The Luminescence of Some Deep-sea Fishes of the Families Gadidae and Macrouridae

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INTRODUCTION

WHILE STUDYING THE JAPANESE FISH *Physiculus japonicum* Hilgendorf, of the family Gadidae, Franz (1910) noticed a round black pigmented spot situated ventrally and in front of the anus. He studied its structure, but was unable to explain its physiological function.

Later Kishitani (1930) examined this organ and discovered it was an open type of luminous organ containing symbiotic luminous bacteria. He described its structure and gave a specific name to the bacterium, *Micrococcus physiculus*. He could not see any luminosity while the fish was living under natural conditions, and concluded that the luminous organ merely produced luminous bacteria which were ejected occasionally as a luminous cloud into the surrounding sea water.

In August, 1936, I had an opportunity to observe this fish in the dark in an aquarium tank at the Asamushi Marine Biological Station of Tohoku University. Among many other fishes in the tank, I saw one which I had never seen before, which emitted light from this ventral spot. It did not eject a luminous cloud of matter.

In August, 1937, I observed another species of the Gadidae, *Lotella phycis* Temm. & Schl., which also possessed a similar type of luminous organ, from the duct of which I was able to culture luminous bacteria in artificial media.

The fishes of the family Macrouridae are closely related to the Gadidae and have a luminous organ of the same type. Their luminosity was first recorded by Osorio (1912). One species of the family, *Malacocephalus laevis* (Lowé), has the same type of luminous organ, similarly situated. Osorio stated that it was a practice of the Portuguese fishermen to force luminous matter from the organ by pressing it against pieces of shark flesh which they used as bait. In this way the flesh became luminous, and so was improved as bait for their fishing. This led him to believe that the luminous matter consisted of luminous bacteria, but since he was unable to culture any he could not confirm his belief.

Hickling (1925, 1926) described the structure of the luminous organ of this fish, and stated that it was of a new type, the luminous matter in the organ consisting of luminous granules. In 1931 the same author described the luminous gland of *Coelorhynchus coelorhynchus* Risso, also as a new type of luminous organ containing a luminous granular substance.

Yasaki and Haneda (1936) reported that there were 10 species of the Macrouridae with luminous organs, from the ducts of which they cultured luminous bacteria in artificial media.

In 1938 I examined *Malacocephalus laevis*, described its luminous organ and the contents, and cultivated luminous bacteria from it. Imai (1942) made bacteriological examinations of material from five species of the Macrouridae.

Recently Parr (1946) has studied many macrourid fishes of the western North Atlantic and the Central American seas. He recognized the outer aspect of the luminous organs on the ventral regions of fishes of the genera *Hymenocephalus*, *Malacocephalus*, *Ven-*

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trifossa, *Nezumia*, *Grenurus*, *Trachonurus*, and *Coelorhynchus* as a lens-shaped body, or scaleless "fossa" or naked area.

I have collected and studied the comparative structures of the luminous organs of many specimens of various species, and I have also cultivated their bacteria in artificial media. The results of these observations are presented here.

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MATERIAL

Altogether I have examined material from two species of the Gadidae and 14 species of the Macrouridae.

The Gadidae are comparatively shallow-water fish. They may be caught close to the coast of Japan. *Physiculus japonicus* occurs in water varying in depth from 30 to 50 fathoms. *Lotella phycis* is sometimes taken in extremely shallow water near the surface. This enables one to keep them in an aquarium tank where each can be observed in a natural state. They may be caught at any time of the year by hook and line, and their luminosity may be seen if they are taken during the darkness of the night. *Physiculus japonicus* is occasionally taken by trawlers.

The Macrouridae are always caught by trawlers since they are deep-water fishes living in over 100 fathoms of water. They are taken most abundantly during the winter in Japan.

STRUCTURE OF LUMINOUS ORGANS

Studies made up to the present time show that the Gadidae and Macrouridae possess the same open type of luminous organs. These organs may consist of the following four components: (a) A luminous gland; (b) its canals and their openings; (c) lenses with an external ventral aperture covered with a thin transparent skin through which light is transmitted; and (d) a reflector and chromatophores.

