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COMPARATIVE STUDY OF THE GILL STRUCTURE AND FEEDING HABITS OF THE ANCHOVY, *ENGRAULIS JAPONICA* (HOUT.)*

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ABSTRACT

The development of the structures of gill-rakers and digestive tract and the food and feeding habit of the larvae, postlarvae, juveniles and adults of *Engraulis japonica* (Houttuyn) from coastal waters of Taiwan were studied. The following results have been obtained.

1). The differentiations of digestive tract, width of mouth, length of gill-rakers, width between gill-rakers, length of denticles and width between denticles except the width between denticles coincide with the increase of the growth stage of the anchovy.

2). The incidence of feeding gradually increases with the increase of the size of anchovy. The lowest values are found in larvae of 10-20 mm and juveniles of 20-30 mm, of which 10-20 mm are the minumum size of fishes caught by fishermen and specimens used in this investigation. This phenomenon shows clearly that it is related to the structure of the gill-rakers and digestive tract of the developing anchovy.

3). Phytoplanktons were found in the greatest abundance in the diet of postlarvae and juveniles ranging from 30-45 mm in standard length. The phenomenon is related to the changes which take place in filtering net of the larvae along with the development of the gill-rakers.

4). The stomach contents of the early larval stage show that the the main component of the diet is copepoda. Then the intake of phytoplanktons gradually increases according to their developmental stage. Among the copepoda, calanoids are the most abundant.

INTRODUCTION

Up to the present time no paper on the feeding habits of the larvae of marine fishes has been published in Taiwan. The present investigation is the first study of this nature; it refers to the coastal area of Taiwan and Pescadore Islands and deals with the problems related to the feeding habits of the larvae, juveniles and adults of Taiwan anchovy.

In this paper are described the food and feeding habits and feeding mechanism of the anchovy at different growth stages. This study is based upon the quantitative and qualitative determination of stomach contents in order to obtain a better assessment of the contribution of different groups of organisms to the diet of the larvae, juveniles and adults of the anchovy. The characteristics of the feeding of the young forms of the anchovy at different stages of development were studied in relation to the morphological changes which take place throughout the

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growth of the individuals. The morphological characters most closely related to the feeding process in fishes are: the digestive tract, the dimensions of the mouth and the structure of gill-rakers. Therefore, in the present work, special emphasis has been given to a detailed study of these morphological elements. Also, the analysis of the monthly changes in the feeding habits of the larvae, postlarvae, juveniles and adults of the anchovy has been attempted.

Together with the anchovy, larvae, postlarvae, and juveniles individuals of another species, *Stolephorus zollingeri*, were gathered in Chin-shan and Ba-do-dz. The individuals of this species are found to share the habitat with the anchovy. The purpose of collecting other material was to study the stomach contents of the individuals of the other species with the aim of obtaining comparative material as the frame of reference for the anchovy, taking especially into account the competition for their food supply. The results of the analysis of the feeding habits of *Stolephorus zollingeri* will be reported in another paper.

MATERIALS AND METHODS

The specimens of anchovy at the different stages of growth were caught by touch-light net, beach seine, or purse seine. Two to four samples each month were collected from the coastal waters off Su-ao (蘇澳), Ta-chi (大溪), Ba-do-dz (八斗子), Chin-shan (金山), Kao-hsiung (高雄) and Peng-hu (澎湖) stations (Fig. 1 and table 1). The larvae and post-larval stages were obtained only in April, May and November. It is shown clearly that they spawned twice a year. The juveniles

TABLE 1

Number of specimens collected in the area extending between Su-ao and Peng-hu, from May 1968 to June 1969.

Locality / Month	Chin-shan		Ba-do-dz		Ta-chi		Su-ao		Kao-hsiung		Peng-hu		Total	
	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi	No. of Sample	No. of Indivi.
1968May	—	—	3	166	—	—	2	120	—	—	—	—	5	186
Jun	—	—	4	169	—	—	3	113	—	—	—	—	7	282
Jul	—	—	5	257	—	—	2	120	—	—	—	—	7	377
Aug	—	—	4	57	—	—	1	120	—	—	—	—	5	177
Sep	—	—	5	125	—	—	—	—	—	—	1	0	6	125
Oct	—	—	1	60	—	—	—	—	—	—	—	—	1	60
Nov	1	8	2	120	—	—	—	—	—	—	—	—	3	128
Dec	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1969Jan	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Feb	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mar	—	—	—	—	—	—	—	—	—	—	3	156	3	156
Apr	6	271	—	—	—	—	—	—	—	—	6	355	12	626
May	5	300	3	180	3	401	—	—	2	0	4	240	17	1121
Jun	1	60	4	235	4	381	—	—	1	0	3	281	13	975
Total	13	639	31	1369	7	782	8	473	3	0	17	1032	79	4195

were obtained from March to November, but except July and August (as shown in table 3).

A total number of 4195 (shown in table 1) of larvae, post-larvae, juveniles and adults have been studied, ranging in size from 12.5-122.5 mm in standard length. Of these, 593 individuals contained food in their stomach while the remainders were quite empty.

The material to be studied was fixed in 10% formalin right after collection in order to stop the digestive process. Further treatment of the material was contiued in the laboratory.

