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Some Observations on the Luminous Organs of Fishes.

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With 4 textfigures and 1 plate.

The present paper contains a condensed account of my observations on the luminous organs of the following species of fishes made during the years 1908–9: *Etmopterus lucifer, E. frontimaculatus, Maurolicus pennanti, Myctophum affine, M. spinosum, M. laternatum, M. watasei* and *M. splendidum.* The work was concluded before the publication of Prof. BRAUER's comprehensive and excellent work on the same subject, which has made a detailed treatment on my part unnecessary. It is a pleasure to me to express at the outset my hearty thanks to Prof. IJIMA, Prof. WATASÉ, Prof. GOTO, Mr. MORIWAKI and Mr. TANAKA, who have helped me in various ways, and particularly to Prof. WATASÉ at whose suggestion the work was undertaken.

I. Luminous Organs of Spinacidæ.

In the family of Spinacidæ, I studied two species of the genus *Etmopterus,* namely *E. lucifer* JORDAN and SNYDER and *E. frontimaculatus* PIETSCHMANN. They are very nearly allied to each other, the latter differing from the former only in the form and arrangement of dermal denticles and in having a milky white spot on the head, which, like the white crescent-shaped spot at the posterodorsal margin of the eye, is due to the presence of a subdermal cartilage, and is not a luminous organ, as was supposed to be by PIETSCHMANN.

Topographical Distribution.

One can distinguish two forms of photophores in *Etmopterus*, viz. the punctate and the linear, as JOHANN has found in *Spinax niger*.

The distribution of the photophores in the species studied by me agrees so closely, with that of *Spinax niger*, that I deem a detailed description unnecessary. In *E. frontimaculatus*, in which the photophores are less developed than in *lucifer*, the postanal area of photophores (Textfig. 1 B, *Pa*) gives off posteriorly neither a median nor lateral branches as it does in *lucifer* (A, P_1 and P_2); or more properly speaking, the three branches are united to form a single broad area. In correspondence with this, the caudal area of photophores in *E. frontimaculatus* (*C*) are

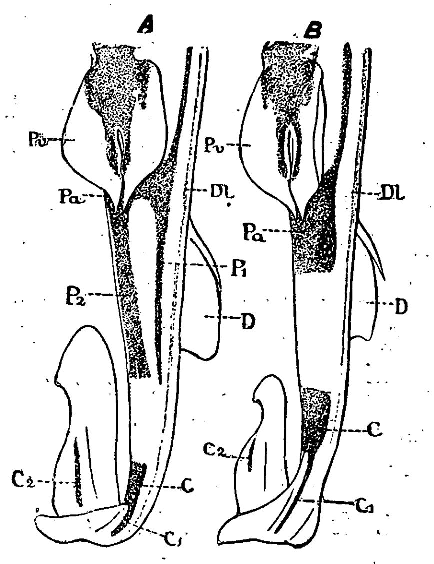

Fig. 1. Postrior regions of (A) *Etmopterus lucifer* and (B) *E. frontimaculatus*, showing the distribution of photophores. Oblique view of the ventral side; the photophores are indicated by dots and broken lines. $\times \frac{2}{3}$. *C* caudal area of photophores, C_1 posterior prolongation of the caudal area, C_2 solitary area on the tail fin, *D* second dorsal fin, *Dl* dorso-lateral row of photophores, *Pa* postanal area of photophores, P_1 lateral posterior prolongation of the same, P_2 median posterior prolongation, *Pv* pelvic fins.

broader, its caudal prolongations on both sides of the tail fin (C_1) longer, and the solitary areas on the tail fin (C_2) shorter than in *lucifer*.

In both species the punctate photophores are densely clustered in the following parts: small areas surrounding the nostrils, the ventral margin of the orbit, bases of paired fins, and lastly the postanal and caudal areas with their extensions. In these areas there are to be counted as many as sixty or seventy photophores in a square mm. of the skin, while in most other parts their number in an equal area does not exceed thirty or forty, and in still other parts where they are most scattered, it sinks to ten or thereabout.

External Features.

In spirit or formalin specimens, the photophores are seen as minute "nicht glänzende Punkte" on the dark skin. But this is not the case in the fresh state, when they appear as spots of a pearly lustre and their distribution can be made out with the naked eye without much difficulty. Under a low magnification, each organ is seen to be composed of a number of polygonal elements of a pearly lustre clustered together to form a rounded area and surrounded by a black ring of thickly accumulated pigment. The pearly lustre vanishes in preservative media.

