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On the Luminous Cardinal Fish, *Apogon ellioti* DAY

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(With 4 Text-figures)

A considerable amount of literature has been accumulated dealing with the bioluminescence of fishes. The majority of those given by earlier investigators have dealt with the light organs arranged on the body surface of deep-sea fishes. However, the subsequent progress of research on this problem revealed that bioluminescence occurs not merely in deep-sea fishes but also in littoral fishes caused by the symbiosis of luminous bacteria. In his comprehensive review of the luminous organisms, HANEDA (1955) classified the luminous fishes into three types based on the mechanism of luminescence and structural evidence of luminous organ. The luminous source of first and second types is the symbiotic luminous bacteria. The first one, including fishes of the genus *Monocentris* and those of the family Macrouridae for instance, bears the luminous gland on the body surface. On the other hand, the second one represented by fishes of the genus *Acropoma* and those of the family Leiognathidae, conceals the gland within the body. The third type is represented by fishes bearing non-bacterial luminous organ or skin photophore. Most of lantern fishes and luminous shark belong to this group. In addition to these groups, KATO (1947) found another new type of the luminous organ in a cardinal fish, *Apogon marginatus* DÖDERLEIN. This is peculiar in the following points: (1) The organ is closely associated with the intestine, and (2) the luminous source is not bacterial but is photogenic cells in the organ.

In a collection of bottom fishes made by one of us (H. A.) at the Gulf of Tongking during May-August, 1957, 6 specimens of *Apogon ellioti* DAY were found to possess a distinct accessory organ on the intestine. Upon careful examination it was found that the structure of the organ is exactly similar to that of *Apogon marginatus* described by KATO (1947). Because no additional information on this type of luminous organ has been published since the date of KATO's paper and because little speculation has to date been done on the luminescence of the apogonids, the present investigation was undertaken in order to cast further light on the problem. Incidentally an attempt has also been made to clarify the taxonomic status of these two species, *A. ellioti* and *A. marginatus*, which remained in a state of confusion up to the present day. The present communication offers the full descriptions of the species and anatomical features of the luminous organ.

We wish to express our gratitude to Professor K. MATSUBARA, under whose direction this investigation was carried out. Thanks are due to Professor R. ISHIYAMA of Shimonoseki College of Fisheries and Mr. M. KAWAKAMI of Taiyo Fishery Co. Ltd, for their kindness extended to us in various ways. Dr. Y. HANEDA of Yokosuka City Museum was kind enough to offer the criticism of the manuscript.

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Material and Method

The material thus far examined consisted of 6 specimens taken from the Gulf of Tongking (107°25 30″ E., 19°31′ N) by otter trawler at a depth of about 50 meters on June 5, 1957. All specimens were fixed in 10% formalin. Counts and measurements of bodily parts were made according to standard practice as outlined by MATSUBARA (1955). The viscera for histological observation were sectioned by the usual paraffin method at a standard thickness of 10μ. As a stainining combination, haematoxylin and eosin were employed.

Description of the species

Apogon ellioti DAY (Fig. 1)

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Amia marginatus, SMITH and POPE, Proc. U. S. Nat. Mus. 31:468, 1906.

Amia marginata, JORDAN, TANAKA and SNYDER, Jour. Coll. Sci. Univ. Tokyo, 33:139, fig. 97, 1913.

Apogon arafurae, GÜNTHER, Rep. Voy. Challenger 1:38, 1880.