Each individual was measured and weighted and its digestive tract and gill-rakers were separated for the morphological study, specimens were measured under a dissecting microscope by means of a micrometric eye piece. The examination of the stomach contents was performed under a shadowgraph. All of the components were separated, counted and measured by means of a micrometric mechanical stage on the shadowgraph. The larvae, postlarvae, juveniles and adults were classed in standard length classes with 5 mm intervals.

In the quantitative treatment of the data, one of the methods used was the determination of the frequency of occurrence. The calculation of the percentage composition of the various food components was based on the total number of each kind of organisms divided by the total number of the stomach contents of each individual, and the result was multipled by 100.

The measurements of the dimensions of the mouth were made by means of the micrometric eyepiece. The mouth was opened with very thin needles and the length and the width of the mouth were measured from approximately the same angle. The first branchial arec of the left side was used always for measuring and observing the development of gill-rakers.

DEVELOPMENT OF WIDTH OF MOUTH, GILL-RAKERS AND DIGESTIVE TRACT

Figure 2 shows the relationship between the width of the mouth and the range of prey length. The fact that the length of prey is much longer than the width indicates the possiblity that the ingestion of a given organism depends more upon its length than upon its width. The correlation found between the width of the mouth and the body length of anchovy is lineal. The mouth begins to resemble that of an adult anchovy when the larva reaches a standard length of 27.5 mm. The dimensions of the largest organisms ingested by larvae with the body length of 12.5-22.5 mm ranged betwen 100-600μ. In the post-larvae with body length of 22.5-37.5 mm, the dimensions of the mouth increased, the size of prey were longer and range between 300-1400μ. Preys of much greater size are found in the juveniles with body length of 37.5-57.5 mm. The size of prey shows close correlation with the width of mouth in larvae, post-larvae and juveniles.

It is well known that, beside the gill filaments of respiratory function, the gill-rakers at the inner side of the gill arch serve as a sieve to collect plankton and bring them down to the alimentary canal. In Figures 2 and 3 and Tables 4, 5 and 6, the development of the gill-rakers in the larvae to adults, whose length ranges from 12.4-122.5 mm, is shown. In A of Figure 3, gill-rankers appear as a few, small protuberances on the lower part of the first branchial arch, and 11 in number, when the larva reaches a

standard length of 14.6 mm. In the larva whose length reaches 24.5 mm in standard length, the gill-rakers, which are 14.63 in number, (shown in Figure 6) reach a length of 0.517 mm (show in Figure 7). Over the gill-rakers, 4-6 noticeable protuberances appear. These protuberances will transform themselves into the future denticles or process. In the larvae having a standard length of 32.5 mm the gill-rakers (25.12) reach a length of 1.45 mm and the number of protuberances corresponding to future denticles. As the larvae grow, the nuumber, length and width of gill-raker and the length of protuberances also rapidly increase but the width of protuberances (shown in Figure 7 and 8). At this stage, protuberances become denticles. The juveniles having a standard length of 57.5 mm have 36.33 gill-rakers (shown in Fig. 6), which are denticled and have a length of 2.62 mm (shown in Figure 7 and Figure 3B). The adults with a standard length of 115.0 mm have 38 fine denticled gill-rakers measuring 6.75 mm in length.

As it is shown in this brief analysis of the development of gill-rakers, the filtering apparatus of the anchovy begins to functional as the juveniles reach a standard length of 37.5 mm (shown in Figure 5 and Table 3). In this stage of development, the small phytoplanktonic organisms appear to increase in the stomach contents, probably being retained in the fine filter net which formed by fine denticled gill-rakers. As far as the scarceness or absence of phytoplanktons in the stomach contents in some adult individuals of anchovies is concerned, the filtering net could become coarser because of the increase in width between gill-rakers (shown in Figure 7).

As seen in Figure 6, the gill-rakers in larvae and juveniles are different in different localities. In the larvae having a standard length of 17.5 mm (range 15-20 mm) which were collected from Ba-do-dz mean of the number of gill rakers was 13.04. But the mean of the number of gill-rakers of the same size is 16.17 from Ta-chi. In the juveniles whose standard length reaches 47.5 mm (range 45-50 mm), the mean of gill-raker number in the specimens from Ba-do-dz was 31.11 that from Ta-chi was 34.72. It can be assumed that the fewer number of gill-rakers in Ba-do-dz specimen is effected by the temperature ranged 26°-27°C and lower salinity off Ba-do-dz to the Northern parts. The water temperature was 28°-29°C off Ta-chi to the Eastern parts of Taiwan. Also, the differences of the number of gill-rakers of the larvae and juveniles of anchovies at the two different localities may be due to population differences.

As shown in Figure 5, the digestive tract of the larva, until they reach a standard length of at least 20 mm, is a short and completely straight tube, differentiated only after the esophagus. In the larvae of 20 mm in standard length, the straight tube becomes a bent tube, which enlarges and forms a small "bulb-like" stomach in which the rudiments of the pyloric caeca appear. Then the pneumatic duct connects with the bent part of the end of the straight tube (shown in Figure 5B). At a standard length of 31 mm, the stomach and pyloric caeca are in a rather advanced development states and pigments begin to appear on the anterior and posterior parts of the intestine. In the juveniles of 37.5 mm standard length, the pyloric caeca corresponding to the stomach is well developed and the digestive tract resembles to the adult individual. From Figure 5. it can be seen that the structure of the intestine of the larvae under 20 mm standard length still

maintains a straight tube like shape, and their incidence of feeding is the lowest (shown in Table 2). The differentiation of the digestive tract coincides with the increase of the incidence of feeding.

