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Development and Replacement of Teeth on Jaws and Pharynx in a Gobiid Fish *Sicydium plumieri* from Puerto Rico, with Comments on Resorption of Upper Jaw Teeth

Kenji Mochizuki[1], Shojiro Fukui[2] and Solomon Gultneh[3]

1) Natural History Museum and Institute, Chiba, 955-2 Aoba-cho, Chiba 280, Japan
2) Ukui 165-6, Nachi-katsuura, Wakayama Pref. 649-53, Japan
3) Japan Overseas Cooperation Volunteers, Japan International Cooperation Agency, Hiroo, Shibuya-ku, Tokyo 150, Japan

Abstract Shapes, arrangement, development, replacement and resorption (or shedding) of teeth on the upper and lower jaws and the pharynx in a gobiid fish *Sicydium plumieri* from Puerto Rico are reported in the present study. The digestive system and gill arches are also examined to discuss function of these teeth.

Key words: Jaw teeth, Pharyngial teeth, *Sicydium plumieri*, Gobiidae, Puerto Rico.

It is well-known that many species of the subfamily Sicydiaphiinae, family Gobiidae, have numerous upper jaw teeth in a single row to scrape off algae from the surface of stones (Erdman, 1961, 1986; Hilderbrand, 1935; Sakai and Nakamura, 1979). Mochizuki and Fukui (1983) studied development and replacement of the upper jaw teeth in a Japanese species, *Sicyopterus japonicus* Tanaka, and they found that the teeth are completely resorbed in the soft tissue of the upper jaw. It was probably the first report of resorption of teeth in vertebrates. Kakizawa et al. (1986) made histological studies on the jaw teeth of the fish and got almost the same results as the previous study in the shapes and development of the upper jaw teeth. However, they did not report or discuss replacement and resorption of the upper jaw teeth.

Mr. Donald S. Erdman sent us specimens of *Sicydium plumieri* (Bloch), one species of the subfamily, from Puerto Rico. According to Erdman (1961, 1986), the fish lives in fast-moving water of rivers, and feeds by scraping off algae from hard bottoms. Circumstances of its habitat and food habits are very similar to those of *S. japonicus* reported by Fukui (1979).

We examined both the jaws and the pharynx of the specimens from Puerto Rico and found that the upper jaw teeth were also very similar to those of *S. japonicus* in many respects. However, the examination showed some important differences between the two species in shape, arrangement, and replacement of the upper jaw teeth.

In the present paper we report shapes, arrangement, development, replacement and resorption (or shedding) of the teeth on both the upper and the lower jaws and the pharynx of *S. plumieri*. We also report the absence of gill rakers and the pattern of the digestive system of the fish to discuss the function of the teeth. These results are also discussed in comparison with those of *S. japonicus*.

Materials and Methods

Materials of *S. plumieri* examined in the present study are as follows. FUMT (Department of Fisheries, University Museum, University of Tokyo)-P 21097-21110, 14 specimens, 58-107 mm SL, in Rio Bauza de Maricao, Puerto Rico, by Fernando Villa and the staff of the Maricao Fish Hatchery, on 27 Feb., 1984 (Fig. 1). These specimens were kept in alcohol after collection, and were sent to us by Mr. D. S. Erdman. Results of

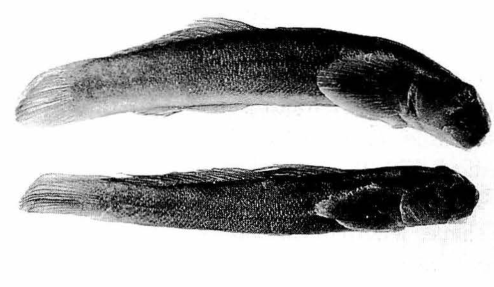


Fig. 1. *Sicydium plumieri* from Puerto Rico. Top: FUMT-P 21103, female, 83 mm SL; Bottom: *FUMT-P* 21105, male, 74 mm SL.

the present examination on the fish are compared with those of *S. japonicus* which were reported by Mochizuki and Fukui (1983). In order to make more sufficient comparison between them, one specimen of *S. japonicus*, FUMT-P 21115, 73 mm SL, female, collected from the Takada River, a branch of the Kumano River, Japan, on 15 Aug., 1979, is also examined for its upper jaw teeth and digestive system.

First, the outside appearance of the jaw teeth of the specimens were observed. The shapes and the arrangement of the teeth of the left upper jaws of eight specimens and a left lower jaw of one specimen were obserbed by a binocular microscope. Two of the upper jaws and a right half of the head were dried by the critical drying method, and were observed by a scanning electron microscope (Hitachi S-700) in the University Museum, the University of Tokyo. Some of the upper jaws and the lower jaw were cut to sections, and these were observed to examine initiation, development, replacement and resorption of the teeth in each succession. Some of the sections were dyed by alizarin red-S and kept in 3-5% KOH solution for 2-8 weeks to make them clear and/or facilitate the break-up into individual tooth in order to observe the shape of each tooth.

Mochizuki and Fukui (1983) had named a small material between the dentine and the premaxillary in the upper jaw teeth of *S. japonicus* as "a basal bone". However, it was already named "pedicel" (Shellis, 1981 : pp. 211-212), and the present authors have corrected its name to "pedicel" in the present paper.

Results

Shape and ankylosis of the upper jaw teeth

The upper jaw teeth of *S. plumieri* are uniform in shape and size except for some teeth in the posterior part of the upper jaw which decrease in size and the shape of the crowns are slightly simplified. Each tooth consists of three parts: enameloid (crown), dentine (tooth shaft), and pedicel (Fig. 2).

The enameloid is very slender and rectangular in shape ; length of the short side is about 0.08 mm and is about 13% of the length of the long side which is about 0.63 mm, in FUMT-P 21000, 107 mm SL. There are two parallel ridges on its anterior (labial) surface, and the enameloid has two shallow notches at its tip, tricuspids (Figs. 3, 4, 5C).

The dentine is very long, about 1.31 mm along its long axis, and its width is about 0.18 mm at its middle part in FUMT-P 21000. The long axis of the dentine roughly makes a right angle with that of the enameloid (Fig. 5B).