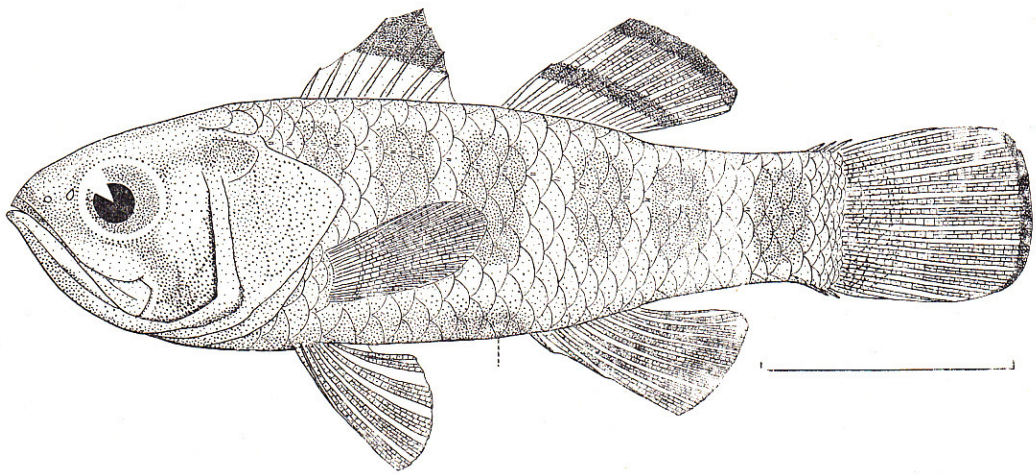

Fig. 1. Lateral aspect of *Apogon ellioti* DAY. Scale bar indicates 20 mm.

Standard length.....45.0-79.0 mm.
Fins: Dorsal VII, I, 9; Anal II, 8; Pectoral 16: Ventral I, 5.
Scales in lateral line.....22-23.
Gill-rakers on lst arch .....2—3+11—12.
Branchiostegal rays.....7
Proportions of bodily parts:

In standard length:

Lenth of head	2.4-2.5
Depth of body	3.2-3.3
Width of body	6.1-6.9
Base of 1st dorsal	5.7-5.9
Base of 2nd dorsal	5.8-5.9
Base of anal	6.4-7.6
Depth of caudal peduncle	6.3-6.9

In head length:

Snout	4.8-5.2
Diameter of eye	3.7-4.0
Interorbital space	4.2-4.8
Length of upper jaw	2.0-2.1
Length of longest dorsal spine (4th)	2.6-3.1
Length of longest dorsal ray (3rd)	1.7-1.9
Length of 2nd anal spine	3.5-4.2
Length of longest anal ray (2nd)	1.9-2.1
Length of pectoral	1.9-2.3
Length of ventral	2.0-2.3

Body oblong and compressed. Head relatively large. Gape obliquely directed upward and forward; posterior extremity of maxillary extending immediately before a perpendicular through posterior margin of eye. Snout moderately long 1.2-1.5 in diameter of eye. Eye rather large; the diameter greater than snout or interorbital width. Interorbital space flat. Preopercular edge and ridge armed with small uneven serration. Dorsal fins well separated. First dorsal inserted a vertical through midway between tip of opercle and upper end of gill-opening. Second dorsal opposed to anal; lst anal spine set below base of 3rd dorsal ray. Ventral inserted below base of pectoral. Tip of caudal rounded or truncated even when the fin is streched. Scales on cheek and body mostly large: pored scales in lateral line 22-23, 2-3 rows of scales between lateral line and origin of dorsal, 5-6 rows between lateral line and anal opening, 2 rows on cheek, and about 4 rows on opercle. About 8-10 rows of small scales on caudal base.

Teeth uniformely villiform, in bands on jaws, vomer and palatines. Gill-rakers lanceolate and moderate in size. Pseudobranchae well developed.

Ground color in formalin pale brown except for belly where the skin whitish and dotted with melanophores. A prominent round or ocellate black bloch on upper angle of opercle. Body furnished with 6-8 parallel transverse dark bands, the first one below lst dorsal spine and the last one at caudal base; sometimes the bands wider than their interspaces. First dorsal with apical black band. Second dorsal marked with two longitudinal blackish bands; one along the margin and the other on median portion. Caudal edged with narrow blackish band.