In some species the luminous gland may be so small as to be almost invisible. The canal leading from the gland may be either very short or very long. The structure of the lens may be very complicated, or very simple and inefficient. The reflector may vary also in its efficiency according to its structure.

The external ventral aperture through which light is transmitted is visible externally and may be comparatively large, or very small, or it may be absent. It may be bean-shaped, or circular, or very long and filiform, and in some species there may be two external apertures. The figures illustrate the many forms which can be seen. In the first type the luminous organ is very small and barely visible (as in *Coelorhynchus anatirostris*). It has a very short luminous duct, and is situated very close to the anus lying ventrally in the muscles, and has neither reflector, lens, nor external aperture. The organ cannot be seen externally, and gives the impression that it does not exist. Only when the fish is sectioned longitudinally and a cut is made through the organ can it be seen that there is a luminous duct which is extremely small and inefficient. In this duct are luminous bacteria. Although it is vestigial, it is nevertheless a true luminous organ, difficult as it is to determine.

Coryphenoides garmani and *C. misakius* are two other species which have very short and inefficient luminous ducts. The lenses and external apertures are inefficient, and from a casual inspection it is difficult to say whether they are luminous or not. However, luminous bacteria live in the duct of the gland.

In what may be considered the normal type or the typical luminous organ—such as that found in *Physiculus japonicus*, *Lotella phycis*, *Abyssicola macrochir*, *Coelorhynchus kishinouyei*, *Coelorhynchus japonicus*, and *Nezumia condylura*—the organ consists of a rather large luminous gland, the reflector, the lenses, and a scaleless external aperture covered with thin transparent skin. The canal in some species is rather long and in others very short; for

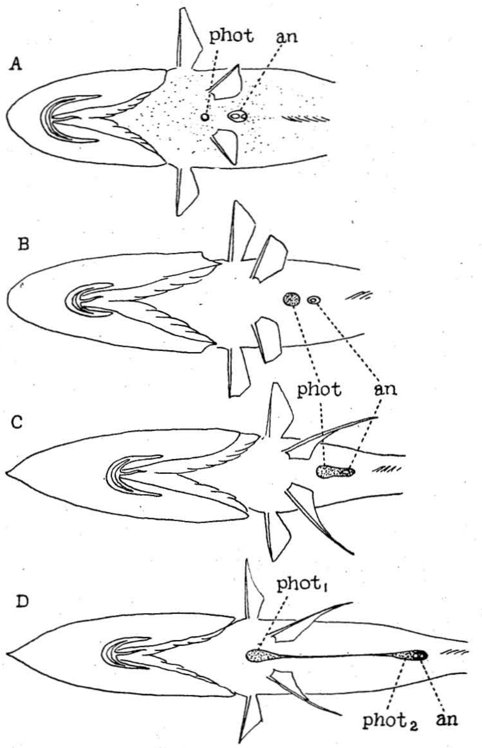

FIG. 1. Diagrams of the luminous organs of some Macrouridae. *a*, *Coryphaenoides garmani; b*, *Abyssicola macrochir; c*, *Coelorhynchus japonicus; d*, *Coelorhynchus hubbsi*. phot, luminous organ; an, anus.

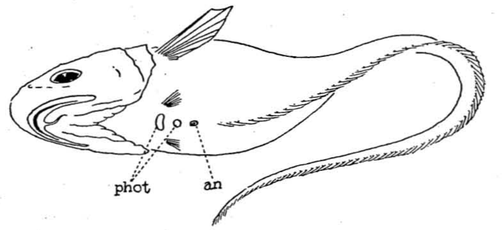

FIG. 2. *Malacocephalus laevis* (Lowé). phot, luminous organ; an, anus.

example, *C. japonicus* has a very short canal with the external aperture close to the anus.

Some species have two scaleless external ventral apertures. Examples of this type are *Malacocephalus laevis* (Lowé) and *Malacocephalus nipponensis*, each of which has two external apertures, one bean-shaped and one round. The inner structure is of the normal type, i.e., it has a large luminous gland, a reflector, two lenses, and two external apertures. Their structure has been described by both Dr. Hickling and myself.