The dentine is attached to the pedicel at its basal part ; it has a groove at its basal margin and

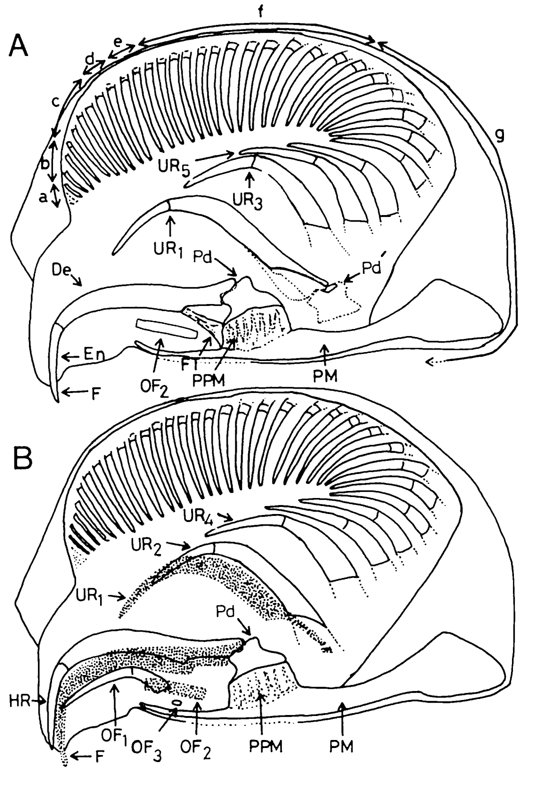


Fig. 2. Successions of upper jaw teeth of *Sicydium plumieri*, FUMT-P 21102, 90 mm SL. A : a succession which includes a functional tooth (F) ; B : a succesion which includes a half-erupted replacement tooth (HR). Dotted parts in B show positions of a functional tooth, an unerupted replacement tooth (UR1) which moves to the position of a half-erupted replacement tooth in the next replacement, and an old functional tooth (OF2) under resorption respectively. De : dentine ; En : enameloid (crown) ; FT : fiberous tissue ; OF1 : an old functional tooth in front of HR ; OF2 : an old functional tooth in front of F ; OF3 : an old functional tooth in front of OF1 ; PD : pedicel ; PD' : developing pedicel ; PM : premaxillary ; PPM : Projection of premaxillary ; UR1, UR2, UR3, …… : unerupted replacement teeth : a, b, c, d, e, f, g : developmental stages of the upper jaw teeth (see text for detailed descriptions).

seats astride of the pedicel at the groove. The pedicel firmly ankyloses to a porous projection of the premaxillary, and is not movable. The functional teeth, when they are forced, are generally broken at the connection between the dentine and the pedicel, and the dentine is probably slightly movable at this connection (Fig. 2, 5B).

The teeth are also directly connected with the premaxillary by fibrous tissue at a projection of the dentine near its distal margin which is situated at the anterior margin of the pulp opening (Fig. 2).

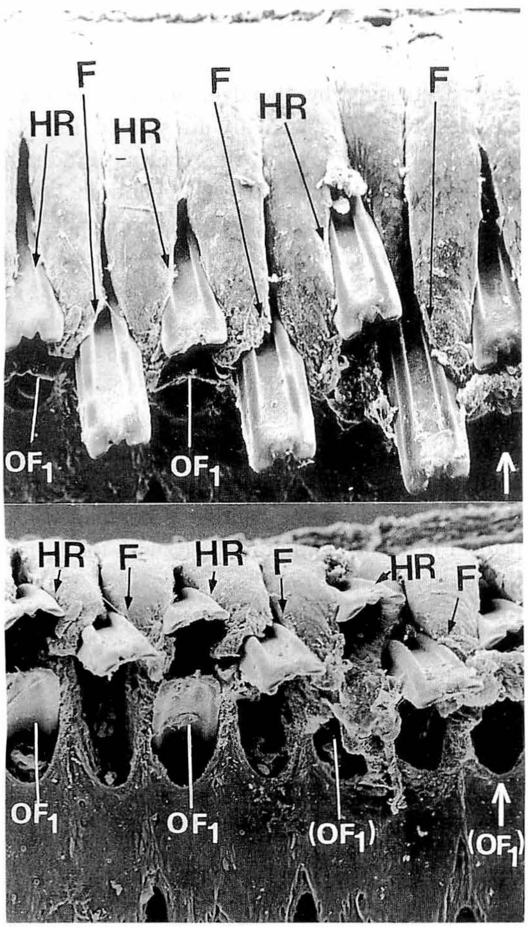


Fig. 3. Upper jaw teeth of *Sicydium plumieri*, FUMT-P 21102, 90 mm SL. Top : anterior view of rows of the functional teeth and the half-erupted replacement teeth in the middle part of the left upper jaw. Bottom : ventral view of the same part as A in this figure ; some teeth of OF1 are observed in front of HR and OF1 in parentheses have already disappeared by sinking into the upper jaw. White arrow : see the explanation of Fig. 4. Abbreviations : see the explanations of Fig. 2.

Arrangement, development and resorption of the upper jaw teeth

This fish has 76-106 successions of the upper jaw teeth in number between the premaxillary and the maxillary in the 58-107 mm SL specimens.

In each succession there are many unerupted replacement teeth which are developing (about 35 teeth in number in each succession of 90 mm SL), and the teeth, including pedicels, are completed at the last stage of development of the upper jaw teeth at the UR1 position (Fig. 2). In each succession there is a functional tooth, or a half-erupted replacement tooth, in front of the nearly completed unerupted replacement tooth (UR1 or UR2 in Fig. 2) that is used as a functional tooth in the next replacement. There is a fair distance between the functional tooth (or the half-erupted replacement tooth) and the nearly completed unerupted replacement tooth (Fig. 5F). Both the functional and the half-erupted replacement teeth ankylose to the premaxillary (Figs. 2, 5B). The successions which include the functional teeth and those wchch include the half-erupted replacement teeth are arranged alternately, i. e. if the func-

