	6	2.5	4	3.0
7	*Trachurus japonicus*	390	1.5	8	2.1	11	2.6
8	*Gadus macrocephalus*	424	1.5	11	2.0	5	2.6
9	*Chrysophrys major*	—	1.3	5	1.9	12	2.5
10	*Girella punctata*	882	1.3	9	1.9	14	2.1
11	*Mylio macrocephalus*	—	1.1	10	1.6	10	1.9
12	*Engraulis japonica*	250	1.1	12	1.5	16	1.8
13	*Fugu rublipes*	303	0.9	14	1.4	13	1.8
14	*Harengula zunasi*	291	0.8	16	1.3	17	1.5
15	*Sardinops melanosticta*	426	0.8	15	1.3	15	1.5
16	*Konosirus punctata*	264	0.7	13	1.2	19	1.3
17	*Clupea pallasi*	728	0.7	17	1.0		
18	*Cololabis saira*	546	0.6	18	0.9		
19	*Plecoglossus altivelis*	375	0.5	19	0.8		

* Larval fish in the time of commencement of feeding.

Therefore, the calculated mouth size is 2.97 mm, and the mouth size as a percentage of the total length is extremely high, being 37.1% and 17.6% at the two points, and it is learnt that the ratio of mouth size to the total length is smaller in fry than in larval fish.

The fish are listed below in order of decreasing mouth size at a total length of 10 mm.

Thunnus albacares, Katsuwonus pelamis, Seriola quinqueradiata, Scomber japonicus, Seriola purpurascens, Lateolabrax japonicus, Trachurus japonicus, Gadus

<u>macrocephalus</u> (mouth sizes 1.5 to 3.3 mm).

<u>Chrysophrys major</u>, <u>Girella punctata</u>, <u>Mylio macrocepoalus</u>, <u>Engraulis japonica</u> (mouth sizes 1.1 to 1.3 mm).

<u>Fugu rublipes</u>, <u>Harengula zunasi</u>, <u>Sardinops melanosticta</u>, <u>Konosirus punctatus</u>, <u>Clupea pallasi</u>, <u>Cololabis saira</u>, <u>Plecoglossus altivelis</u> (mouth sizes 0.5 to 0.9 mm).

When the total length was 15 mm, the order was as follows:

<u>Thunnus albacares</u>, <u>Katsuwonus pelamis</u>, <u>Seriola quinqueradiata</u>, <u>Trachurus japonicus</u>, <u>Scomber japonicus</u>, <u>Lateolabrax japonicus</u>, <u>Gadus macrocephalus</u>, <u>Mylio macrocepoalus</u> (mouth sizes 2.0 to 4.0 mm).

<u>Seriola purpurascens</u>, <u>Chrysophrys major</u>, <u>Girella punctata</u>, <u>Engraulis japonica</u>, <u>Harengula zunasi</u>, <u>Konosirus punctatus</u>, <u>Sardinops melanosticta</u>, <u>Fugu rublipes</u> (mouth sizes 1.0 to 1.9 mm).

<u>Clupea pallasi</u>, <u>Cololabis saira</u>, <u>Plecoglossus altivelis</u> (mouth sizes 0.8 to 1.0 mm).

For the case when the total length was 20 mm, the order was as below.

<u>Thunnus albacares</u>, <u>Katsuwonus pelamis</u>, <u>Gadus macrocephalus</u>, <u>Seriola quinqueradiata</u>, <u>Lateolabrax japonicus</u>, <u>Scomber japonicus</u> (mouth sizes 3.0 to 4.7 mm).

<u>Mylio macrocepoalus</u>, <u>Seriola purpurascens</u>, <u>Engraulis japonica</u>, <u>Harengula zunasi</u> (mouth sizes 2.1 to 2.6 mm).

Girella punctata, *Konosirus punctatus*, *Fugu rublipes* (mouth sizes 1.8 to 1.9 mm).

Clupea pallasi, *Sardinops melanosticta*, *Plecoglossus* 360
altivelis (mouth sizes 1.3 to 1.5 mm).