The following table shows the dimensions of the organs measured in preparations mounted *in toto*:—

Dimensions in mm. / Specimens examined.	Length of body including tail.	Diameter of punctate photophores.	Linear photophores.	
			Length.	Breadth.
Embryos of *E. lucifer.*	65–100	0.05–0.08	0.30	0.10
Adult *E. lucifer.*	310–340	0.10–0.15	0.30–1.35	0.10–0.20
Adult *E. frontimaculatus.*	175–270	0.10–0.15	0.40	0.10–0.15

Histology.

The punctate or circular photophore is a hemispherical cup-shaped epidermal swelling embedded in the cutis, while the linear or elongate photophore is a semicylindrical body, which may be regarded as being formed by coalescence of a number of punctate photophores. The following description refers chiefly to the punctate ones.

The general features of the organ under the microscope agree, on the whole, with the description given by JOHANN from *Spinax niger*.

One can find the following elements in each organ: 1) involucre of pigment, 2) blood sinus, 3) photogenic gland-cells, 4) "iris" with the pigment cells arranged in a ring, 5) "Keimlager" and palisade cells, 6) lens-cells.

In paratangential sections through the organ, the photogenic cells, about fourteen in number, appear radially arranged, while in *Spinax niger* only from four to six of them have been stated to be found.

Around the orifice of the hemispherical body of photogenic cells, a number of pigment cells are arranged in a circle, which

I shall call "iris" (Pl. I, figs. 1–4, *ir*). The reason thereof will become clear further on. These pigment cells send out their pseudopodia-like projections in three directions: the principal ones run perpendicularly to the axis of the organ, thus forming a cover over the cup (Textfig. 2, *i*); the second run distad nearly parallel to the axis at first and then bend axiad, forming likewise a cover externally to that formed by the first (*ii*); the third and least developed of all run proximad and axiad along the inner surface of the cup, inside the blood sinus (*iii*).

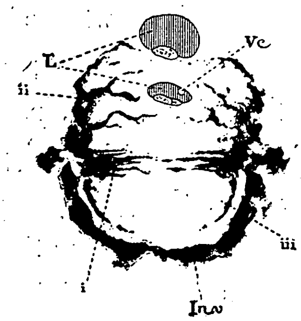

Fig. 2. Diagram showing the pigmentation of the punctate photophore of *Etmopterus*. *i* group of horizontal processes of iris, *ii* group of external processes, *iii* group of internal processes, *Inv* involucre of pigment, *L* lens-cells, *Vc* vacuole.

In sections these three projections are found in both contracted and expanded states. In *E. frontimaculatus*, in which pigmentation is generally weaker than in *lucifer*, the impression is very often produced that the organ is perfectly free from pigment along the axis, thus allowing the light produced to pass freely to the exterior (Pl. I, figs. 3 and 4). JOHANN has described and figured the organ in this state, without mentioning the fully expanded condition of the pigment cells. (Pl. I, figs. 1 and 2).

JOHANN thought that the lens-cells originated in the "Keimlager" and were then successively pushed distad increasing in size on the way. The lens-cell when fully developed is of a rounded or somewhat lenticular form with compact and homogeneous contents readily stainable with orange-G and often containing one or more vacuoles (Pl. I, figs. 1 and 3, *l*). The nucleus is usually found appressed to the proximal wall.

At first, soon after its formation in the "Keimlager," the lens-cell is generally flat and stains deep bluish black with iron-hæmatoxylin (Pl. I. fig. 1, *l′ ll″*). In the course of its displacement towards the surface during general growth of the epidermal cells, the contents of the lens-cell undergo a gradual change into a loose and granular matter (Textfig. 3, 1–3), passing through a stage in which it stains brick-red with orange-G, as stated above. The cell is now much swollen, the granular contents becoming coarser and looser. When the cell reaches the external surface of the epidermis, its contents are ejected leaving the nucleus attached to the cell wall.

As the rate of growth of the epidermis is greatest over each organ, the nuclei of the epidermal cells, arranged in a domelike fashion over it, assume a flattened shape; while those lying between the organs assume a vertical position on account of the relatively slow growth of the intervening parts. Owing to the same cause, the transformed lens-cells often change their course and at last may come to assume a vertical position, with the nucleus attached to the proximal end (Textfig. 3).