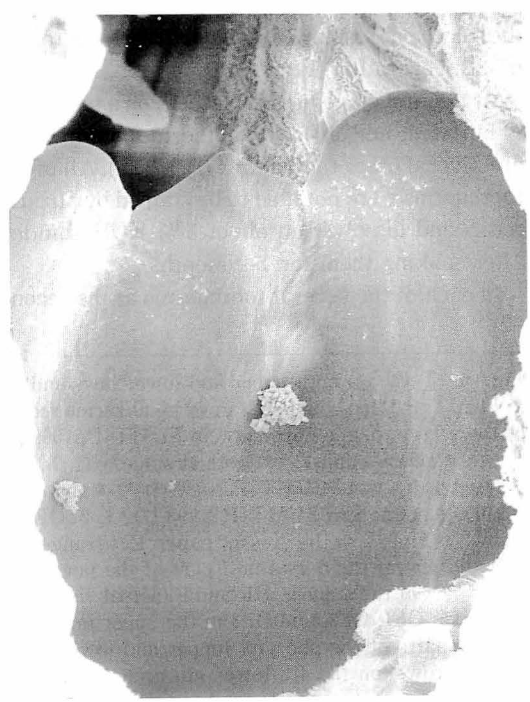


Fig. 4. Middle part of the tip of OF1 in the hole of the upper jaw shown by white arrows in *Fig. 3*. Abbreviations : see the explanations of Fig. 2.

tional teeth are arranged in odd successions, the half-erupted replacement teeth are arranged in even successions (Fig. 3, 5G).

Both the functional teeth and the half-erupted replacement teeth are arranged in a single row (Fig. 3). The latter row is situated slightly behind the former, and each tooth of the functional teeth is situated diagonally behind the tooth of the half-erupted replacement teeth. If the functional teeth belong to the nth (n : positive integral numbers) generation, the half-erupted replacement teeth belong to the n+1th generation. Each tooth in the n+2th generation is situated behind each of the functional teeth and they are arranged in a single row. Each tooth in the n+3th generation is situated behind each of the half-erupted replacement teeth, and they are arranged in a single row. The following generations follow in this order, and there is an initiation of toothgerm at the opposite end of each succession (Figs. 5E, 5F, 6).

The old functional teeth in front of the half-erupted replacement teeth (Fig. 2 : OF1), which are resorbed in soft tissue, belong to the n−1th generation, and those in front of the old functional teeth of the n−1th generation (Fig. 2 : OF3) belong the n−3th generation. Those in front of the functional teeth (Fig. 2 : OF2) belong to the n−2th generation (Figs. 2, 6).

At the first stage of each succession a toothgerm is initiated, and in front of the toothgerm there are several other toothgerms (Fig. 2 : a). All of the toothgerms were not able to be stained by alizarin red-S and dissolved in about 3 % KOH solution after soaking them for 1-2 months.

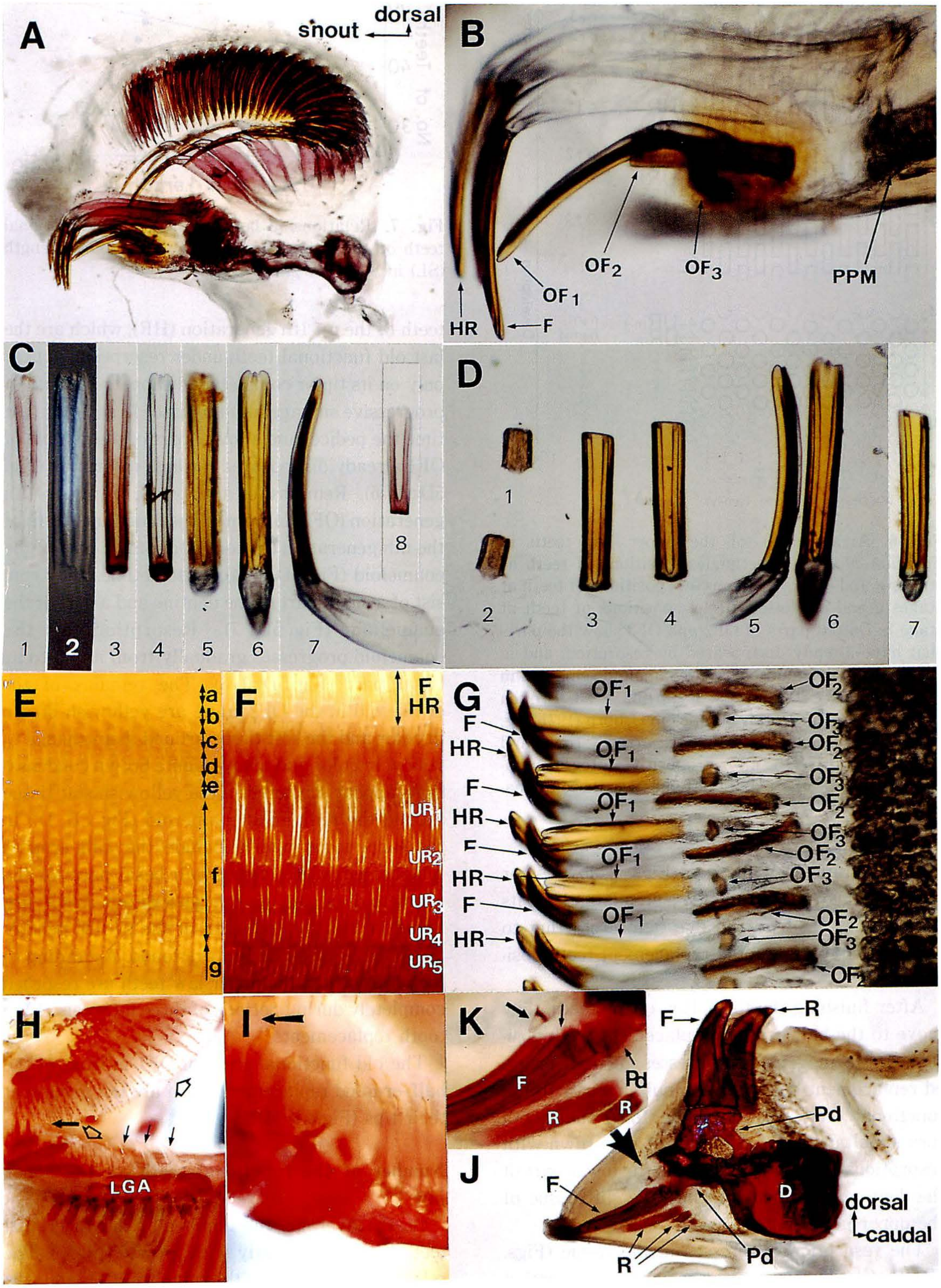
In each of the several toothgerms at the second stage (Fig. 2 : b), a colorless, transparent and tricuspid material is found, and is similar to a complete crown of the teeth in shape. These teeth are not stained by the dye and do not dissolved in about 3 % KOH solution after soaking them for about 2 months.