It was found from the above that whereas the mouth sizes all increase as the fish grow, the order of about six species in the top rank with the larger mouth sizes does not change and their growth was quite fast. The most conspicuous item here is the mouth size of *Gadus macrocephalus*. When the total length was 10 mm its order was 8th, at 15 mm total length it was 7th, but at 20 mm total length its rank became 3rd, and it is thought that from around this time the mouth size of *Gadus macrocephalus* increases rapidly.

Moreover, among *Seriola quinqueradiata*, *Seriola purpurascens*, *Katsuwonus pelamis*, *Girella punctata* and *Clupea pallasi*, which have large mouth sizes (their body lengths vary according to the species) at the time of commencing feeding, the mouth sizes of *Girella punctata* in Scombridae and of *Clupea pallasi* become small compared with the other species when their total length is 10 mm, and it is notable that they are also small when the body length is in the 20 mm range.

Mouth Sizes of Larval Fish and the Size of Natural Foods They can Take

Newly hatched larval fish first absorb the yolk and then commence feeding. Then, about what sized natural foods can they eat?

The author has been discussing the mouth size of each fish species when the opened mouth percentage was 100%, but more accurate measurement is necessary for feeding. First of all there is a question here as to whether or not fish can feed with a 100% opened mouth. In fact it is thought that generally it is a very rare condition that they feed with a 100% opened mouth(for instance that larval fish with a 1.0 mm mouth size feed on food 1.0 mm in diameter), so the author investigated the relation between the mouth size and the food by regarding the average mouth opening percentage in feeding to be 50 to 75%, judging by the mouth angle during feeding.

Figure 7 shows the mouth sizes of larval fish at the time of commencing feeding and the size of their foods. The thick black lines in the diagram show the actual size range of the natural live foods and they were divided into two groups, viz. fresh-water live foods, and marine-water live foods. Moreover, the species and sizes of the main natural live foods are shown in Table 3.

The fresh-water fish Hypomesus olidus can eat 115

to 170μ size foods at the time of commencing feeding (needless to say they can take any food whose size is less than that). Actually they cannot eat fresh-water fleas Daphnia or Moina because they are too large and it is impossible for them to eat even their nauplii. However, half fresh-water and half marine-water Rotifera, Brachionus 361
plicatilis[11-13] can just be eaten. Therefore, if Rotifera are insufficient naturally, Hypomesus olidus will have to depend mainly on Protozoa[3,15] or phytoplankton. In the case of artificial culture, they may be bred by providing newly hatched Chironomus dorsalis larvae[16] or Anguillula silusiae[17-19] since these are a definitely feedable size. The size of food which Plecoglossus altivelis and Carassius auratus can take is between 190 and 290μ, and between 200 and 300μ respectively. Therefore, it is either impossible or extremely difficult for them to take the nauplii of some water-fleas such as Daphnia rosea, D. pulex, Bosmina coregonitypica, B. longirostris, Moina macrocopa or M. affinis[20]. However, they are able to feed on the nauplii of Moina dubia, Ceriodaphnia megops, C. regaudi, etc.. It is considered that since the larval fish of natural Plecoglossus altivelis inhabit marine water, they take this sized sort of food, and in the case of artificial culture Brachionus plicatilis or Chironomus dorsalis larvae will be the most suitable food for them. In Cyprinus carpio