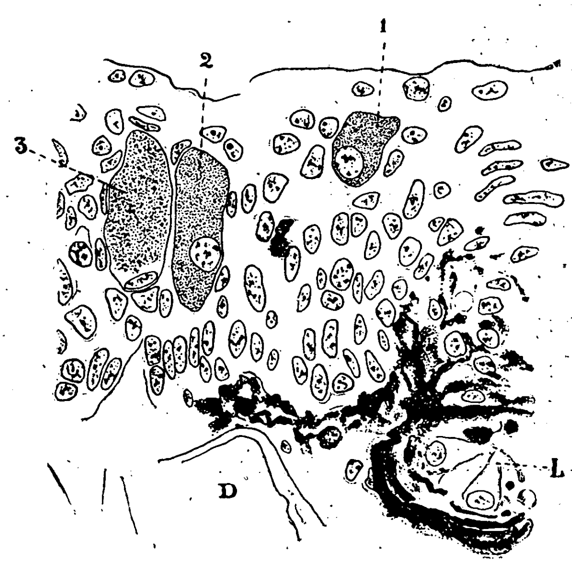

Fig. 3. Three successive lens-cells of *E. lucifer* undergoing transformation and change of their course (1, 2, 3). × 400. *D* young dermal denticle, *L* luminous organ.

Some lens-cells are found in stages intermediate between those described above, showing a brick-red border around the black central mass or granular contents inclosing a homogeneous remnant in the interior.

These changes of the lens-cells can be observed easily in *E. lucifer*, while in *frontimaculatus* they are much obscured by the general thinness of the epidermis and the weaker development of the lens-cells.

The linear photophores are more or less of a similar structure as the punctate ones, and are hardly distinguishable from these in transverse sections. The most conspicuous point of difference between the two lies in this, that in the linear photophore the lens-cells are more numerous and lie closer together than in the punctate one, besides being arranged usually in two layers scarcely leaving space enough for epidermal cells to lie between.

Luminescence.

The luminescent phenomena were observed on a number of *E. frontimaculatus* which were fortunately brought alive to the Misaki Station.

In ventral aspect, nearly the whole surface of the fish could be seen as a faint, whitish, phosphorescent body, when a proper stimulus was applied to it. At the bases of paired fins, in the postanal region and in two discontinuous parts of the caudal area, the luminosity was somewhat stronger, while the eyes, the mouth, the mandibular spaces (a pair of narrow triangular spaces on both sides in front of the gill-clefts, with apices directed rostrad and mediad), the anal region and the peduncular part remained dark. On the dorsal side of the fish I have not been able to observe any luminescence.

The light was quite tranquil and not flaring, and it must be stated in particular that spontaneous luminescence has never been observed.

When the fish was held in one hand and was pressed or rubbed with the other, the luminescence was not immediately called forth but became apparent after some minutes, the light gradually appearing or vanishing or attaining maximum intensity here and there at different places.

Stimulation with ammonia water did not show any effect on luminescence.

Previous accounts of the luminescence of Selachians, but especially those of BENNETT for *Isistius brasiliensis* and of BEER for *Spinaxniger*, agree well with my results as regards the topography of lightproducing areas and the parts where the light was most intense. But BEER's statement that he observed no change of luminosity on application of diverse mechanical stimuli does not agree with my observations. The reason lies perhaps in the fact that he experimented on a severely wounded specimen. It seems to me too great an exaggeration to say, as BURCKHARDT did, that the phenomena might be observed even in day-light. In fact, the intensity is far from being strong, so that one can not recognize the light in a dark room unless the eyes were previously brought into adaptation with the darkness.

The facts that no sudden change of luminosity takes place and that there is such a local difference in the intensity of the emitted light may, in some cases, be due to the action of the pigment cells* which form what I have called the "iris." When contracted, they allow the exit of the light produced in the photogenic body lying underneath, while their expansion makes the iris act as a screen that shut in the light.

If it be, as JOHANN has made out in *Spinax niger*, that the organ is not specially innervated, this may be in relation with the fact that mechanical stimulation does not cause immediate change of the luminescent phenomena.

II. Luminous Organs of Sternoptychidæ.

As a representative of the family Sternoptychidæ, I have taken *Maurolicus pennanti* (WALBAUM) for the study of the luminous organ.

Topographical Distribution.

GATTI is entirely right in his description of the distribution of the organs, the number of photophores as given by him exactly coinciding with that of my specimens, while those given by USSOW, JORDAN and EVERMANN and recently by MANGOLD differ from mine.

External Features.