TABLE 2

Incidence of feeding in larvae, postlarvae, juveniles and adults of the anchovy.

Body length (mm)	Number of individual	Incidence of Feeding
10~20	374	6.5
20~30	490	15.05
30~40	506	24.80
40~50	461	44.71
50~60	421	52.40
60~70	511	62.33
70~80	401	62.37
80~90	233	63.50
90~100	322	70.50
100~110	213	74.27
110~120	188	75.41
120~130	75	78.63
Total	4195	

COMPOSITION AND SIZE OF FOOD IN STOMACH CONTENTS

An examination of the stomach contents of 4195 individuals ranged from 12.5-122.5 mm in standard length collected from six stations (shown in Table 1), showed that only individuals contained food in their stomach. As Table 2 shows, the incidence of feeding is remarkably low, especially at the larval stage ranging from 10 mm to 20 mm in standard length, then it begins to increase gradually as the larvae grow. This fairly agree with the structures of the filtering net of the gill-rakers and the digestive tract.

The sizes of the various organisms found in the stomach contents of each size of fishes were measured except the broken ones, and the maximum and minimum sizes of food in relation to the length of the anchovies were plotted (as shown in Figure 2). It agrees with size of larvae and juveniles but not in the adult forms. The reason has been mentioned above.

The composition of the stomach contents is shown in Table 3. These results have been obtained with one year samples, it is therefore difficult to find remarkable seasonal variations. But it is seen that there are more organisms composing the diet of the adult individuals from March to September.

It is shown clearly that the food components at the larval stage is mainly zooplankton, and only a few kinds of organisms are found in the stomach contents. At the postlarval stage they begin to feed on more phytoplankton; however, the contribution of the phytoplankton to their diet is still quite small. The diet of the juveniles is made up almost exclusively of phytoplankton and comprised more kinds of organisms than at the larval stage, especially in May. For the adults above 60 mm in standard length, it was possible to give an account, as shown in Table 3, of the food composition throughout the year except Jaunary, February, November and December when no specimen could be collected. In these winter months, fishermen can not go out for fishing because of the bad weather and rough sea in the Northern parts of Taiwan.

As can readily be seen from Table 3, the basic food supply for the adults comprises most kinds of organisms, especially in March and June, among which coepoda are found to be highly significant in respect to the total food

TABLE 3

Monthly variation of feeding index of different food organisms

Stage / Month / Organism	LARVAE AND POSTLARVAE (LO–35 mm in standard length)												(35–60 mm				
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Chlorophyceae																	
Trichodesmium sp.				10.41	8.16						42.92				38.00	16.00	10.97
Bacteriastrum sp.				1.72							6.46					4.50	1.23
Diatom remains															42.00	49.00	32.02
Ceratium sp.				0.24	0.18						4.00						0.16
Calanus finnarchicus																	0.33
Paracalanus parvus																	0.33
Oncaea sp.																	0.33
Microsetella sp.											3.75						
Copepoda remains				82.27	91.78						42.25				19.00	19.50	54.23
Euphanusiacea																	0.08
Amphipoda					0.05												3.28
Mysidacea				1.72													
Ostracoda																10.00	
Phyllopoda																	0.07
Rotifera				3.96							0.63					1.00	
Sagitta sp.															1.00		
Polychaeta																	
Fish egg																	

supply. Besides copepods, diatoms and *Trichodesmium* sp. are specially abundant in March and Octomber. *Calanus finuarchicus* are abundant in May and July. Although *Euphausiacea, Ostracoda, Paracalanus parvus, Rotifera,* and *Phylopoda* are found in many individuals, only some of them are occasionally abundant.

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in larva, postlarva, juveniles and adult of the anchovy.

JUVENILE (in standard length)							ADULT (above 60 mm in standard length)											
Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
												0.15						
12.86			23.75		3.89				25.90	13.07	6.59	16.42	9.12	6.87	13.26	12.75		
32.14			22.50		11.56				21.81	21.46	18.08	18.24	20.62	21.95	26.49	24.85		
					0.30				9.98	10.97	22.91	9.23	49.18	10.10	4.97	3.74		
												0.40		10.03	5.03	6.36		
									0.18									
53.57			53.75		81.63				37.09	53.39	35.90	53.63	10.63	44.97	37.86	52.40		
					2.48				1.00	0.68	5.04	0.15		0.13	0.10			
									1.63	0.26								
					0.11						11.20		9.04					
										0.02		10.04		6.00	11.20			
									2.01	0.03		0.07						
1.43										0.12	0.32	1.06	0.63	0.08	0.07			
									0.09									
									0.03									
					0.04				0.01							0.02		

LEGEND OF FIGURES

Fig. 1. Map showing localities mentioned in the text, with the surface sea water temperature in April and September of 1967. ····· The surface temperature of April.
——— The surface temperature of September.
● Stations have been setted. O Planned stations.

Fig. 2. Relationship between the width of the mouth and range of prey length in the anchovy of different lengths.
| : Range of prey length.

Fig. 3. Development of gill-rakers at the different growth stages of anchovies. Also showing the development of denticles.