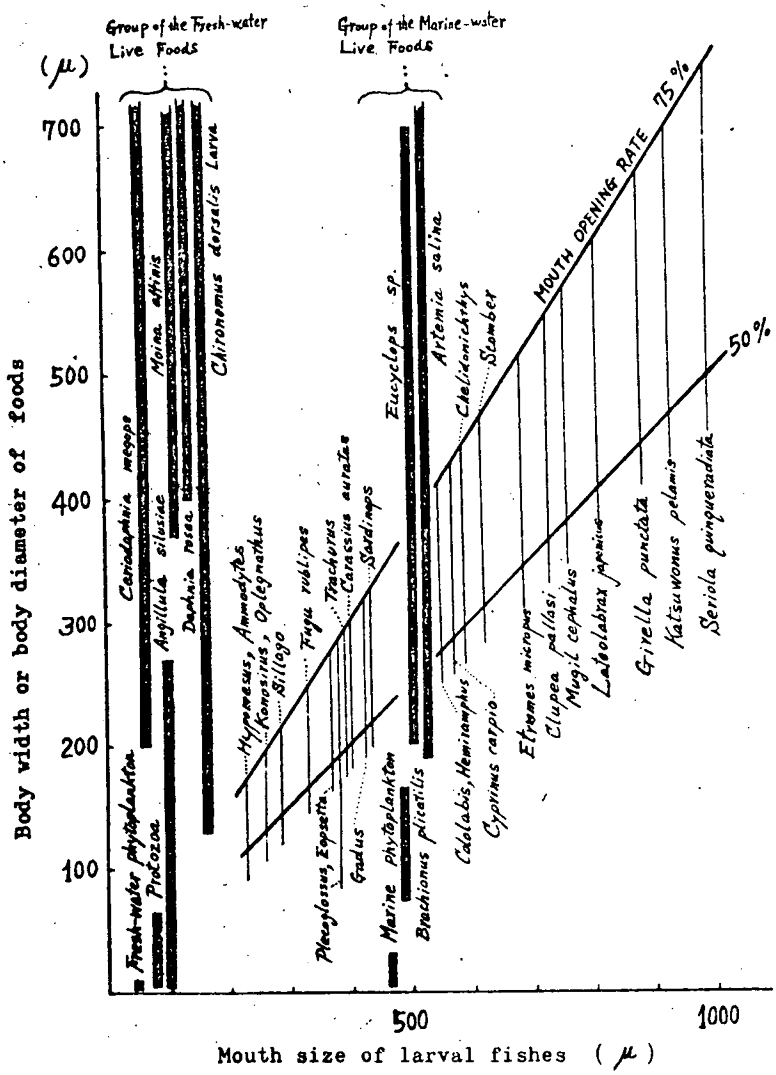

Fig. 7. Relationship between the mouth sizes of larval fishes and the size of live foods. The mouth opening rate is 50～75%.

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food of 285 to 425 μ size is edible, and although their range of foods is slightly larger than that of Carassius auratus nauplii are their main foods, so that when they are bred in 364
the laboratory, the food given must be selected from the nauplii of water fleas.

Table 3. Species and the size of natural live foods for larval fishes.

Fresh-water live foods	
Species	**Size**
Chlorella ellipsoidea	5~3 μ×7.5~9.5 μ
C. vulgaris	5~10 μ
Scenedesmus bijuga	4~7 μ×7~18 μ
S. dimorphus	3~6 μ×16~22 μ
S. armatus	4~8 μ×7~14 μ
S. obliquus	3~9 μ×10~21 μ
S. quadricauda	3.5~6 μ×11~15 μ
Microcystis incerta	3~4 μ (colony 100×300 μ)
M. aeruginasa	0.5~4 μ (colony 5×200 μ)
Euglena oxyuris	19~38 μ×140~450 μ
E. terricola	8~17 μ×68~93 μ
E. rostrifera	18~48 μ×90~140 μ
E. minima	10~15 μ×25~40 μ
E. retronata	9~15 μ×18~34 μ
Daphnia rosea	0.4~1.2 mm×0.8~2.0 mm
D. pulex	0.5~1.4 mm×1.1~2.3 mm
Ceriodaphnia megops	0.2~1.0 mm×0.8~1.5 mm
C. regaudi	0.25~0.3 mm×0.4~0.5 mm
Bosmina coregonitypica	0.4 mm×0.45 mm
B. longirostris	0.35~0.46 mm×0.46~0.6 mm
Moina dubia	0.11 mm×0.38 mm
M. macrocopa	0.37~1.1 mm×0.6~1.8 mm
M. affinis	0.45~0.5 mm×0.7~1.0 mm
Glaucoma scintillans	40~50 μ×60 μ
Tetrahymena faurei	40 μ×60 μ
T. pyriformis	40 μ×55 μ
Colpidium striatum	45~65 μ×90~120 μ
Anguillula silusiae	8 μ×0.17 mm~0.25×2.3 mm
Limnodrilus gotoii	0.7~1.0 mm×7~10 cm
Chironomus dorsalis	0.13×0.7 mm~1.28 mm×1.3 cm