At the next stage (Fig. 2 : c), 2 to 4 crowns of teeth are stained partly by the dye ; in the earlier part of this stage only a part near its tip is dyed, and then the dyed part spreads to its basal part. In the last part of this stage most part of each crown is dyed. Crowns of these teeth are closely similar to the complete ones in shape and size (Fig. 5C : 1-3).

The next 2-3 teeth (Fig. 2 : d) are entirely stained strongly by the dye, and the next 2-3 colorless teeth (Fig. 2 : e) are not stained (Fig. 5C : 4). Then the color of the crowns gradually changes from light to darker yellowish brown with development and its shape is not changed at this stage (Fig. 2 : f ; 5C : 5-6). No changes are observed in the crown after this stage (Fig. 2 : g).

When the crown is transparent at stage e, growth of the dentine appears at the basal part of the crown, and then the dentine rapidly grows additionally (Figs. 2, 5C : 5-7). The dentine is completed at this stage before starting to move to the position of the half-erupted replacement teeth. At the position where the dentine is completed, the pedicel is formed simultaneously with the formation of the basal part of the dentine (Fig. 2). At the first stage of pedicel formation, a colorless, transparent material is formed, which has almost the same shape as a complete pedicel and is not dyed by alizarine red-S. Then a part near the dentine

Fig. 5. Teeth on both upper and lower jaws and pharynx in *Sicydium plumieri*. A : section of the left upper jaw in FUMT-P 21100 which is stained by alizarine red-S ; 4 successions are found in this figure. B : antero-ventral part of the section of the upper jaw in FUMT-P 21099 which is stained by alizarine red-S and this section consists of 4 successions. C : upper jaw teeth at stages c (1, 2), d (3, 8), e (4), f (5) and g (6, 7) in FUMT-P 21098 (1, 3, 4, 8), FUMT-P 21100 (2, 5, 7) and FUMT-P 21099 (6) ; 1-4 and 8 are stained by alizarin red-S. D : old functional teeth in FUMT-P 21099 (1-6) and in FUMT-P 21098 (7) ; 1, 2 : OF3 ; 3, 4, 7 : OF ; 5, 6 : OF1 ; 1-6 were taken out from the section shown in Fig. 5B in the present paper. E : arrangement of the upper jaw teeth at the a to early part of the g stages (dorsal view of the dorsal half part of the jaw in FUMT-P 21100). F : arrangement of the upper jaw teeth at the latter part of the stage g, HR and F (dersal view of the ventral half of the jaw in FUMT-P 21098). G : arrangement of HR, F, OF1, OF2, and OF3 in the upper jaw of FUMT-P 21099 (ventral view). H : tooth patches on dorsal and ventral parts of the pharynx (upper and lower open arrows respectively) and projections like gill rakers (small black arrows) on the 4th lower gill arch of FUMT-P 21098 ; large black arrom : Oesophagus. I : Enlarged photograph of the ventral tooth patch on the pharynx ; black arrow : oesophagus. J : cross section of the lower jaw in FUMT-P 21098 ; large black arrow shows the position of Fig. 5K. K : enlarged photograph of a part shown by large arrow in Fig. 5J. D : dentary bone ; LGA : lower gill arches ; R : replacement teeth ; For the other abbreviations : see the explanations in Fig. 2.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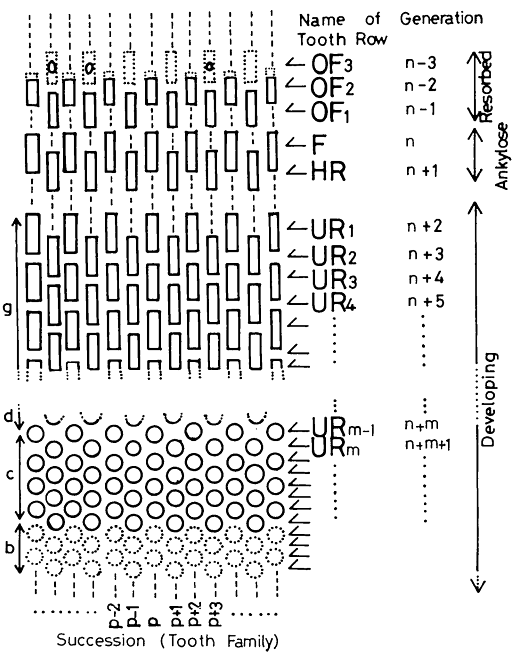

Fig. 6. Arrangement of the upper jaw teeth in *Sicydium plumieri*. Rectangles: positions of teeth at stages g and older; open circles: positions of teeth at stages c and d; dotted circles: positions of teeth at stage b. Dotted parts of OF2 and OF3 show the parts that have already disappeared by resorption, and in this figure only small parts of enameloid remained in the three successions P−5, P−3 and P+3. Broken lines: successions (tooth families in Osborn (1971: fig. 1) and Nakajima (1979: fig. 5)); arrows: rows and generations of teeth. m, n, p: positive integral numbers; For the other abbreviations: see the explanations in Fig. 2.

becomes stained by the dye (Figs. 2, 5A). After that the dyed part gradually spreads and all its parts are stained by the dye before starting to move to the half-erupted replacement teeth position.

After finishing the formation of the teeth, they move to the half-erupted replacement teeth position. As the movement progresses, the half-erupted replacement teeth move simultaneously to the functional teeth position. The functional teeth turn simultaneously on the tip of the crown with resorptions from the pedicel and the lower part of the dentine, and then sink into the soft tissue of the upper jaw (Figs. 3, 6).