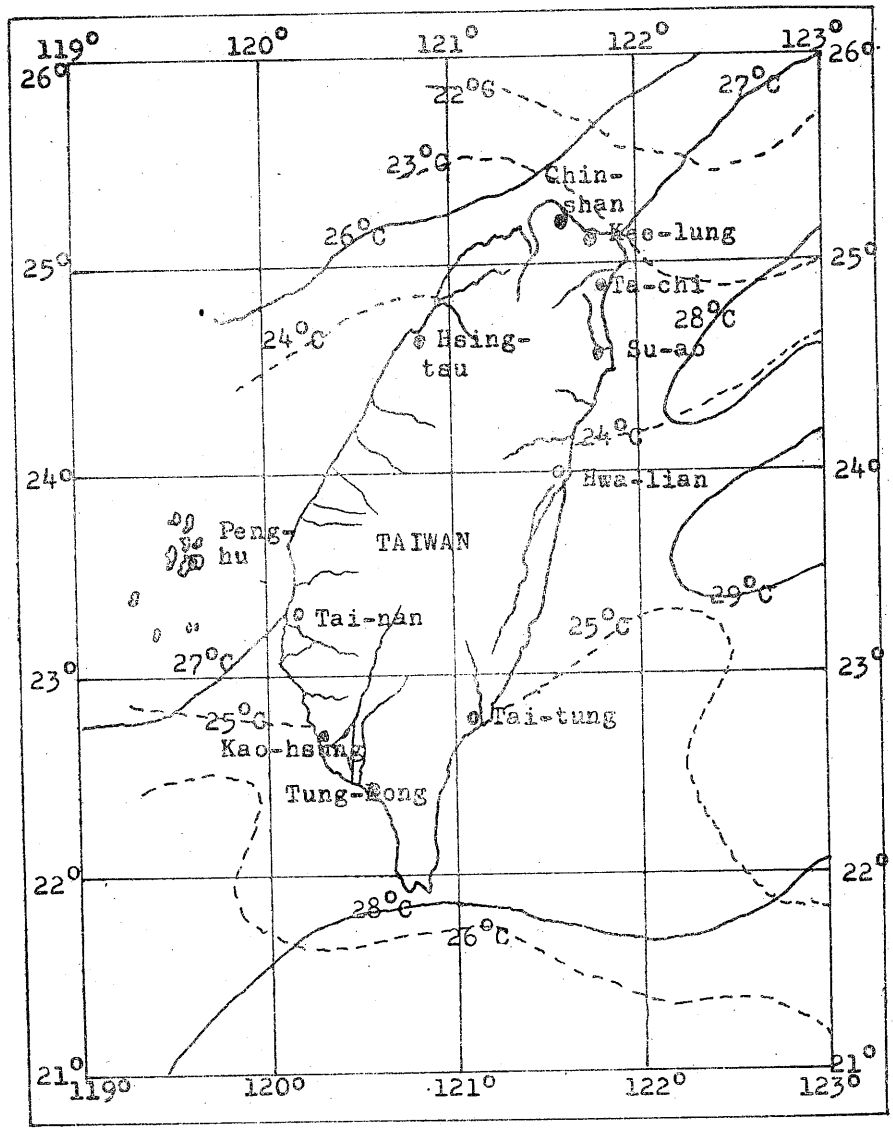
Fig. 4. Showing the appearance of the gill arches, gill-rakers, and denticles at the different development stages of anchovy.

Fig. 5. Showing the development of the digestive tract of anchovy at the different stages of growth. P.C.=Pyloric caeca. P.d.=Pneumatic duct. G.b.=Gas bladder. P.P.=Pyloric portion. B.S.=Blind sac.

Fig. 6. Shows the number of gill-rakers varies from different localities. The horizontal line for each size is the range, the vertical cross-bar is the mean.

Fig. 7. Relationship between the length of gill rakers, width between gill rakers in different stage of anchovy.

Fig. 8. Relationship between the length of denticles and width between denticles in different stage of anchovy.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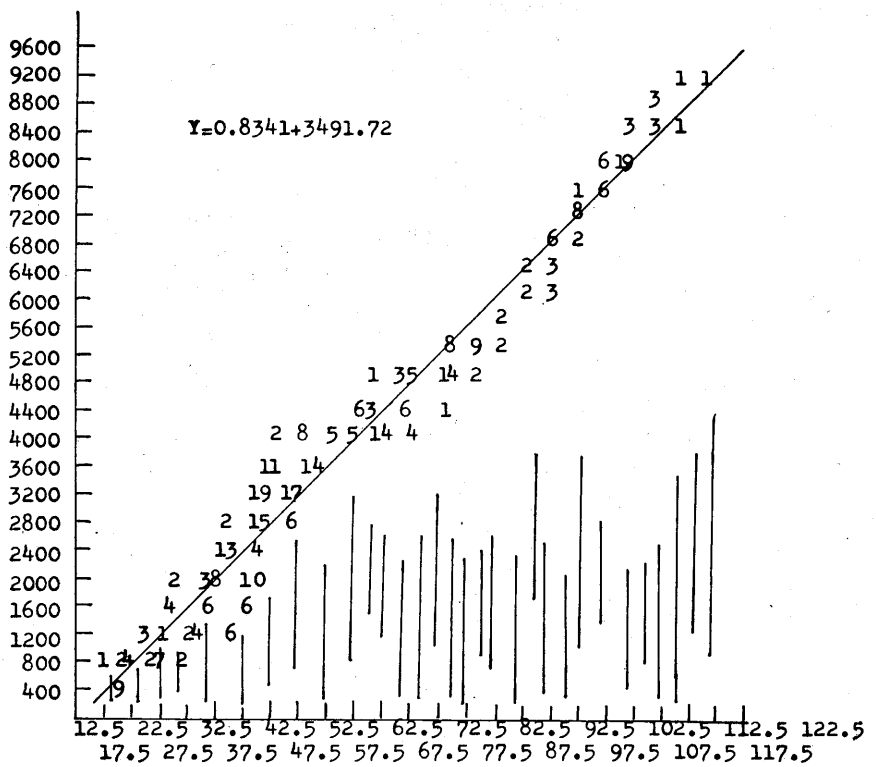
28°C
29°C
25°C
Chin-shan
Kao-lung
Ta-chi
Su-ao
Hsing-tsu
Hwa-lian
Peng-hu
TAIWAN
Tai-nan
Kao-hsung
Tung-kang
Tai-tung