Marine-water live foods	
Species	**Size**
Thalassiosira condensata	17~30 μ×50~100 μ (max. 5 cells)
Skeletonema costatum	18~35 μ×10000 μ
Chaetoceros compressus	10~24 μ× 〃
C. brevis	10~40 μ× 〃
C. lorenzianus	10~40 μ× 〃
C. sp.	5~20 μ×25~100 μ (max. 4~5 cells)
C. simplex	3~4 μ×5~10 μ
Trichodesmium thieboutii	5~16 μ×500~600 μ
T. erytheraeum	5~20 μ×100 μ
Brachionus plicatilis	72×96 μ~165×236 μ
Eucyclops sp.	0.2~2.5 mm×0.7~0.9 mm
Artemia salina	0.19×0.46 mm~1.6 mm×10~12 mm

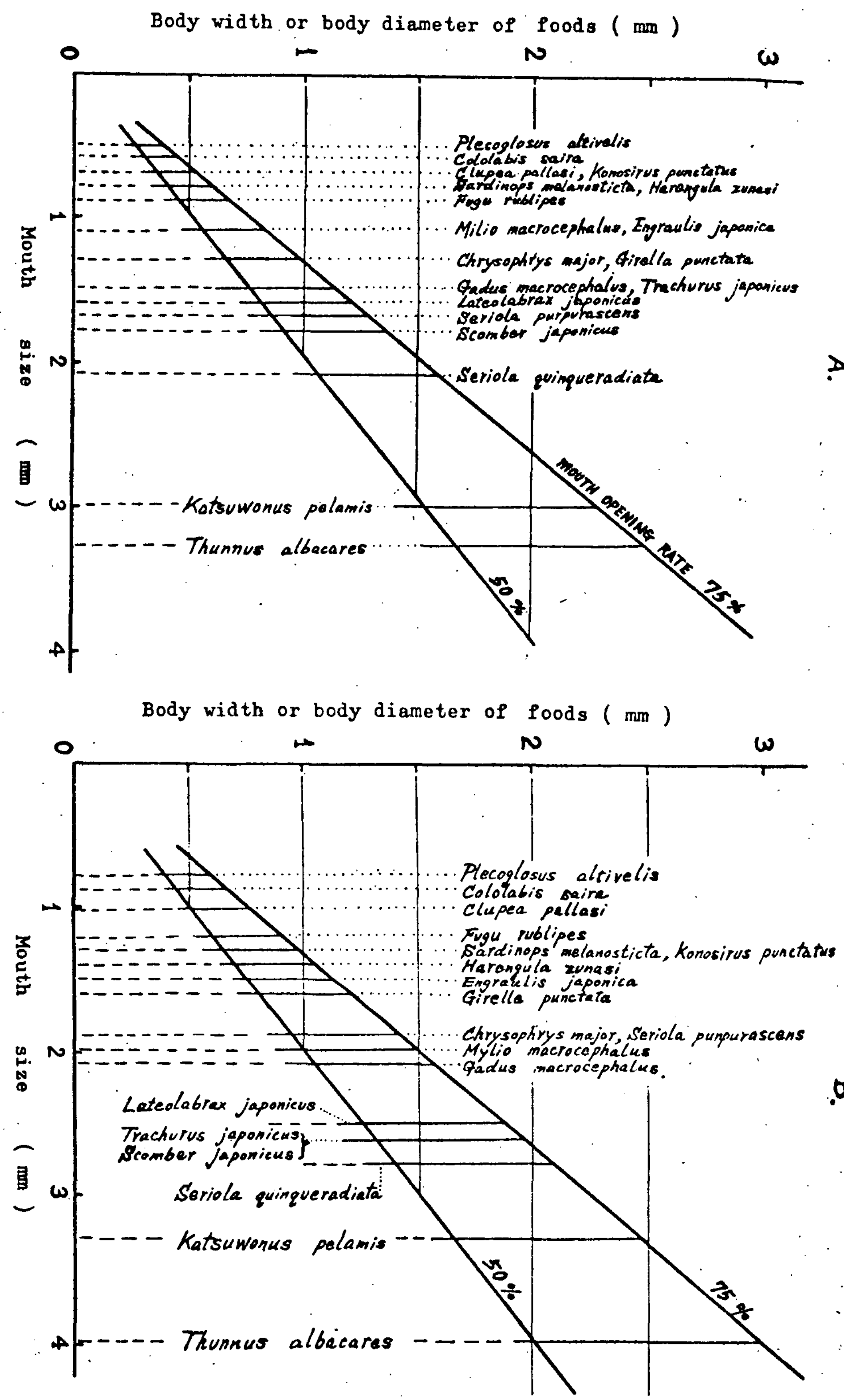

Fig. 8. The relations between mouth size and size of live foods in larvae of various species of fish at the stages of 10mm (A) and 15mm (B) in the total length.

In the fish culturing case, it can be well understood that the above-mentioned matters become the largest cause by which a phenomenon of tobi (accelerated growth) pointed out by Nakamura[21] occurs. In this way, it is considered that in so far as the mouth size of larval fish and the size of their food are closely related, whether or not some natural animal food can be eaten exerts a great influence on the growth and fight of each species for food, even at the individual level.

On the other hand, the case of marine fry or larval fish is exactly the same as the fresh-water case. Now, let us investigate the feeding conditions of larval fish at the time of commencing feeding by choosing *Artemia salina*[1,22-24] as their food. It can be seen that swellfish, *Pleuronichthys cornutus* and *Sillago sihama* can eat newly hatched *Artemia salina* larvae only with difficulty (In some cases it is rather difficult because of the large swimming legs of *Artemia salina*). It is considered impossible for *Opegnathus