Remarks: In spite of the efforts of previous investigators, *Apogon ellioti* appear to has been splitted into two distinct species, *Apogonichthys ellioti* (DAY) and *Apogon marginatus* DÖDERLEIN. JORDAN and SNYDER (1901) distinguished *A. marginatus* from *A. ellioti* by the fact that the latter has grayish lateral bands. However, they described and figured four or five dark cross shades for *A. marginatus*, though very faint. FOWLER

and BEAN (1930) also separated *A. ellioti* from *A. marginatus* and indicated the distribution of the former species as follows: India, East Indies, Philippines and Queensland. Conversely, WEBER and DE BEAUFORT (1929) amalgamated both species under the name of *Apogon ellioti*. LIANG (1948) pointed out that *A. margtnatus* is probably a synonym of *A. ellioti*.

On the basis of results of careful examination presented above we reach to the conclusion that *A. marginatus* is identical with and predated by *Apogon ellioti*. The following features may serve this conclusion, (1) Both the former and latter bear peculiar luminous organs as discussed below in detail. (2) No significant feature which would enable us to separate these species is recognized. In almost all of the features, our 6 specimens agree in description with *A. ellioti* presented by previous authors. In our material, however, the band on anal fin is obscure as compared with that fairly well figured and described in previous literature.

A few more points may be discussed on the generic characters of *Apogon* and *Apogonichthys*. According to JORDAN and SNYDER (1901) *Apogon* is characterized by having a serrated preopercular margin versus characterized by lacking serration in *Apogonichthys*. SMITH (1949) indicated the difference between these two genera as follows: the caudal fin is forked in *Apogon* and is rounded in *Apogonichthys*. Certainly, both characters are of much value in some cases. But some fish referred to the genus *Apogonichthys* bear a weak serration along the preopercular margin. Conversely, the fish, bearing strongly serrated preopercular margin, has rounded caudal fin as is seen in *Apogon niger* DÖDERLEIN. The species examined in this study is referable either to *Apogon* in the preopercular feature or to *Apogonichthys* in the caudal feature. It would seem that these features are insufficient to separate these two genera. Therefore, the fishes belonging to the family Apogonidae stand in need of an extensive revision. We are of opinion that such peculiar feature as luminrus organ is important as a generic diagnosis. Accordingly, further investigation may demand a new generic name for the present species.

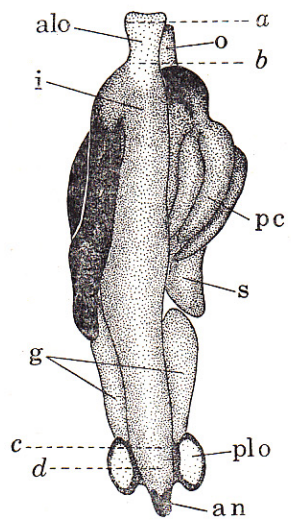

Fig. 2. Ventral aspect of alimentary canal and its appendages. alo. anterior luminous organ. an. anus. g. gonad. i. intestine. o. oesophagus. pc. pyloric caeca. plo. posterior luminous organ. s. stomach.

Gross anatomy of alimentary canal

Since the luminous organs of this species are closely associated with the digestive system, we make first a brief description on the structure of alimentary canal. The general appearance of the alimentary canal of this species is similar to that of the other apogonids. The oesophagus is a short but thick tube opening abruptly into a large stomach. Externally, there is no apparent dimarcation between the oesophagus and stomach. The stomach is Y-shaped and composed of three parts; short cardiac and pyloric portions and large blind sac. The wall is thick and lined with longitudinal mucous folds. It is well known that the stomach showing such a

peculiar structure, is capable of taking large amounts of prey. Coloration of the oesophagus and stomach is uniformly black.

Four well developed pyloric caeca, blackish brown in coloration, are attached to the pyloric region. It is relatively large; the length being about as long as the stomach.

The intestine arises from the left antero-ventral end of the stomach, and extends latero-posteriorly along the right border of the stomach to the level of the end of the stomach where it turns anteriorly. Then it reaches to below the origin of stomach where it again inverses posteriorly. From the origin to this second bend, the intestine is rather narrow and jet black in color. From the anterior end of the secoud bend a small protuberance is projected anteriorly. This is the anterior luminous organ (Fig. 2, alo.). In the 74.0 mm. specimen, it is approximately 2.5 mm. in length, and is 2.0 by 2.2 mm. in cross section. Since few chromatophore is present on its surface layer, it is light yellow in coloration.