FIGURE 1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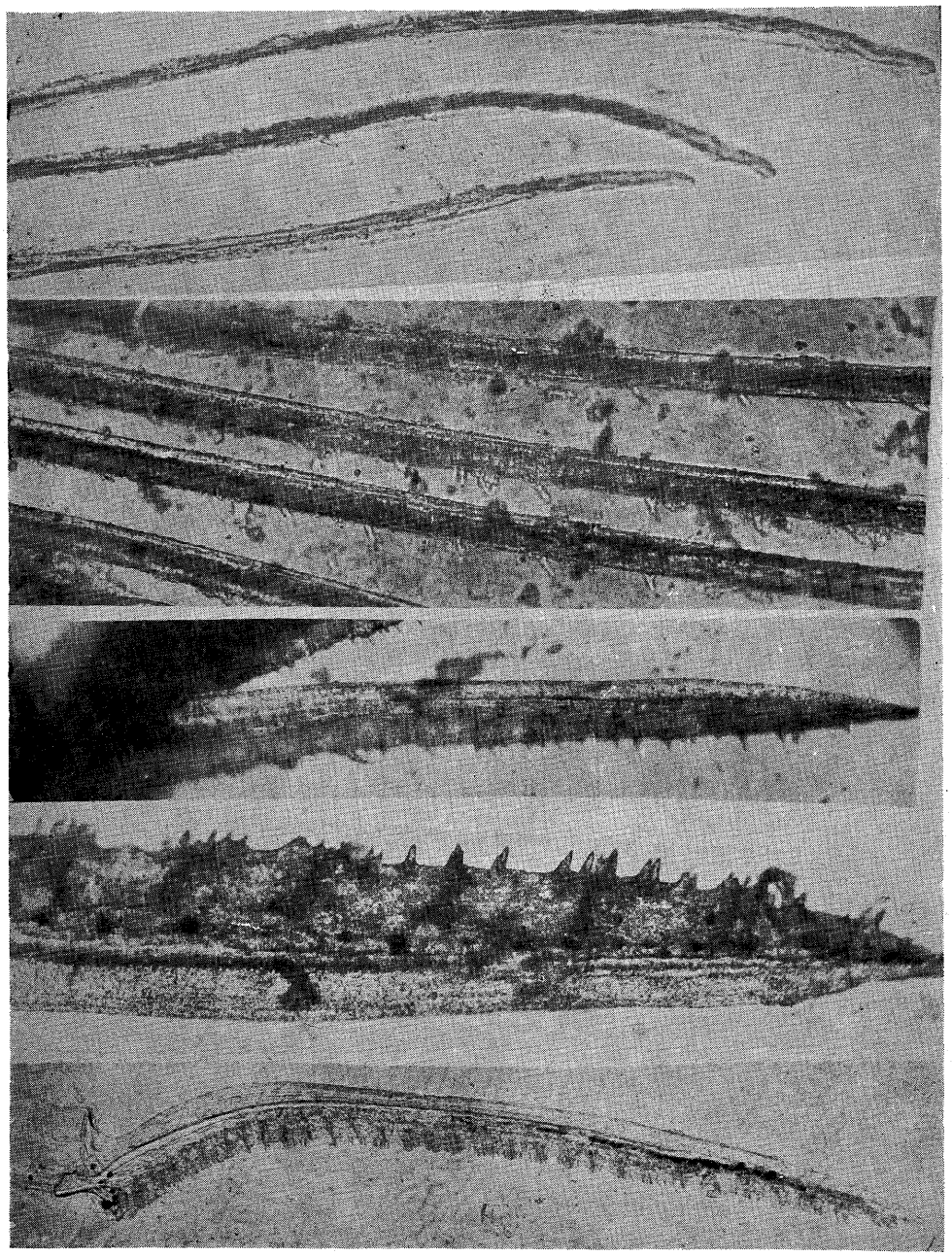
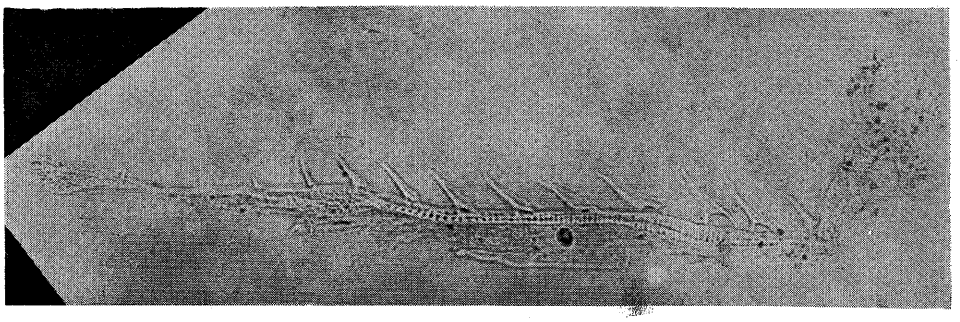
12.5 22.5 32.5 42.5 52.5 62.5 72.5 82.5 92.5 102.5 112.5 122.5
17.5 27.5 37.5 47.5 57.5 67.5 77.5 87.5 97.5 107.5 117.5