The luminous organs, when viewed from the ventral side, are of a beautiful amethyst colour in the fresh state, with a slightly convex surface. MANGOLD is of the opinion that the colour is a "Strukturfarbe" or an interference colour caused by a special arrangement of the spicules forming the reflector, but my observations have led me to a different conclusion.

* Prof. WATASÉ has expressed a similar opinion on the luminous organs of *Abraliopsis*.

The coloured part always coincides with the extent of the lens; for instance, when such of the organs as open obliquely to the surface, as, f.i., the branchiostegals, is seen from the surface, the coloured part is scarcely visible, being covered by the lateral portion of the reflector, while the whole of the parabolic area, where the gelatinous tissue and the median wall of the reflector come directly in sight, is white and argenteous. If the amethyst colour is due to the reflector, why should not the former come into evidence where the latter is shown to such an advantage? Moreover, the colour fades within some hours after preservation. It is, consequently, highly probable that the amethyst colour is inherent in the lens.

In the thoracic organs, arranged in double rows on the ventral side between the pectoral and pelvic fins and opening vertically to the surface, the diameter of the largest one as measured at the orifice was 0.95 mm., while the posterior anals, which form hindmost rows in the caudal region, measured from 0.6 to 0.45 mm. across, the length of the fish being 42 mm. exclusive of tail.

Histology.

The luminous organ of *Maurolicus* is composed of the following elements: 1) layer of pigment cells, 2) reflector, 3) connective tissue, 4) photogenic body, 5) lens, 6) gelatinous connective tissue. The reflector may be absent, as, f.i., in the anteorbital organ.

The reflector is highly differentiated and consists of two parts of different structure, the inner and the outer.* The

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* These are not identical with MANGOLD's "innere" and "äussere" reflector, which are merely parts of my inner reflector.

inner reflector (Textfig. 4, *iR*) encloses chiefly the inner bulbous section of the organ. Towards the exterior it stretches out into a thin layer lined by the outer reflector. It is composed of bundles of fine fibrous "spicules," running parallel to one another and sparsely mixing between them elongate nuclei of the connective tissue. It appears grey with transmitted light and shining silvery with reflected light.

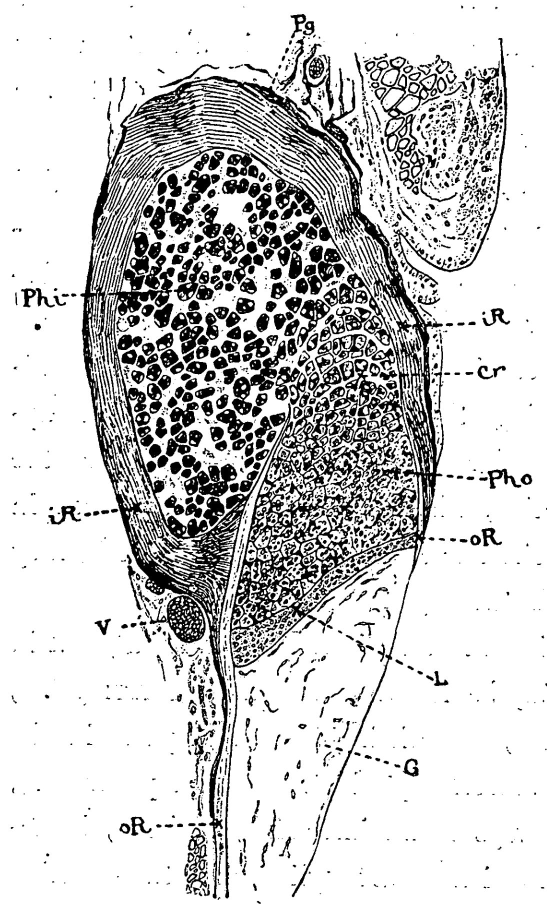

Fig. 4. A branchiostegal photophore of *Maurolicus pennanti* cut transversely to the long axis of the fish. × 80. *Cr* semicircular cracks in the photogenic body, *G* gelatinous connective tissue, *L* lens, *Pg* pigment layer, *Phi* photogenic cells of the inner section, *Pho* those of the outer section, *iR* inner reflector, *oR* outer reflector, *V* blood vessel.