The resorption progresses in the tissue (Figs. 5B, D, G). The teeth of the n−1th generation (OF1) in front of the half-erupted replacement

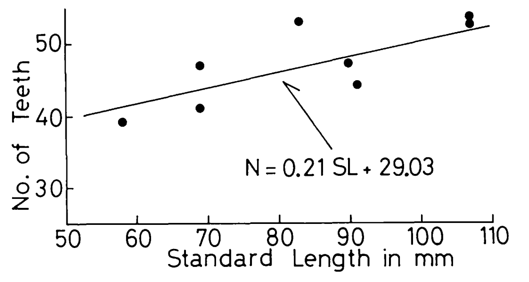

Fig. 7. Relationship between number of functional teeth on the left upper jaw (N) and standard length (SL) in *Sicydium plumieri*.

teeth of the n+1th generation (HR), which are the last old functional teeth under resorption, appear only on its tip or completely disappear because of progressive sinkage into the tissue (Fig. 3). At that time the pedicel and a lower part of the dentine of OF1 already disappeared through resorption (Fig. 5D: 5, 6). Remains of the teeth of the n−2th generation (OF2) in front of the functional teeth of the nth generation (F) consist of only a part of the enameloid (Fig. 5D: 3, 4), or sometimes they consist of a small part of the dentine and a part of the enameloid (Fig. 5D: 7). Resorption of the enameloid progresses gradually from its tip to its basal part (Fig. 5D: 1-6). The remains of the enameloid in the OF2 stage are yellowish brown in color and the soft tissue around them change to yellow in color and many minute brown condensations appear scattered in the yellowish soft tissue around the remaining enameroid (Fig. 5B, D). In the successions which include the half-erupted replacement teeth, very small besal parts of the enameloid of the n−3th generation (OF3) are found in front of the teeth of the n−1th generation (OF1), or no remains are found. According to the observation, the upper jaw teeth are resorbed completely during periods of three intervals of the tooth replacements.

The old functional teeth of OF1 in front of the half-erupted replacement teeth are not ground at their tips (Figs. 4, 5D).

Number of the functional teeth on the upper jaw

On the average, the number of the functional teeth increases linearly with growth (Fig. 7). The relationship between the number (N) and the standard length in mm (SL) is calculated by the least square method as follows.

$N=0.21SL+29.03$ $(58\text{ mm}\leqq SL\leqq 107\text{ mm})$

Therefore, the number of the functional teeth is about 40 in 50 mm SL, and about 50 in 100 mm SL. The number of the successions is about 80 in 50 mm SL, and about 100 in 100 mm SL because each of the functional teeth is arranged in alternate successions. The mean increment of the number of the functional teeth is 0.21 per increment of 1 mm of standard length and the number of the successions is about 0.42 per increment of 1 mm of standard length.

Teeth on the lower jaw

There are two kinds of teeth on the lower jaw ; canine-like teeth in a single row on the dorsal side of the jaw, and slender teeth in a single row on the anterior side of the jaw (Fig. 5J).

The former consists of up to about ten in number. Each tooth consists of enameloid, dentine and pedicel, and ankyloses to the dentary bone by the pedicel. The dentine is connected to the pedicel by fibrous tissue. Their toothgerms are found in a soft tissue mainly between the bases of the functional teeth.

The slender teeth consist of many slender needle-like teeth, and each tooth also consists of enameloid, dentine and pedicel. All the teeth are completely embedded in skin and soft tissue (Fig. 5J). This part of the jaw form a high ridge with a sharp edge, and the teeth support the ridge like the skeletal system of vertebrates which supports the body. Their toothgerms are found in soft tissues near the bases of the functional teeth at its ventral side. Developmental stages of the toothgerms vary in different positions, and their replacement does not occur in a line simultaneously but occurs individually. The old functional teeth disappear completely before the replacement teeth start to move to the functional teeth position, and it is not clear whether the teeth are resorbed in the tissue of the lower jaw or are shed outside the skin.

The dentine of the functional teeth on the anterior side of the lower jaw is connected to the pedicel by fibrous tissue, and a small dorsal part of the base of each dentine is not ossified. Therefore, the teeth are probably movable toward the dorsal side.

Several tooth-like materials are found at the dorsal side of the base of the teeth on the anterior side of the lower jaw (Fig. 5K). These resemble the teeth in shape, but no further examination was made in the present study.

Pharyngeal teeth and gill arches

The fish has only pharyngeal teeth except for teeth on both the upper and lower jaws. The teeth are distributed in two rounded patches on the dorsal and ventral parts of the pharynx (Figs. 5H, 8). The two patches face each other. Teeth in the inner posterior part of each patch are bigger in size than those in the outer anterior part. Each tooth in the patches recurves to the oesophagus. Most part of each tooth is buried by skin, and only the tip sticks out of the skin. The teeth in both patches ankylose by a pedicel (Fig. 5H, I). Toothgerms are found among the functional teeth in both patches.

The fish has no gill rakers on all gill arches. The third and fourth lower gill arches are armed with several to ten projections of soft tissue that look like a gill raker in shape ; the projections do not include any hard tissue (Figs. 5H, 8).

Digestive system and its contents

The fish has a moderate sized stomach and a very long intestine. The total lengths are 3.60 and 4.01 times of SL in 107 and 90 mm SL respectively. The intestine is strongly convoluted (Fig. 9). Though no gut contents are found in all the specimens examined in the present study, the long convoluted intestine probably indicates that the fish is herbivore.

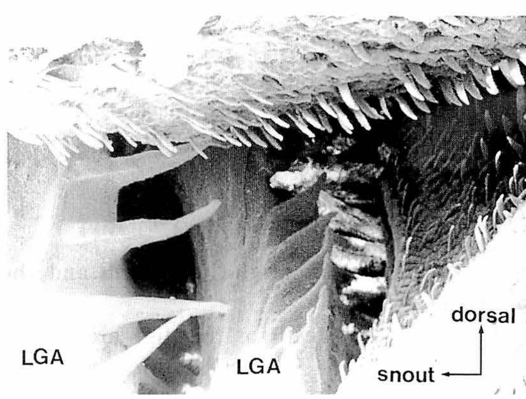

Fig. 8. Tooth patches on dorsal and ventral surfaces of the pharynx and soft projections on the 3rd and 4th lower gill arches (LGA) in the right part of *Sicydium plumieri*, FUMT-P 21098.