FIGURE 2

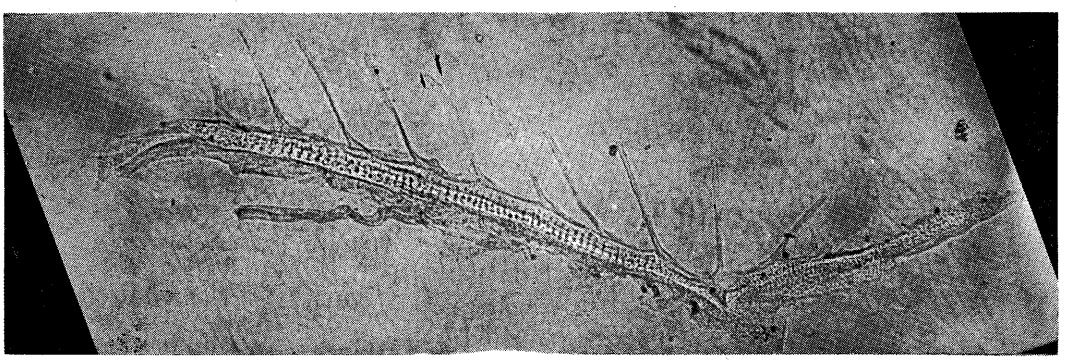


A. 47.8 mm ×100 B. 65.3 mm ×100 C. 78.8 mm ×50 D. 87.8 mm ×50 E. 115.0 mm ×20

FIGURE 3

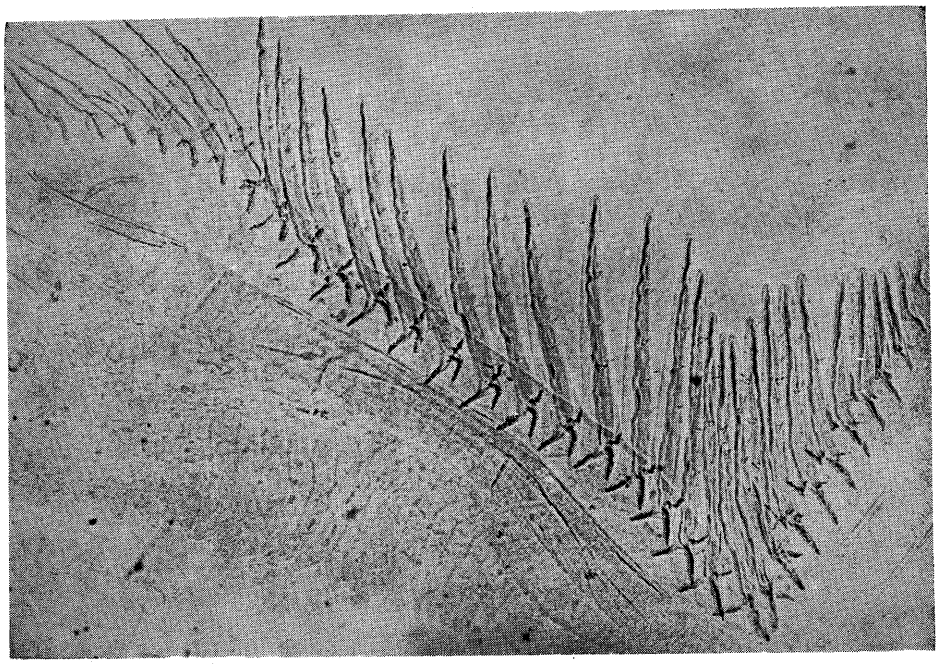


A. 14.6 mm×100

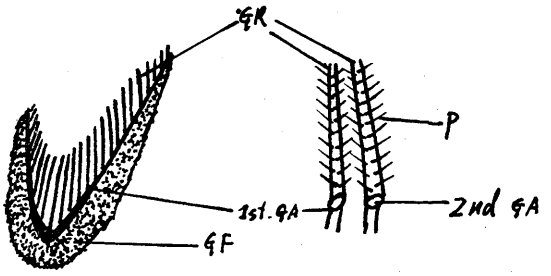


B. 19.6 mm×100

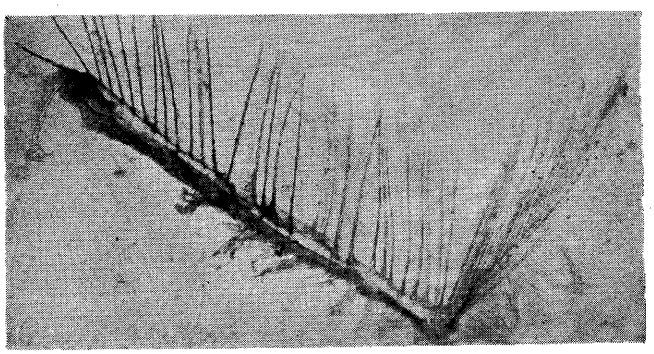
FIGURE 4



C. 24.5 mm×50



D. Structure oi gill arch.



E. 50.9 mm×10