The outer reflector (*oR*), which lines the external section of the organ in the form of a funnel with the thickest part of its wall at about the opening of the organ, is composed of fibres running straight outwards and which appear to have no silvery lustre but are quite transparent. This outer reflector appears to have been overlooked by most observers. Only BRAUER distinguished in *Sternoptyx* and *Argyropelecus* a layer of loosely arranged fibres which showed no silvery lustre. It apparently corresponds to what I have called the outer reflector in *Maurolicus*, but differs in having an additional pigment layer lining it on the inner surface, which layer is absent in my species. It seems that there exist no spicules in this part; the elongate nuclei are found very sparsely.

The internal space enclosed by the reflectors is filled up with photogenic body and connective tissue. The connective tissue, in which the blood vessels are sparsely distributed, is very weakly developed around the photogenic cells.

The photogenic body consists of irregular polyhedral gland-cells (*Phi* and *Pho*), filling the interior of the organ apparently without any regular arrangement except near the opening of the inner section, where the cells are arranged in layers parallel to the semicircular cracks (*Cr*). When fresh, they form a milky mucus which turns greyish in spirit.

Most of the photogenic cells contain a single nucleus, but in some of them two nuclei may be found as stated by GATTI (Pl. I, figs. 5 and 6, *nu*). Moreover, one distinguishes two parts in the cell, the cytoplasm and the secretion product. The cytoplasm (*pr*), in which the nucleus is always found imbedded, is dense, homogeneous and highly stainable with hæmatoxylin, while the secretion product (*sc*), which readily stains with eosin, appears like a sort of fat-drops of various sizes or like starch grains of potato cells. Drops of the secretion occupy a part of the cytoplasm in which they were produced, gathering together in a common vacuole-like space formed inside the cell. GATTI found the cytoplasm form a network which he called "massa filare," in the meshes of which a plasmatic substance, "massa interfilare," was contained. Judging from his figure (Tav. I, 7^{a}), his "massa interfilare" does not appear to be identical with the fat-like substance of mine. The latter is found well preserved only in specimens* fixed with ZENKER's fluid, while in those which were treated like GATTI's with formalin or formalin-sublimate, it has entirely disappeared, the remaining cytoplasm forming a network that appears exactly like that figured by him. BRAUER's description of the "Drüsenzellen" of *Polyipnus*, *Sternoptyx* and *Argyropelecus* agrees with what I have found in *Maurolicus*, the only difference lying in the absence of any regular arrangement into groups found in those three genera. MANGOLD, like other authors, has fallen into a mistake in saying that the "Drüsenkörper" of the inner part is histologically indistinguishable from that of the outer. On careful comparison, I have found a difference between the photogenic gland-cells of the outer section and those of the inner, the difference consisting in the different relative quantity of the secretion product and the cytoplasmic portion. In the cells of the outer section (Pl. I, fig. 6) the fat-drops are large and numerous, occupying almost the whole interior of the cell, while in those of the inner section (fig. 5) they are few and minute, there being a great preponderance of the cyptoplasmic matter.

The meaning of MANGOLD's "Drüsenkappe" (Textfig. 4, *L*) is a mooted point. He emphasized its glandular nature, and concluded that GATTI's unhesitating decision as lens was erroneous. That body lies at the distal border of the photogenic body, completely spanning over the aperture of the organ. In vertical sections through the layer one finds the cells arranged in rod-like groups at right angles to its surface (Pl. I, fig. 8, *l*). MANGOLD stated that the arrangement of the "Leuchtdrüsen" reminds one somewhat of the sublingual gland.

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* These belong to Mr. MORIWAKI's collection.

This makes me suppose that he saw his "Drüsenkappe" in paratangential sections (fig. 7), in which one often sees structures somewhat resembling those of the salivary gland, the connective tissue dividing the cells into many groups. Each cell of the "Kappe" contains a rounded nucleus and a very finely granulated cell body readily stainable with eosin and orange-G, and rather hard in sectioning. I have found clear vacuoles (*vc*) in some of these cells, sometimes minute and inconspicuous, at other times relatively large. On examining BRAUER's recent work, I find in his descriptions of *Polyipnus*, *Sternoptyx* and *Argyropelecus*, that his "Linsenkörper" or "linsenförmiger Körper," which forms a typical lenticular body, agrees exactly with the layer in question, this being only less thick than in BRAUER's species. I will consequently follow GATTI and BRAUER in regarding this layer as a lens, though it must be remarked that in this case, owing to its form, it can not serve as a condenser.

The gelatinous connective tissue directly covers the outer surface of the lens and is exposed directly to the exterior (Textfig. 4, *G*). It has, as I have already mentioned, a slight outward convexity in the fresh state, which made MANGOLD take it for the lens. The tissue is loose and transparent and has no light-refracting property necessary for a lens. It is shrunken in preserved specimens.