Therefrom, the intestine runs posteriorly along the midline of the abdominal cavity to the vent without any convolution. This portion is dark gray in color and considerably broad as compared with the anterior half of the intestine. But it gradually decreases in diameter from its broadest region near the level of posterior end of stomach toward the vent. To immediately befor the vent the intestine is accompanied with a pair of the posterior luminous organs (Fig. 2, plo.). They are bean-like in shape, and are black dorsally and silvery white ventrally. The organs are visible without dissection through the translucent muscle. The measurement of the posterior luminous organ in 74.0 mm. specimen is 2.8 mm. in length and 0.5 by 1.5 mm. in cross section.

Structure of luminous organs

The histological features to be described below are based on cross sections of each luminous organ or intestine. The anterior luminous organ, shaped roughly like a pocket, arises from the anterior end of the second bend of the intestine (Fig. 2, alo.), and forms a blind pouch at the anterior extremity. Posteriorly, it opens into the left side of the intestine. The organ is glandular in structure. Internally the lining of the gland is similar to that of the intestine, that is, it is elevated in narrow folds or ridges. However, the epithelial cells are somewhat differ from those of the intestine. In the luminous gland the epithelium is composed of a single layer of tall columnar cells with nucleus at the base, whereas intestinal epithelium consists of goblet cells and columnar cells with a striated border. The epithelial cell in the gland is deeply stained with eosin, and is about twice as thick as the goblet cell in the intestine (Fig. 4 A). KATO (1947) called this cell as "Photogenic cell". These cells are supported by the tunica propria. At the posterior juncture of the organ with the intestine, the right half of the surface of intestine is lined with the typical intestinal epithelium, and the other half is lined with a distinct columnar epithelium found in the lumiuous gland (Fig. 4 A). Successive layers forming the anterior luminous organ are the muscularis and serosa as is the case with the intestine.

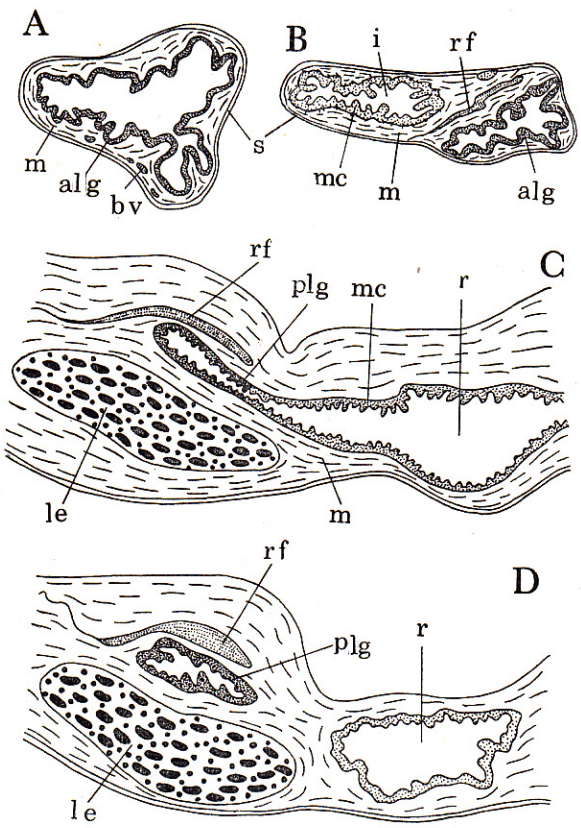

Fig. 3. Anterior aspect of cross sections of luminous organs at levels indicated in figure 2. alg. anterior luminous gland. bv. blood vessel. i. intestine. le. lens. m. muscularis. mc. mucosa. plg. posterior luminous gland. r. rectum. rf. reflector. s. serosa.

Within the muscular wall lying between the intestine and the posterior portion of the luminous gland there extends an opaque collagenous membrane in lengthwise direction (Fig. 3 B, rf.). It separates the muscularis of the organ from the wall of the intstine. This structure, therefore, apparently serves as a reflector.