FIGURE 4

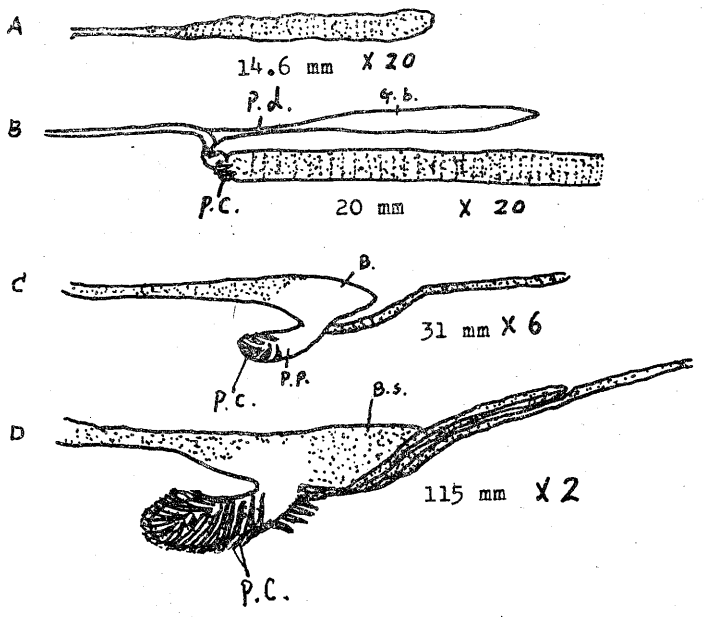


FIGURE 5

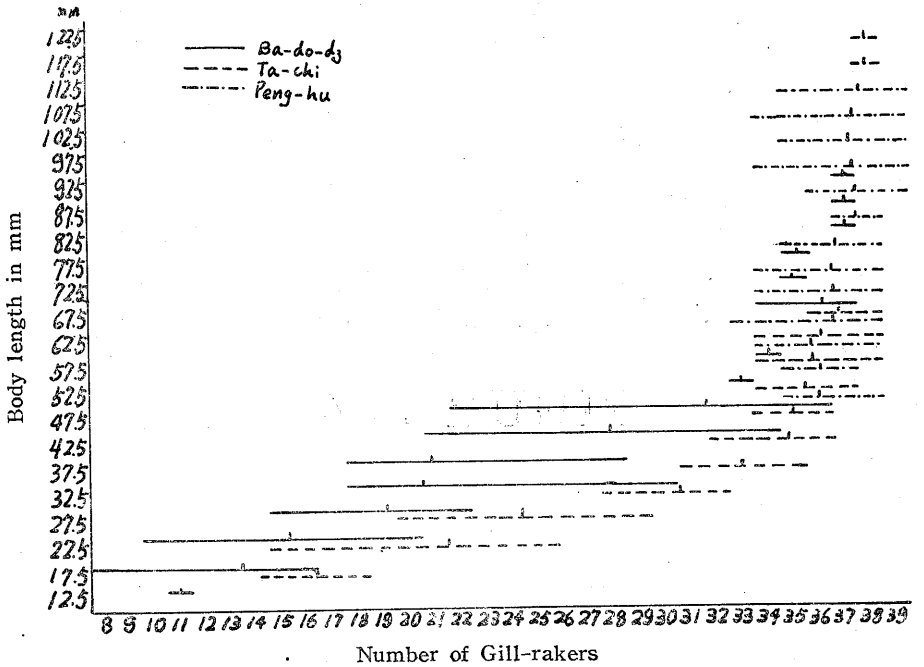


FIGURE 6

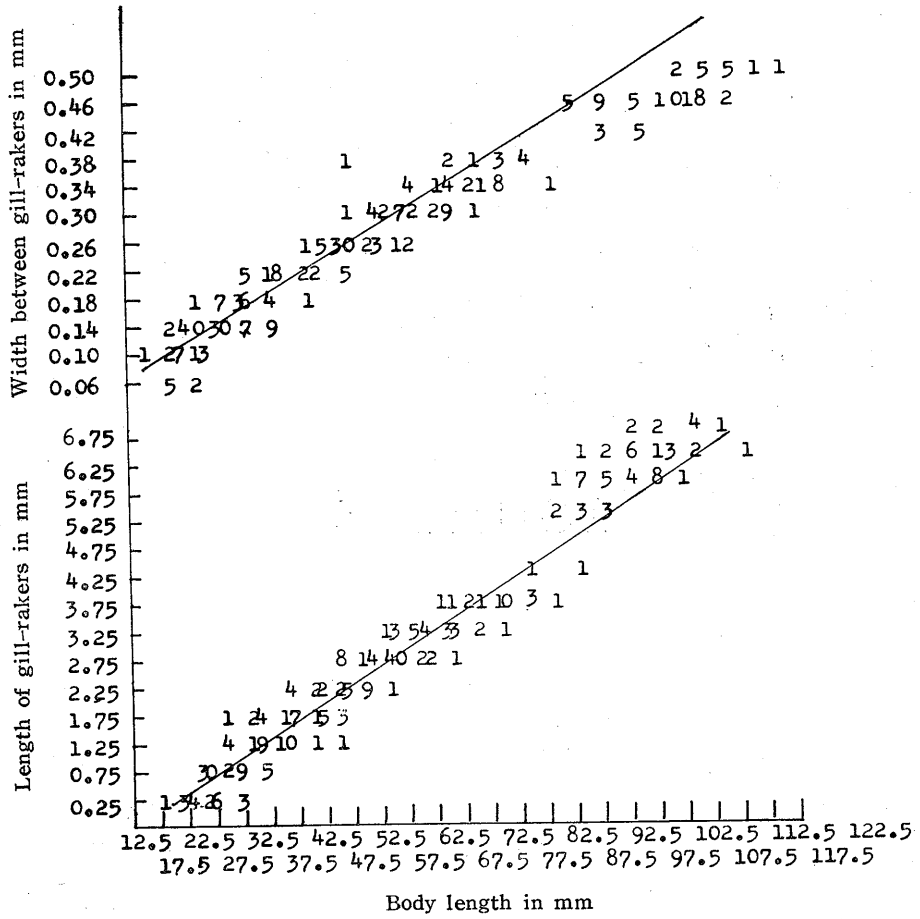

Width between gill-rakers in mm
0.50
0.46
0.42
0.38
0.34
0.30
0.26
0.22
0.18
0.14
0.10
0.06
Length of gill-rakers in mm
6.75
6.25
5.75
5.25
4.75
4.25
3.75
3.25
2.75
2.25
1.75
1.25
0.75
0.25