The organ receives a rich supply of blood, the vessels becoming markedly impregnated by CAJAL's method. They penetrate the reflector at several places and then split up into capillaries which ramify in the interior. They are more abundant in the funnel-shaped outer, than in the inner, section of the organ.

On the other hand, my attempts to find out the nerves in the organ have yielded no positive results. Some doubtful cases of them were indeed met with, but I could not decide whether I really had a nerve or something else before me.

Luminescence.

The fishes were observed in a small fishing boat off the coast of Manadzuru, Sagami, on a moonless night.

My observations differed from MANGOLD's in that no luminescence could be observed when the fish was simply put in fresh-water. A continuous light was made visible only when some drops of formalin were added to it. The yellowish green light was very feeble, not strong enough to illuminate any object held near by.

It was "ein ruhiges, nicht flackerndes Licht"; there was no sudden appearance and disappearance of light, nor any sudden change in intensity. When the organs were crushed between the fingers and their contents exposed to the air, the mucous matter (the mass of photogenic gland-cells) attached to the fingers was found to be *equally luminous*.

As regards the anteorbital organ, no luminosity could be seen from the exterior.

In agreement with MANGOLD, no spontaneous luminescence has been observed.

III. Luminous Organs of Myctophidæ.

From among this group of fishes with peculiarly developed luminous organs, I have examined *Myctophum* (*Myctophum*) *spinosum* (STEINDACHNER), *M.* (*M.*) *affine* (LÜTKEN), *M.* (*M.*) *laternatum* GARMAN, *M.* (*Diaphus*) *watasei* (JORDAN and STARKS) and *M.* (*D.*) *splendidum* BRAUER.

External Features.

All the organs, except the luminous scales or "Leucht-schuppen" of BRAUER, are brightly shiny owing to the presence of a reflector.

As variously sized specimens of *M. watasei* could be obtained, I have measured the size of the luminous organs in relation to entire length of the fish:

Nos. of specimens.	I	II	III	IV	V
Length of fish in mm. excluding tail.	34	39	47	95	155
Diameter of photophore in mm.	0.60	0.65	0.70	1.40	1.80
Ratio of photophore diameter to body length.	1: 56.7	1: 60	1: 67.1	1: 67.9	1: 86.1

The diameter was always measured on the third thoracic organ across the pigment septum.

The table shows that the organ grows faster and attain complete development relatively earlier than the length of body.

Histology.

The constituent parts of the luminous organs of Myctophidæ are: 1) photogenic body, 2) investing connective tissue, 3) gelatinous tissue, 4) peculiar membrane, 5) "schuppenartige Lamella" or "squama profonda," 6) layer of hexagonal iridescent elements, 7) reflector, 8) pigment layer, 9) lens, 10) nerves and blood vessels. The parts 4-9 are however accessory parts and may be wanting in some cases.

The morphological nature of the photogenic body has been more or less erroneously construed by previous authors. BRAUER'S opinion regarding it appears to me to be the most probable.

The element which I call the peculiar membrane was found by BRAUER in the "schüsselförmigen Organe" of the subgenera *Diaphus* and *Lampadena*, lying directly behind the lens and appearing transversely striated in section. I have also found it in the subgenus *Myctophum*, in which BRAUER failed to find it, lining the ventral half of the orifice and lying over the gelatinous tissue.

Very often we meet with another peculiar layer composed of hexagonal, iridescent elements, lining the concave surface of the pigment layer. This is visible from the outside with the aid of the microscope, and LEYDIG has already dealt with it. It doubtlessly serves as a reflector and consists of short and relatively thick hexagonal prisms of spicules arranged obliquely to the surface of the pigment layer. When treated with acids, the spicules are dissolved, leaving behind a part of the gelatinous connective tissue that fills up the intervals, thus giving rise, in horizontal sections, to an appearance of honey-comb like hexagonal septa and in transverse sections, to that of oblique striations.

Another form of reflector is composed of bundles of thin spicules running parallel to the surface, a form that has been well known to previous observers (Pl. I, fig. 9, *r*).

The lenticular thickening of the scale associated with the organ is a peculiarity of the Myctophidæ. Well developed lenses were observed in the subgenus *Myctophum*, while in *Diaphus* they are but weakly developed. Usually they are more convex on the inside than on the outside, and their thickest part lies opposite the ventral half of the organ.