The canal is very long in some species, such as *Coelorhynchus parallelus* and *C. tokiensis*. The canal itself functions as a luminous gland with a long reflector, a poor lens substance, and no external aperture. However, one can see the long luminous duct through the transparent scales on the lowest part of the abdomen.

In their young stages these fishes are very strange, and only in this stage are they strongly luminous, the luminosity being visible ventrally as a single line. When full grown, this thin duct is covered with black pigment, which renders it useless as a luminous component in spite of the fact that luminous bacteria are living within it. The luminosity of *Coelorhynchus coelorhynchus*, as described by Hickling (1931), may be due to the fact that perhaps he saw a young specimen, as it is probable that this species is very similar to the two species under discussion.

Coelorhynchus hubbsi Matsubara has an extremely thin, long canal, each end of which is swollen into a club-shaped gland. The

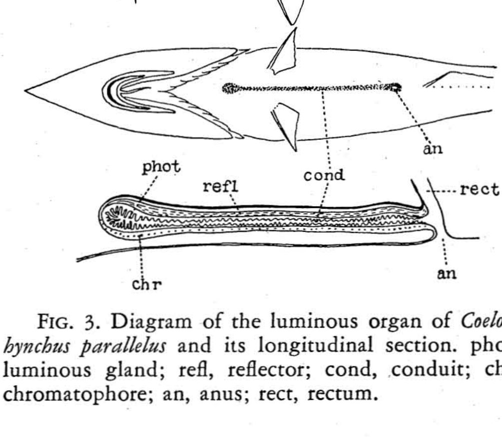

FIG. 3. Diagram of the luminous organ of *Coelorhynchus parallelus* and its longitudinal section. phot, luminous gland; refl, reflector; cond, conduit; chr, chromatophore; an, anus; rect, rectum.

TABLE 1

DATA ON COLLECTIONS OF LUMINOUS GADIDAE AND MACROURIDAE

SPECIES	PLACE OF COLLECTION	DATE OF COLLECTION
Coryphaenoides garmani Jordan and Gilbert Sagami-Sokodara*	Chōshi fish market, Chiba Prefecture.. Mimase fish market, Kōchi Prefecture	Nov., Dec., 1934 Jan., Mar., 1935
Coryphaenoides misakius Jordan and Gilbert Misaki-Sokodara*	Chōshi fish market..................	Nov., Dec., 1934 Jan., Mar., 1935 Jan., 1936
Abyssicola macrochir Günther.............. Tenaga-dara*	Chōshi fish market..................	Oct., Nov., Dec., 1934 Feb., Mar., 1935
Coelorhynchus anatirostris Jordan and Gilbert Nezumi-Hige*	Chōshi fish market..................	Nov., Dec., 1934 Feb., 1938
C. japonicus Temm. and Schl............... Tojin*	Mimase fish market.................	Mar., 1935 Feb., 1938
C. kishinouyei Jordan and Snyder........... Mugura-hige*	Numazu fish market, Shizuoka Prefecture Heta fishing village, Shizuoka Prefecture	Mar., 1935 Mar., 1938
C. parallelus Günther.................... Soroi-hige*	Mimase fish market.................	Jan., Mar., 1935 Mar., 1938
C. tokiensis Steindachner and Döderlein..... Nezumi*	Mimase fish market.................	Jan., Mar., 1935
C. hubbsi Matsubara...................... Moyō-Hige*	Mimase fish market.................	Nov., 1934 Mar., 1935 Mar., 1938
Nezumia condylura Jordan and Gilbert...... Nezumi-dara*	Chōshi fish market..................	Nov., Dec., 1934 Mar., 1935
Malacocephalus laevis (Lowé).............	Mimase fish market.................	Apr., 1935 Jan., Apr., 1936
Hymenocephalus striatissimus Jordan and Gilbert Suji-dara*	Mimase fish market.................	Apr., 1935 Apr., 1938
H. Kuronumai Kamohara................. Yari-dara*	Mimase fish market.................	Mar., Apr., 1938
H. gracilis Gilbert and Hubbs............. Hoso-suji-dara*	Mimase fish market.................	Mar., Apr., 1938
Physiculus japonicus Hilgendorf............ Chigo-dara*	Mimase fish market................. Chōshi fish market Asamushi Marine Biological Station, Aomori Prefecture Misaki fish market, Kanagawa Prefecture	Jan., Apr., 1935 Apr., 1937 Aug., 1938 Aug., 1938
Lotella phycis Temm. and Schl............	Misaki Marine Biological Station, Kanagawa Prefecture	Aug., 1938

* Japanese name.

ventral area is scaleless and there are two external apertures. Behind the swelling at the posterior end is a reflector. By examining fresh material in the dark, two luminous points can be seen.