12.5 22.5 32.5 42.5 52.5 62.5 72.5 82.5 92.5 102.5 112.5 122.5
17.5 27.5 37.5 47.5 57.5 67.5 77.5 87.5 97.5 107.5 117.5
Body length in mm

FIGURE 7

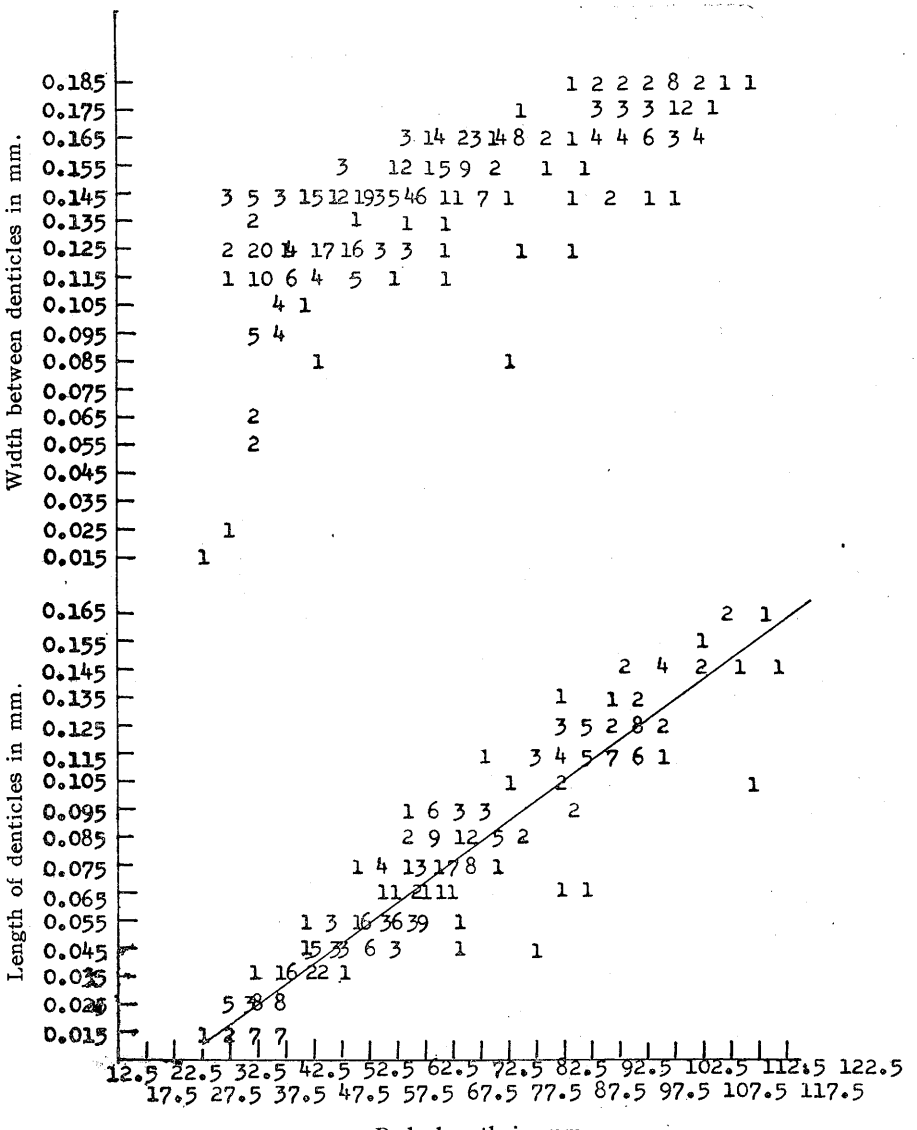

Width between denticles in mm.
Length of denticles in mm.
Body length in mm
12.5 22.5 32.5 42.5 52.5 62.5 72.5 82.5 92.5 102.5 112.5 122.5
17.5 27.5 37.5 47.5 57.5 67.5 77.5 87.5 97.5 107.5 117.5

FIGURE 8