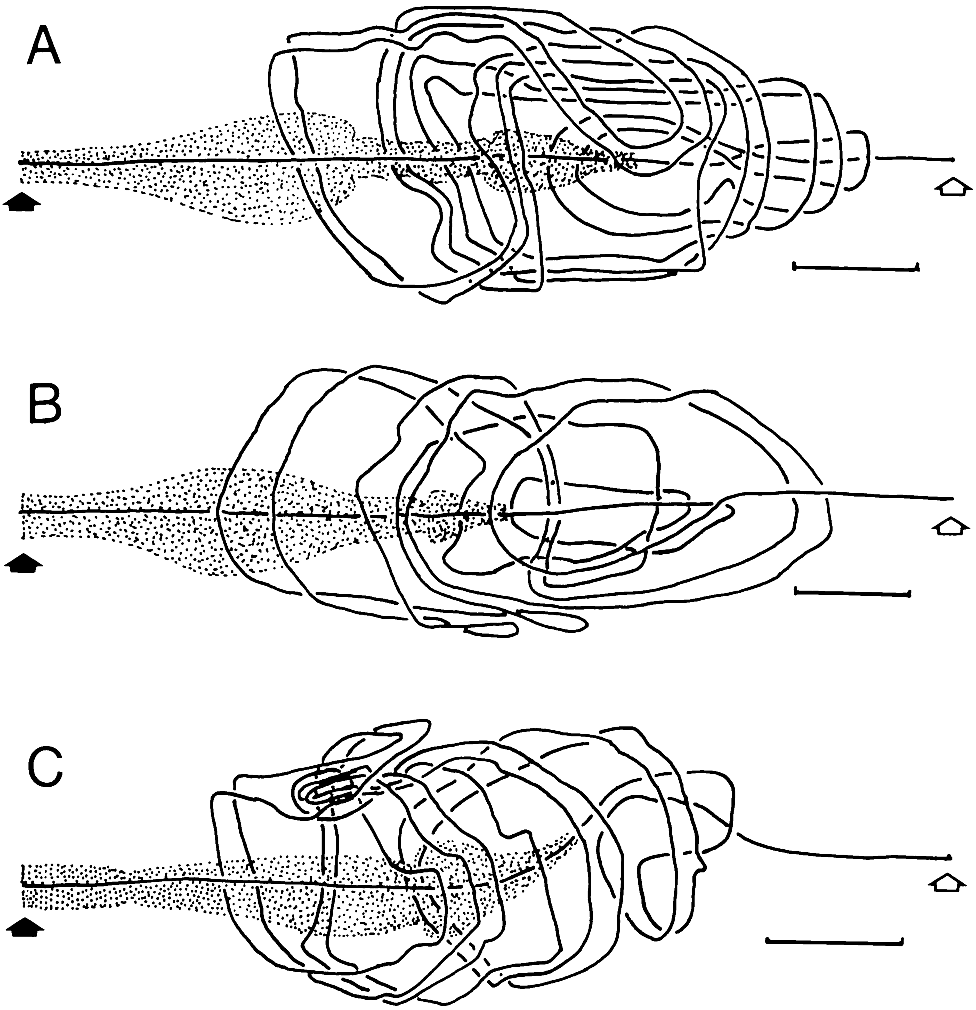

Fig. 9. Patterns of stomach and intestine. A : *Sycydium plumieri*, FUMT-P 21100, 107 mm SL, dorsal view, length from pharynx to anus 3.60 times of SL ; B : *Sicydium plumieri*, FUMT-P 21102, 90 mm SL, ventral view, length from pharynx to anus 4.01 times of SL ; C : *Sicyopterus japonicus*, FUMT-P 21115, 73 mm SL, dorsal view, length from pharynx to anus 4.22 times of SL. Black arrow : pharynx ; open arrow : anus. Dotted areas : outline of stomach and anterior part of intestine. Bars : 5 mm.

Discussion

Shape and function of the jaw teeth and the pharyngeal teeth

The upper jaw teeth of this fish are closely similar to those of *S. japonicus* (Mochizuki and Fukui, 1983 ; Kakizawa et al., 1986). The teeth consist of three parts, i. e. enameloid, dentine and pedicel and each tooth has a tricuspid crown. The fish has many replacement teeth behind each of the functional and half-erupted replacement teeth. However, some important differences are found between them.

The enameloid of *S. plumieri* is much more slender and rectangular in shape than that of *S. japonicus* : the width is about 13 % of the length in the former instead of about 46 % in the latter. It has two ridges on its anterior surface (no ridges in *S. japonicus*) (Fig. 3A). The long axis of the enameloid roughly makes a right angle with that of the dentine (Fig. 5B) instead of about 130 degrees in *S. japonicus*. Though *S. plumieri* has the tricuspid upper jaw teeth, the cusps in each tooth are much smaller than those of *S. japonicus* ; the height of the cusps, except for the middle one, are about 80 % of the crown length in the latter (Mochizuki and Fukui, 1983) and the tricuspids of the former are no more than two shallow notches at the tips of their crowns (Figs. 3, 5C). These differences probably indicate differences in their use of the teeth.

The direct connection of fibrous tissue between the projection of dentine and the premaxillary is much less developed than that of *S. japonicus* (Mochizuki and Fukui, 1983). The function of the tissue, which is considered to be more or less elastic, is probably to help in protecting the teeth from the impact of rubbing between the tip of the teeth and stone surfaces when the fish scrapes off algae. Thus the attachment between the dentine and the pedicel possibly functions as a fulcrum. Since the tissue is less developed in *S. plumieri*, it is less adapted to scrape off algae by pressing the teeth hard against a hard bottom and move them at the same time.

In *S. japonicus* each succession of the upper jaw teeth includes a functional tooth, and the functional teeth are very closely placed to each other (Mochizuki and Fukui, 1983). But in the present fish the functional teeth and the half-erupted replacement teeth are arranged in alternate series respectively, and a space roughly corresponding to the width of the crown is found between neighboring functional teeth (Fig. 3A). Therefore, in this fish the efficiency to scrap off algae from stone surfaces is very different from that in *S. japonicus*.

About half of the enameloid of the upper jaw teeth disappears in *S. japonicus* when resorption of the teeth starts (Mochizuki and Fukui, 1983 : fig. 4). This result shows that the fish presses its upper jaw teeth hard against hard bottoms in order to scrape off algae and that the teeth are rapidly ground down from their tips. These well correspond with the observation of its feeding behavior in the field and also with the facts that many small pieces of stones were found in its gut contents (unpublished data of the present authors). On the other hand the enameloid of *S. plumieri* is not worn off when resorption of the teeth starts (Fig. 4). This difference between the two species shows that the fish from Puerto Rico gets their food in a different method from that of *S. japonicus*, i. e. the former does not touch the surface of hard bottoms using the upper jaw teeth.