Considerable differences are to be noticed between the luminous organs of the Myctophidæ and those of other families. The principal of them lie in the thinly lamellar structure of the photogenic body and in the fact that the organs are distinctly innervated.

Even in sections stained by ordinary means, one can find with ease the nerves entering the organ, as were already described by LEYDIG, EMERY, GATTI etc. I was fortunate enough to succeed with the silver impregnation method of CAJAL.

In the orbital organs the nerves enter usually in company with blood vessels. They penetrate the reflector vertically, then to run with their main part directly to the periphery of the organ, sending out in their course small branches between the photogenic cells (Pl. I, fig. 9, *n*).

In some sections through one of the anterior anal organs of *M. watasei*, small nerves were found breaking up into fascicles and running distad, parallel to the lamellar gland-cells (figs. 10 and 11, *n*).

As to blood supply, one can always find in every luminous organ a plenty of capillaries forming a plexus around the photogenic bodies (*v*).

Luminescence.

I have observed a number of living fishes belonging to the present family, together with the above mentioned *Maurolicus*, in Sagami Sea.

The most brilliant light was produced from the anteorbital organs and the luminous scales, the former throwing the rays rostrad and ventrad just like the head-light of an automobile. I have unintentionally omitted to pay attention to the mediocaudal photophores ("Leuchtplatten" of BRAUER), which were subsequently found to be very imperfectly developed in the specimens I had examined in life. The branchiostegals, the operculars and all other "schüsselförmige" organs shine more feebly than the anteorbitals and the luminous scales.

The light omitted is of a pretty blue colour, but its power of illumination is so weak that in *M. watasei,* with all the photophores in action, I never could recognize even big prints on a paper held almost in contact with the fish, though care was taken previously to entirely adapt my eyes to darkness.

The light was *a momentary one* just like an electric spark, quite different from those of *Maurolicus* and *Etmopterus.*

No spontaneous gleaming was observed.

In fresh-water and in a dilute solution of formalin the fish remained dark.

Mechanical stimuli were effective in bringing the organ into action, as when the fish was pressed between the fingers, or when the brain was cut out. The latter operation was always followed by emission of light of maximum intensity from the anteorbitals and the luminous scales.

By the mode of action one can distinguish two groups of the organs, the anteorbitals and the luminous scales (and probably also the mediocaudals) on the one hand, and all the other small organs on the other. The two groups act quite independently of each other, while within each all the photophores become simultaneously active. A weak stimulation was followed by the emission of light only from the second group, while the first group could be forced to action only by a stronger stimulation.

Once some dying fishes brought ashore in a basket fell into my hands. Subjecting them under observation, I have found that their luminous phenomena differed markedly from the normal in that the photophores, especially the anteorbitals, showed a faint *continuous* luminescence.

Instances of actually observed luminescence are given by GUNTHER, GUPPY, EMERY and NISSEN. The first mentioned two authors give precise accounts of the matter but had before them half-dead fishes only. The accounts given by the last two observers are unfortunately very brief, though they seem to have had good material. At any rate, I am of the opinion that statements to the effect that their fish was spontaneously luminous were due either to the abnormal state of their material or to insufficiency of observation.

"The larger pearly bodies of the pectoral region" which GUPPY found in a *Scopelus* were, I suppose, luminous scales.

IV. Summary.

I have dealt in the present paper with three forms of luminous organs which show different degrees of development. They are:

(1) The organs in Selachians. No numerical definiteness exists here, the organs being diffusely scattered, minute, epidermal swellings partly sunk in the cutis. The photogenic body consists of a small number of conical photogenic cells arranged radially into a hemispherical or semicylindrical mass. The lens is unicellular. No unequivocal innervation has been proved, whilst the blood supply is carried on by a sinus underlying the organ. The light produced from the organ is tranquil and faint, probably controlled by special activity of pigment cells.

(2) The organs of the Sternoptychidæ (in strict sense):

They are definite in number and arrangement according to species, complicated in structure and are in some cases provided with a system of intercommunication between the internal parts of the neighbouring organs. The photogenic body is formed by numerous polyhedral gland-cells filling the interior of the organ in either regular or irregular arrangement. The lens is multicellular, and lenticular or flat in form. The blood capillaries form a network between the photogenic cells. The presence of nerves has been proved in a few cases. The luminescence is not momentary but continuous, the light being not very intense. The photogenic body emits light in the air even when taken out of the organ.