The combination of a very long canal and a compound lens occurs in some species, such as *Hymenocephalus striatissimus* Jordan and Gilbert, *H. gracilis* Gilbert and Hubbs, and *H. kuronumai* Kamohara. In these there is a long, thin canal at the end of which is a club-shaped luminous gland to which is attached, ventrally, a swollen pouch-shaped body. This is a lens. Just behind and below it in the skin of the abdomen is a swelling which is doubly convex. This is a second lens which directs the light ventrally to the outside. It is a very complex organ. This type of luminous organ has already been reported by Vinciguerra (1932).

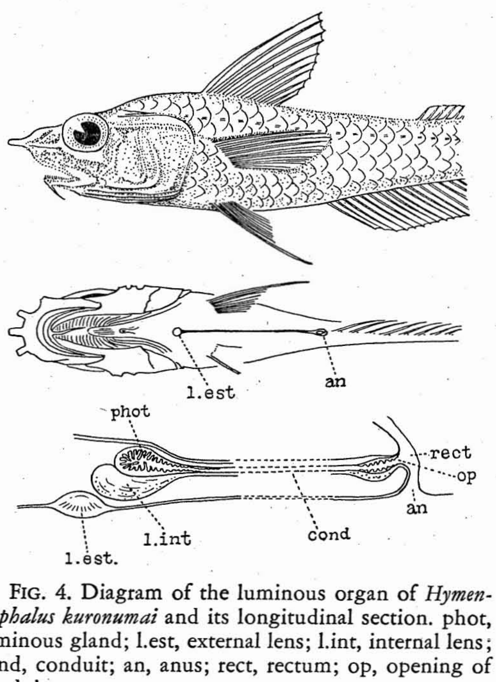

FIG. 4. Diagram of the luminous organ of *Hymenocephalus kuronumai* and its longitudinal section. phot, luminous gland; l.est, external lens; l.int, internal lens; cond, conduit; an, anus; rect, rectum; op, opening of conduit.

All of these are luminous glands and their innermost surfaces are lined with a layer of epithelial cells. Within the cavities formed by the folds of the glands resting on the inner ends of the epithelial cells are other cells which contain capsules in which are masses of bacteria, variously arranged. Some of these capsules are entire and contain the bacteria, others are ruptured and have allowed the bacteria to escape into the fluid of the gland ducts. Hickling says these masses are granules of luminous matter and that they exist in four states, viz.: (a) as closely packed masses filling their capsule; (b) as closely packed masses, but only half filling their capsule; (c) as loosely packed individuals in a ruptured capsule; and (d) as dispersed individuals free from their now empty capsule.

Both Kishitani and I, however, consider these so-called luminous granules to be masses of luminous bacteria. We have examined a great amount of material from many species and it all shows the same characteristics.

LUMINOUS PHENOMENA OF THESE ORGANS WHEN SEEN IN DARKNESS

Inasmuch as *Lotella phycis* and *Physiculus japonicus* live in comparatively shallow water, they can be kept in aquaria where their luminosity, if visible, could be seen in the dark. I have kept many specimens under observation but almost all of them displayed no luminosity which could be seen externally.

In August, 1936, while working at the Asamushi Marine Biological Station, I had a further opportunity to observe these fishes in the dark. Among many specimens of *Physiculus japonicus* in an aquarium tank, I saw one fish with a luminous ventral aperture. This aperture could be seen only when the fish swam upwards and thus showed its ventral surface. It could not be seen when it swam downwards from the top of the tank, showing only its dorsal surface, or when it swam horizontally, showing either one of its lateral surfaces.