Erdmam (1961, 1986) mentioned that the fish feeds by scraping slime algae such as desmids off the upper surfaces of stones and rocks in the stream. Hilderbrand (1935) reported that "The contents of the intestinal tract of 8 specimens examined consisted chiefly of vegetable debris including diatom shells, though one specimen had ingested a few mollusks, another one a chironomid larva and an ostracod, and still another one contained many sponge spicules". Though the present authors have no data and/or information to solve the problem whether the animals from the intestinal tracts of the three specimens were exceptional or general foods of the fish, from the above publications it is suggested that the fish feeds at least mainly on algae growing on the surfaces of hard bottoms by their specialized upper jaw teeth.

Results in the present study show close similarity in length and patterns of the digestive system in *S. plumieri* and *S. japonicus* ; their guts are very long, 3.60 and 4.01 times of SL in the former and 4.22 in the latter, and each has a highly convoluted digestive system (Fig. 9). Gut contents of *S. japonicus* are composed of diatoms, fragments of algae, detritus, and many minute pieces of stones according to unpublished data of the present authors and from results of the present examination on FUMT-P 21115. These results strongly indicate that the Puerto Rican fish is also a herbivore like *S. japonicus* though no gut contents were found, and we agree to the information provided in the publications. However, in the present study we observed that the crowns of the fish from Puerto Rico are not worn off at the start of resorption (Figs. 4, 5D : OF1) and this might imply that the upper jaw teeth are not pressed hard against the stone surfaces when the fish gets their foods. And also, the gut contents do not contain any minute pieces of stones. Thus, further study on the food habits of the present fish is needed, especially on the kinds of foods and how the upper jaw teeth are used.

Of the two types of the lower jaw teeth, those on the anterior side are probably considered to function as a dustpan. The fish presses the ventral side of the ridge of the lower jaw, where the teeth are embedded, against the stone surfaces and sucks water efficiently to mix the foods. The facts that a small dorsal part of the base of dentine is not ossified and also the dentine is connected to the pedicel by fibrous tissue (Fig. 5J) probably imply that the teeth are more or less movable to the dorsal side, and these are probably adaptations to the feeding mechanism of pressing the ridge against hard bottoms.

We have no information or idea about the function of the canine-like teeth on the dorsal side of the lower jaw. However, considering the teeth position, shape and size, they do not seem to be adapted to the food habits.

The position of the tooth patches on the pharynx and the shape of each tooth in the patches suggest that the teeth aid in sending foods to the oesophagus. But the foods are probably minute particles of algae scraped off from the surface of hard bottoms which are then mixed in water. Unless these minute particles are gathered together into bigger masses by some kind of mechanism, it is very difficult to explain the function of the teeth. Moreover, the present fish has no gill rakers nor gill raker like projections except for several to ten rather big projections on the third and fourth lower gill arches (Figs. 5H, 8). Plankton feeders generally have many long slender branched gill rakers on their outer gill arches, and piscivorous or carnivorous fish generally have few undeveloped, sometimes rudimentary, gill rakers (Yasuda, 1960). The structure of the gill arch of the present fish is not that of a plankton feeder but is very similar to that of carnivorous or piscivorous fishes, and these results support the presumption that the minute particles are gathered together to form bigger ones. Therefore, to account for the function of the pharyngeal teeth we propose the following hypothesis. The mucus secreted from the surface of the oral cavity catches minute particles of foods in the water and these develop into bigger ones, and the bigger masses consisting of foods and the mucus are hooked by the teeth and are sent to the oesophagus.

Replacement pattern of the upper jaw teeth

S. plumieri has several characteristics of replacement pattern of the upper jaw teeth. (1) In a replacement, resorption and movement of the functional teeth start and advance simultaneously in a row, and also the movement of the half-erupted replacement teeth to the functional tooth position starts and advances simultaneously in a row. (2) The number of unerupted replacement teeth is the same among the successions except for some successions near the symphysis and in the posterior part of the upper jaw. (3) In each succession, a toothgerm is initiated at a distal end, and a functional tooth and old functional teeth in the processes of being resorbed are situated at the opposite end (Figs. 2, 6). (4) Each replacement tooth is situated diagonally behind the teeth of the last generation and before those of the next generation (Fig. 5E, F, 6).

Considering these characteristics, it is presumed that toothgerms are initiated simultaneously at one distal end in alternate successions in a row and that they are of one generation. Moreover, in one replacement each tooth probably moves ahead along a succession (tooth family) to the next position. These imply that the simultaneous initiation of the toothgerms at alternate positions and the movement to the next position in one replacement are influenced by the teeth condition of the last generation and/or one before it. This means the functional teeth condition might be very important in starting the replacement process.

Replacement patterns of pharyngeal teeth in some cyprinid and cobitid fishes (Nakajima, 1979, 1984, 1987) are very similar to those of *S. plumieri* in having their functional teeth arranged in alternate positions, and also in ankylosing new functional teeth alternately to the next positions in one replacement. This similarity strongly suggests the existence of common law(s) governing their tooth replacement. To explain the dentition and replacement pattern of a cyprinid fish, Nakajima (1979) accepted the theory of Osborn (1971) based on the ontogeny of tooth succession in a lizard *Lacerta vivipara* Jacquin. Replacement of the upper jaw teeth of the present fish might be explained by this theory. But replacement of their lower jaw teeth is different from that of the upper jaw teeth. Further examination is needed to reach a conclusion.

On the other hand, Wakita *et al.* (1977)

examined the jaw teeth of an acanthuroid fish *Prionurus microlepidotus* Lacepède (= *P. scalprus* Valenciennes) and explained its replacement pattern by the "Zahnreihen" theory proposed by Edmund (1960) who also studied tooth replacement in reptiles and aves.

In *S. japonicus*, each replacement tooth except for ones at the last stage of development is situated diagonally behind teeth of the last generation (Mochizuki and Fukui, 1983) and replacement teeth in two rows (generations) are arranged in a single row at the last stage of tooth development. Therefore, functional teeth of this fish arranged in a single row consist of two generations, and all of them are replaced simultaneously in one replacement. This replacement pattern is considered to be a modification of that of *S. plumieri*. This modification is more adaptable to scrape off minute algae from the surface of stones efficiently.