The posterior luminous organs, shaped roughly bean-like, lie on each side of the rectum (Fig. 2, plo.). It opens into the rectum at the antero-proximal side (Fig. 3 C). The epithelial coat of the inside of the organ is virtually the same as that of the anterior luminous organ (Fig. 4 B). Near the opening the epithelial cells are abruptly replaced from the peculiar eosinophil columnar cells of the gland to the goblet cells or columnar cells of the mucosa of the rectum. The gland is covered with a thick layer of circular muscularis.

Within this circular muscle layer and just above the gland, an opaque membrane which is considered to be a reflector lies longitudinally as is seen in the anterior luminous organ (Fig. 3 C, D, rf.). On the other hand, in the ventral side of the gland, there is a distinct longitudinal bundle of muscles (Fig. 3, C, D, le.). These muscles are translucent and enable us to observe the posterior luminous organs from the outside of the body without dissection. The cross seetion of this bundle is lenticular. So that it may probably be able to transmit the light from the gland. These structures well agree with the reflector and lens described by HANEDA (1950) on *Acropoma japonicum*.

The posterior portion of intestine between the anterior and posterior lumiuou sorgans is composed of three major layers: the mucosa, muscularis, and serosa. Of particular interest is the fact that peculiar columnar cells which are representative of the epithelium of the luminous gland, are sporadically found in the mucosa, though most of cells constituting this layer are the columnar cells with a striated border and goblet cells. But whether these peculiar cells have any relation to the luminescence of this portion, we cannot say at present.

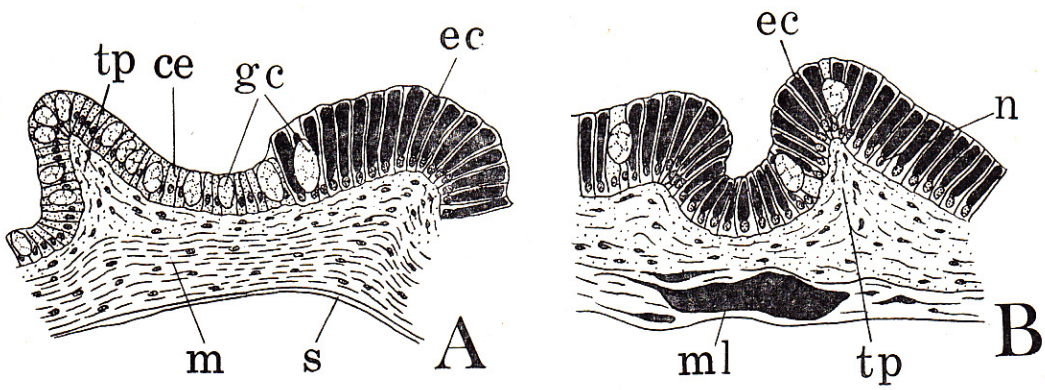

Fig. 4. Cross sections of juncture of anterior luminous organ with intestine (A) and epithelium of posterior luminous organ (B) (Anterior aspect). ce. columnar epithelial cell of intestine. ec. eosinophil columnar cell in luminous gland. gc. goblet cell. m. musculais. ml. melanophore. n. nucleus. s. serosa. tp. tunica propria.

Discussion

There is no doubt of the luminescence of glandular structures associated with the intestine of *Apogon ellioti*. Evidences suggesting that these structures are luminous organ are as follows: (1) The luminescence is obviously observed when the living fish is mechanically stimulated; (2) The organ is provided with a structure like a lens and reflector; (3) No other structure which thought to be a luminous organ is recognized. However, whether the light comes from the symbiotic bacteria or from the photogenic cell, we cannot give a definite decision, because we did not test the organ from a viewpoint of bacteriology and because we were unable to have a chance to examine the luciferin-luciferase reaction of the gland.

KATO (1947), working with the Japanese specimens, presumed that distinct columnar cells lying in the epithelium of the luminous glands are photogenic. These are filled with an eosinophil secretion but are not holocrine type, so that the photogenesis is intracellular. Thus he concluded that *Apogon marginatus* (*ellioti*) is the first instance of self-luminous fish having the luminous organ in the intestine.