fasciatus*, *Konosirus punctatus*, *Hypomesus olidus*, *Ammodytes personatus*, *Lubricogobius exiguus* or *Fugu pardalis* to feed on *Artemia salina*. On the other hand, it will be possible for *Katsuwonus pelamis*, *Seriola quinqueradiata*, *Girella punctata*, *Lateolabrax japonicus*, *Mugil cephalus*, *Clupea pallasi*, *Etrumeus micropus*, *Scomber japonicus*, *Chelidonichthys kumu*, *Cololabis saira* or *Hemiramphus sajori* to feed on *Artemia salina* larvae soon after they have absorbed the yolk. Therefore, in their natural habitat these fish species can probably feed on most nauplii, zooplankton or phytoplankton in marine water without any difficulty. *Trichodesmium thiebautii*[1,25] or *T. erytheraeum*[1] which belong to the marine phytoplankton Cyanophyta are tropical planktons and are found abundantly especially along the coast line[1], but sometimes it is impossible for these to be consumed because the cell chain is long and occasionally their colonies exceed 3,000 μ. *Chaetoceros* or *Skeletonema* are also as above and in the case of intensive culture it is considered necessary to stir well in order to cut down the length of the cell chains.*

However, as the larval fish grow, the size range 365
of foods that they can take changes. The mouth sizes of larval fish of total length 10 mm and 15 mm and the sizes of foods they can take are shown in Figure 8.

If the mouth sizes of fish adopted for culturing including the species discussed in this report are clarified, it is possible to predict what size of foods they can eat, and even in the case of artificial food it will be possible by rational judgement to produce the appropriate size of food particle[26].