These various or modified patterns among fishes imply the presence of more number of replacement patterns in fishes since the number of fishes examined for their dentition are not many. From now on, dentition of many fishes should be examined further in relation to their function to find out common law(s) which govern replacement patterns of teeth in fishes.

Resorption of the upper jaw teeth

After we reported on the resorption of the upper jaw teeth of *S. japonicus* (Mochizuki and Fukui, 1983), some opinions concerning this were raised. One of these opinions denies the existence of resorption, and according to this, the teeth in front of the functional (and half-erupted replacement teeth (OF1, OF2, and OF3)) are not resorbed but are developing as members of the different (second) successions, and the teeth are shed outside the skin without ankylosing or functioning. Naturally the functional teeth are also considered to be shed outside the skin. However, the above opinion does not correspond with the observations made on the two gobiid fishes in the present study and in Mochizuki and Fukui (1983) in the following aspects. (1) The number and positions of the teeth in front of the functional (and half-erupted replacement) teeth well correspond with those of the functional (and half-erupted replacement) teeth in both fishes (Figs. 3, 5G). (2) If the teeth in front of the functional (and half-erupted replacement) teeth are members of the "second" successions, we have to consider that the emameloid in the "second" successions developes additionally in both species (Fig. 5D), and this is inconsistent with the law of enameloid formation. (3) The enameloids in front of the half-erupted replacement teeth are almost the same as those of the functional and half-erupted replacement teeth both in shape and size in the present fish (Fig. 5). (4) The second and third old functional teeth (OF2 and OF3) in *S. plumieri* and the old functional teeth (OF) in the second and/or third rows in *S. japonicus* are frequently disordered in their arrangement and faced each other in different directions (Fig. 5G ; Mochizuki and Fukui, 1983 : fig. 6E).

From these observations we find it hard to accept the opinion that denies the existence of resorption of the upper jaw teeth in *S. plumieri* and *S. japonicus*.

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References

Edmund, A. G. 1960. Tooth replacement phenomena in the lower vertebrate. R. Ont. Mus., Life Sci. Div., Contr. 52 : 1-190.

Erdman, D. S. 1961. Notes on the biology of the gobiid fish *Sicydium plumieri* in Puerto Rico. Bull. Mar. Sci. Gulf and Caribbean 11 (3) : 448-456.

Erdman, D. S. 1986. The green stream goby, *Sicydium plumieri*, in Puerto Rico. Trop. Fish. Hobbyist 35 (2) : 70-74.

Fukui, S. 1979. On the rock-climbing behavior of the goby, *Sicyopterus japonicus*. Japan. J. Ichthyol. 26 (1) : 84-88. (In Japanese with English abstract.)

Hilderbrand, S. F. 1935. An annotated list of fishes of the fresh waters of Puerto Rico. Copeia 1935 (2) : 49-56.

Kakizawa, Y., N. Kajiyama, K. Nagai, K. Kado, M. Fujita, Y. Kashiwaya, C. Imai, A. Hirama, and M. Yorioka, 1986. The histological structure of the upper and lower jaw teeth in the gobiid fish, *Sicyopterus japonicus*. Jour. Nihon Univ. Sch. Dent. 28 (3) : 175-187.

Mochizuki, K. and S. Fukui. 1983. Development and replacement of upper jaw teeth in gobiid fish, *Sicyopterus japonicus*. Jap. J. Ichthyol. 30 (1) : 27-36.

Nakajima, T. 1979. The development and replacement patterns of the pharyngeal dentition in the Japanese cyprinid fish, *Gnathopogon coerulescens*. Copeia 1979 (1) : 22-28.

Nakajima, T. 1984. Larval vs. adult pharyngeal dentition in some Japanese cyprinid fishes. J. Dent. Res. 63 (9) : 1140-1146.

Nakajima, T. 1987. Development of pharyngeal dentition in cobitid fishes, *Misgurnus anguillicaudatus* and *Cobitis biwae*, with a consideration of evolution of cypriniform dentition. Copeia 1987 (1) : 208-213.

Osborn, J. W. 1971. The ontogeny of tooth succession in *Lacerta vivipara* Jacquin (1787). Proc. R. Soc. London, B, 179 : 261-289.

Sakai, H. and M. Nakamura. 1979. Two new species of freshwater gobies (Gobiidae : Sicydiaphiinae) from Ishigaki Island, Japan. Japan. J. Ichthyol. 26 (1) : 43-54.

Shellis, P. 1981. Formation of attachment tissue. In J. W. Osborn (ed.), Dental anatomy and embryology. A comparison to dental studies , vol. 1, book 2, pp. 211-212. Backwell Scientific Publication, Oxford.

Wakita, M., K. Itoh and S. Kobayashi. 1977. Tooth replacement in the teleost fish *Prionurus microlepidotus* Lacepède. J. Morphol. 153 (1) : 129-141.

Yasuda, F. 1960. The relationship of the gill structure and food habits of some coastal fishes in Japan. Rec. Oceanogr. Works Jap. 5 (1) : 139-152.

プエルトリコ産ハゼ科魚類 *Sicydium plumieri* の顎歯と咽頭歯の成長・置換・再吸収

望月賢二[1]・福井正二郎[2]・Solomon Gultneh[3]

1) 千葉県立中央博物館　〒280 千葉市青葉町955-2
2) 〒 649-53 和歌山県那智勝浦町宇久井165-6
3) 国際協力事業団青年海外協力隊　〒150 渋谷区広尾4-2-24

プエルトリコ産ハゼ科魚類 *Sicydium plumieri* の上顎歯，下顎歯，咽頭歯の形態，配列，成長，置換，などについて報告した．このうち上顎歯は，機能歯として使用された後に，上顎の組織内で再吸収されることを示した．これは，日本産ボウズハゼに次ぐ2例目の報告である．また，上顎には1発達系列おきに機能歯をもつこと，それまで機能歯を持たなかった発達系列の最も発達した歯が次世代の機能歯になることなどが本種の特徴であった．消化管の長さと巻き方のパターンや鰓耙の状態についても調べ，これらの歯の機能についてあわせて検討した．