I could not see any luminous, cloudy discharge from the opening, as had been suggested, and this led me to believe that the luminosity arose from a true luminous organ, and that the difficulty in seeing it was due to the expansion of the chromatophores in the transparent, scaleless skin which covers the outside of the aperture. When these chromatophores expand they shut off the light and when they contract the light is transmitted and can be seen. Possibly the expansion and contraction may be determined by the water temperature, the degree of darkness or light, or by other factors, but I did not determine the effects of these factors upon the functioning of the chromatophores.

However, from my observations I am of the opinion that when these fishes are swimming in natural conditions at the bottom of the sea they are normally luminous, emitting light through these ventral apertures.

I have never been able to observe any macrourid fish in a natural condition since they are all deep-sea fish and cannot be kept in an aquarium. I have been able to examine only dead and living material freshly caught by trawlers from deep water. When examining this freshly caught material I could see the luminosity of some, but not of others. When the glands were cut open, however, they were always luminous.

The luminosity of young *Coelorhynchus parallelus* may be seen as a beautiful green filiform line on the ventral surface. *Coelorhynchus hubbsi* has two luminous spots on the ventral surface, and I am of the opinion that these fishes, when in their natural conditions, normally display their luminosity.

I cannot agree with the opinion that these fishes, through the opening of the canal in the anal region, discharge a luminous cloud into the surrounding sea water.

CONTENTS OF THE LUMINOUS DUCTS

Emulsions of the contents of the ducts were made in sterile sea water and were examined in the dark.

When first made, the emulsion was uniformly luminous. After standing in vertical tubes and settling for 20 minutes, the luminosity had collected as an upper layer. When shaken up, it was again uniformly distributed in the tube. If it was centrifuged, the luminosity was concentrated in the sediment at the bottom of the tube and the fluid above was clear and not luminous. If this precipitate was well mixed with sterile sea water the whole mixture became uniformly luminous, but if it was mixed with sterile distilled water, it failed to show any luminosity.

Changes of temperature showed the following results. Luminosity was greatest between 15 and 23°C. and this is the optimum temperature; at 0° C. it ceased; at 3–4° C. it was very weak; at temperatures between 23° and 45° C. it decreased; above this point it finally ceased and could not be reactivated when cooled again to 15–23° C.

The reactions were those of luminous bacteria and an examination under the microscope showed bacteria and segments of the gland duct cells. The bacteria stained red with Ziehl's solution and I was able to culture them by the usual bacteriological methods. Samples were taken from the organs of every fish studied. The characteristics of the luminous bacteria from the luminous ducts of many species of fishes of the Gadidae and the Macrouridae were investigated by the usual methods of culture in artificial media.

I was able to obtain 10 strains of luminous bacteria from each of these fishes—*Lotella phycis*, *Malacocephalus laevis*, *Hymenocephalus gracilis;* 20 strains of luminous bacteria from *Coelorhynchus kishinouyei* and *Nezumia condylura;* and 14 strains from the other species.

These strains of bacteria were taken from various species of fish taken at different times and in different localities. All had the same general biological characters but the optimum temperature, that is, the temperature at which the luminosity was greatest, varied. In some cases it was higher than others, but it never varied much. The optimum temperature for luminosity was lower for the bacteria of those fishes which live in deep and therefore colder water than for those living in the shallower and warmer water. A more complete discussion of these bacteria will be presented in a separate paper.

SUMMARY

Some of the fishes belonging to the families Gadidae and Macrouridae are luminous and possess the "open type" of luminous organ containing luminous symbiotic bacteria. It consists of a gland in the ventral muscles lying in a scaleless depression between the pelvic fins. This is a characteristic of these fishes. Their luminescence is controlled by means of chromatophores. Normally they are deep-sea fishes although at times some of the Gadidae may be caught in shallow water. Observations were made on 14 species of the Macrouridae and 2 species of the Gadidae. Their luminous ducts are very similar but vary in size. In some species they are very long, in others very short, and in others extremely small and not visible from the outside. Some of the luminous ducts are of a comparatively simple construction while others are extremely complex.

I consider the luminous symbiotic bacteria which were cultured from these many fishes to be a species of the new group of luminous bacteria, but a more complete discussion will be presented later in a separate paper.

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