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*In the case of crustaceans, prawns and crabs in particular, the size of food is not very important since in contrast to fish, they chew food.

Growth of Fish and the Mouth Size in the Larval or Fry Stage

As is seen from the above, it is considered that when fish species have larger mouth sizes in their larval stage soon after hatching, their growth will be fast compared with those species with smaller mouth sizes since the former can take larger sizes of food. The mouth size of any fish species becomes larger when the fish grow out of the fry and larval stage, so that from then on they can feed on larger zooplankton without any difficulty. However, the food they take from the fry stage onwards in fact changes from zooplankton to larval and fry fish and to young fish, according to their trophic level. In this way fish continue to grow within the predator-prey interaction, but the relationship between the mouth size and feeding during this stage had not been clarified to date.

Accordingly, an investigation of the relation between the mouth sizes in the larval and fry stages of fish and their body lengths as they grew up to one year old was attempted.

Figure 9 shows the growth up to one year of the main fish species as reported by researchers in or outside Japan in the past. As is seen in the diagram, the values vary greatly according to different researchers. The reasons for this may be due to the different environments of the fish habitat areas or due to discrepancies in age determination by each researcher. Moreover, no satisfactory growth curve could be obtained for Katsuwonus pelamis and Thunnus albacares since the data[27,28] on fry or young fish were fragmentary. Recently the breeding of Seriola quinqueradiata has been conducted actively in many areas and its growth curve is available, but there is the possibility that this species showed the highest growth value because of the amount of food provided to satiety in breeding ponds.

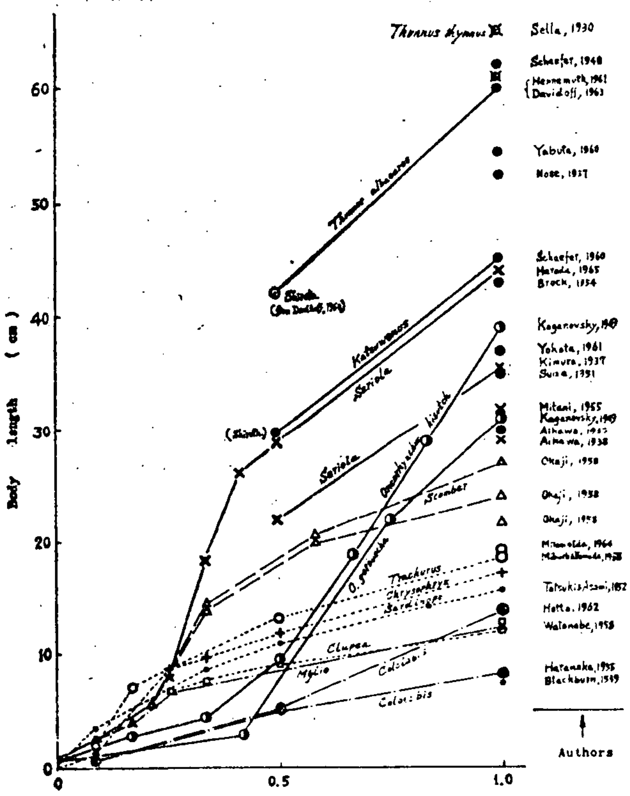

Fig. 9. The growth of fishes given by various authors.

If the body lengths of one-year old fish are compared from this Figure, the longest fish is *Thunnus albacares*, followed by *Katsuwonus pelamis*, *Seriola quinqueradiata* and *Scomber japonicus*. Although the body lengths of *Oncorhynchus kisutch* and *Oncorhynchus gorbuscha* are almost equivalent to those of *Katsuwonus pelamis* and *Seriola quinqueradiata*, their growth curves are different from those of other species. This is related to the fact that it takes four to five months after egg-hatching for Salmonidae to 366
absorb their yolk. Moreover, it is considered that since the body length of their larvae at the time of commencing feeding is long, reaching 3 to 4 cm, and their mouth size is also large, they could eat large-sized Copepoda or middle-sized benthic animals such as *Artemia salina* larvae or many other aquatic insects[29, 30] immediately, resulting in rapid growth after the commencement of feeding. The above-mentioned species are those whose body lengths reach between 22 cm and 63 cm at the age of one year, but there are some fish whose average body lengths do not exceed 20 cm, such as *Trachurus japonicus*, *Chrysophrys major*, *Sardinops melanosticta*, *Cololabis saira*, *Clupea pallasi* and *Mylio macrocepoalus*, the body lengths becoming smaller in that order.