HARVEY (1957) has not confirmed this interpretation, but has surmised that the light is bacterial. In almost cases for which literature is available, it is shown that luminous organs bearing the openings to exterior or to the digestive tract are capable of lighting by the symbiotic bacteria. For example, the luminous organs of *Monocentris* (YASAKI, 1928), *Coelorhynchus* (HANEDA, 1951), *Acropoma* (HANEDA, 1950), *Leiognathus* (HANEDA, 1950), and *Paratrachichthys* (HANEDA, 1957) are all belonging to this type. Therefore, HARVEY's empirical conjecture is, in fact, not unreasonable.

Recently, HANEDA and JOHNSON (1958), studying with *Parapriacanthus beryciformes* FRANZ, discovered unique self-luminous organs which bear the opening to the outside. This finding may suggest that the luminous organ of open-type is not always bacterial luminescence. Accordingly, it is not unlikely that the luminous organ of *Apogon ellioti* might be a non-bacterial type as has been described by KATO (1947).

The structures of the posterior part of intestine possess problem that seems to be worth to discussing. KATO (1947) considered that posterior portion of intestine lying

between the anterior and posterior luminous organs acts also as a luminous organ, and named this area as "Intestinal luminous organ". His conclusion is based on the observation that this portion of the intestinal epithelium is lined with photogenic columnar cells filled with eosinophil secretion. But so far as our examination is concerned, it is lined with typical goblet cells and columnar cells usually found in the intestinal epithelium of many teleostean fishes, though several peculiar cells forming the luminous gland are studded on the epithelium. Furthermore, no reflector-like structure is recognized in this area. These evidences lead the authors to doubt of the conjecture regarding the direct luminescsnce of this portion.

Summary

(1) Results of careful examination revealed that *Apogon marginatus* DÖDERLEIN should be a synonym of *Apogon ellioti* DAY.

(2) *A. ellioti* is provided with three peculiar luminous organs: one, shaped like a small pocket, is attached to the second bend of the intestine and the other two, shaped bean-like, lie on either side of the rectum. All of these bear the opening to the intestine.

(3) Each luminous organ is glandular in structure and equipped with a structure like a reflector and a lens.

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(Excluding those given under synonymies of the present species)

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抄　　録

発光魚シチセンイシモチ（ツマグロイシモチ）について

岩井　保・浅野博利

シチセンイシモチはどちらかといえば内湾性の底棲魚で、本邦中部以南より、南はインド洋、フィリピン、オーストラリアにまで広く分布している。しかし、この魚は魚学者によって査定がまちまちで、日本産のものには *Apogon marginatus* DÖDERLEIN, 印度、フィリピン等南方産のものには *Apogonichthys ellioti* (DAY) という学名がそれぞれ与えられていた。筆者等は南支那海トンキン湾産の標本について検討した結果、両者は同一種であって、学名は先取権の法則にしたがって、*Apogon ellioti* DAY とするのが正しいという結論に達した。

本種は、すでに加藤光次郎博士（1947）によって報告されているように、腸に付属する3個の発光器をそなえている。これらのうち、1個は食道下方の腸の第2反転部より前方へ突出する小盲嚢として、残りの2個は肛門直前の直腸の両側に対をなした豆状の盲嚢として認められる。両者とも腺構造の器官で、前者はその後端において、また後者は前内側において、それぞれ腸に開いている。腺の上皮細胞は、基部に核をそなえたエオシン嗜好性の円柱上皮細胞で、一見して腸の上皮細胞と区別できる。前部発光器と腸の隔壁中、および後部発光器の背面には、不透明膜からなる反射装置がある。また、発光器腹面の筋肉は淡白色半透明で、ホタルジャコの場合と同様、発光器から出る光を体外へ拡散させるためのレンズの役割をなしているものと考えられる。

この魚の発光が発光バクテリアの共生によるものか、あるいはまた、発光器の細胞自身の発光によるものかについては、残念ながら確める機会がなかった。