The ratios of the mouth sizes of each fish species to that of *Thunnus albacares* (when the mouth size of

Table 4. The comparison of the mouth size of each larval fish with that of Thunnus albacares in different sizes.

Total length of fish	10 mm	15 mm	20 mm
Species of fish	Percentage (%)		
Thunnus albacares	100.0	100.0	100.0
Katsuwonus pelamis	90.9	82.5	72.3
Seriola quinqueradiata	63.3	70.0	70.2
Scomber japonicus	54.5	65.0	63.8
Seriola purpurascens	51.5	47.5	55.3
Lateolabrax japonicus	48.4	62.5	68.1
Trachurus japonicus	45.4	65.0	—
Gadus macrocephalus	45.4	52.5	72.3
Chryshphrys major	39.4	47.5	—
Girella punctata	39.4	40.0	40.4
Mylio macrocephalus	33.3	42.0	50.0
Engraulis japonica	33.3	37.5	53.2
Fugu rublipes	27.3	30.0	38.3
Harengula zunasi	24.2	35.0	44.7
Sardinops melanosticta	24.2	32.5	31.9
Konosirus punctatus	21.2	32.5	38.3
Clupea pallasi	21.2	25.0	31.9
Cololabis saira	18.2	22.5	—
Plecoglossus altivelis	15.1	20.0	27.7

Thunnus albacares is made to be 100) at total body lengths of 10, 15, 20 mm were calculated from Table 2 as shown in Table 4. Moreover, in the fish species shown in Figure 9, when the body length of one-year-old Thunnus albacares(60 cm) estimated by Hennemuth[31] and Davidoff[32] is made to be 100, the ratio of the body lengths of each one year old fish species to that of Thunnus albacares were calculated and then compared with the results of Table 4 as shown in Figure 10.

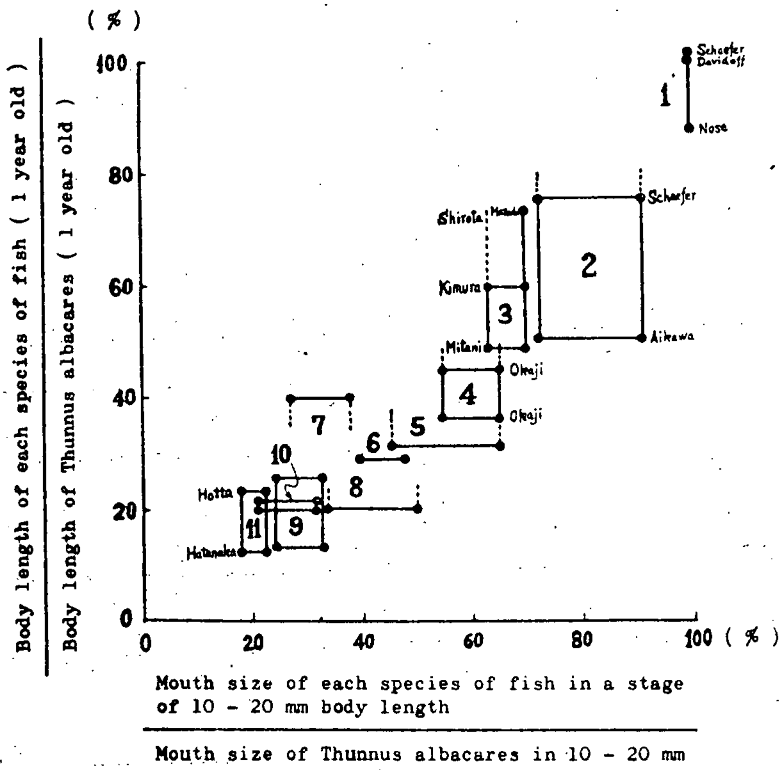

Fig. 10. The relationship between the mouth size of larval fish 1~20 mm in total length and the growth in one year.

1. Thunnus albacares
2. Katsuwonus pelamis
3. Seriola quinqueradiata
4. Scomber japonicus
5. Trachurus japonicus
6. Chrysophrys major
7. Fugu rublipes
8. Mylio macrocephalus
9. Sardinops melanosticta
10. Clupea pallasi
11. Cololabis saira

Since the estimated body lengths of Thunnus albacares which was the basis showed variations according to the different researchers, some differences occurred in the diagram. In Katsuwonus pelamis, Seriola quinqueradiata, Scomber japonicus, Sardinops melanosticta, Clupea pallasi and Cololabis saira, the estimated value of body length varied according to each researcher, and when Thunnus albacares was made to be a basis their percentage mouth sizes in the larval and fry stages varied according to their total length (10 to 20 mm) as seen in Table 4, so that these fish were shown as square measures. Furthermore, the dotted lines in the diagram are estimations by the author.

It was learnt from this Figure that the mouth size 367
and body length of Katsuwonus pelamis are both large and next to tunas, then the sizes become smaller in the order Seriola quinqueradiata, Scomber japonicus, Chrysophrys major, Fugu rublipes, Sardinops melanosticta, Clupea pallasi and Cololabis saira, and consequently it was learnt that the fish species which grow faster have larger mouth sizes at the larval fish and fry stages.

SUMMARY AND CONCLUSION

The mouth sizes in the larval or fry stages of various fish species were measured, and the relation between the mouth size and the total length, and the relation between foods and the one-year-old body length were investigated. The results obtained are as follows:

1. The total length of larval fish at the time of commencing feeding has correlations with the egg size and the total length at the time of hatching, but there is no correlation between the mouth size and the total length.

2. The total length of _Katsuwonus pelamis_, _Scomber japonicus_, _Seriola quinqueradiata_, etc. at the time of hatching and commencing feeding is small, being about half of that of _Clupea pallasi_, but their mouth size is equal to or slightly larger than that of _Clupea pallasi_.

3. The ratio of mouth size to the total length in larval fish at the time of commencing feeding is highest in _Thunnus albacares_, _Katsuwonus pelamis_, _Seriola quinqueradiata_, _Trachurus japonicus_, _Scomber japonicus_ and _Lateolabrax japonicus_, being 15 to 25%, average in _Cyprinus carpio_, _Carassius auratus_, _Clupea pallasi_ and _Cololabis saira_, being 7.5 to 8.5%, and smallest in _Hypomesus olidus_, _Konosirus punctatus_ and _Ammodytes personatus_, being 3 to 5%.

4. The mouth size of larval fish at the time of commencing feeding varies greatly according to different fish species, ranging between 200 to 1,000 μ , and it was observed to have a close relationship to the size of the natural live foods that they take. That is, _Hypomesus olidus_, _Plecoglossus altivelis_, _Ammodytes personatus_, _Sillago sihama_, _Konosirus punctatus_ and _Oplegnathus fasciatus_ which have small mouths at the time of commencing feeding can only

take phytoplankton, Protozoa or the nauplii of small Copepoda, but Thunnus albacares, Katsuwonus pelamis, Seriola quinqueradiata, Girella punctata, Mugil cephalus, Lateolabrax japonicus and Clupea pallasi whose mouth sizes are large can take larger-sized zooplankton (Copepoda) from the beginning.

5. The faster-growing the species (for example, Thunnus albacares, Katsuwonus pelamis, Seriola quinqueradiata, Scomber japonicus, Lateolabrax japonicus, etc.), the larger the mouth size in the larval fish and fry stages.

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