(3) The organs of the Myctophidæ. These are the most highly differentiated forms of luminous organs, some species presenting sexual differentiation as regards their position on body. The photogenic body consists of a number of small lamellar gland-cells. The lens, if present, is formed by a local thickening of the superposed scale. The photogenic body is richly supplied with nerves, and the blood vessels form a plexus around it. The spark-like light is rather bright and is undoubtedly controlled by nerves.

The different forms of the organ have several common features, namely:

(a) They are abundantly supplied with blood.

(b) Within one and the same species, the photogenic bodies are of the same structure, irrespective of their belonging to different forms of the organ situated in different parts of body.

(c) The photogenic cells are always of a glandular nature.

(d) The secretion product in photogenic cells is always stainable with plasma dyes. It is never set free.

(e) No spontaneous luminescence has been observed.

Before concluding I may say a few words concerning the œcological meaning of the luminous organs of fishes discussed by BRAUER.

As regards the frightening purpose, BRAUER states that it is possible only in the case when "entweder das Sekret herausgespritzt würde oder blitzartig auf einen Reiz hin aufleuchten würde." According to my experiments, the latter holds good for *Myctophum*, in which the photophores, especially the large anteorbital organs, glitter spark-like upon stimulation, so that it must be quite useful for frightening purposes, contrary to his statement that "die zweite scheint mir deshalb nicht vorhanden zu sein, weil nach den Beobachtern das Licht gleichmässig in allen Organen auftritt, usw."

As to the use of the organ for illuminating purpose, that seems to occur only in *Anomalops* and *Photoblepharon*, in which the organs are placed inferiorly to the eyes and emit quite intense and continuous light. Such cases are not found in any other group of luminous fishes.

Tokyo, Feb. 7, 1910.

POSTSCRIPT.

While the foregoing was in press, I was fortunate enough to get a copy of HANDRICK's work "Zur Kenntnis des Nervensystems und der Leuchtorgane von *Argyropelecus hemigymnus*" (Zoologica Bd. XXIII, Heft 32, 1901), which I was not able to consult before. In this work HANDRICK mentions the presence of two forms of glandular cells in the luminous organs of *Argyropelecus*, viz., (1) those situated principally near the reflector layer, which have sickle-shaped mass of protoplasm attached to the cell-wall and usually contain vacuoles (Sekreträume), and (2) those found apart from the reflector, without any localized mass of protoplasm and rarely with vacuoles. Both these cells contain in the reticulated protoplasm "verhältnismässig grosse, stark lichtbrechende Körperchen", noted before by BRANDES. In my opinion, the two forms of the cells mentioned by HANDRICK correspond to the two forms of photogenic cells described by me in this paper from *Maurolicus*. Further, the refractive "Körperchen" found by him in the cells can not be anything else than what I have called fat-drops. Then, the only essential difference in the histological structure of the luminous organs of *Maurolicus* and *Argyropelecus* seems to consist in the relative distribution of the two kinds of photogenic cells, viz., while in *Argyropelecus* both kinds appear to occur in the outer funnel-like as well as in the inner bulbous section of the organ, the first near the reflector and the second in a more internal position, the same in *Maurolicus* are found separately in the two sections, in that the first and the second fill up respectively the bulbous and the outer funnel-like section. I may call attention to the fact that in *Maurolicus*, the two forms of the cells are connected by intermediate ones, so that there can be no doubt that all the cells in question are of the same origin, showing differentiation in the quantities of the protoplasm retained and of the fat-drops contained in the cell body.

May 14, 1910.

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Explanation of Plate.

Fig. 1.—Transverse section of the skin from the rostoral region of *Etmopterus lucifer,* showing a punctate photophore with closed iris, cut longitudinally. × 320.

Fig. 2.—Paratangential section of the skin at the level of the iris of a punctate photophore from the abdomen of *E. frontimaculatus*; iris closed. × 320.

Fig. 3.—Transverse section of the skin from the abdominal region of *E. frontimaculatus,* through a punctate photophore with opened iris. × 320.

Fig. 4.—Another organ from the same section as in fig. 2, passing through the level of the opened iris. × 320.

Fig. 5.—Photogenic gland-cells from the inner section of a luminous organ of *Maurolicus pennanti.* × 1,000.

Fig. 6.—Photogenic gland-cells from the outer section of the same. × 1,000.

Fig. 7.—Paratangential section through a lens of a thoracic organ of *Maurolicus pennanti.* × 400.

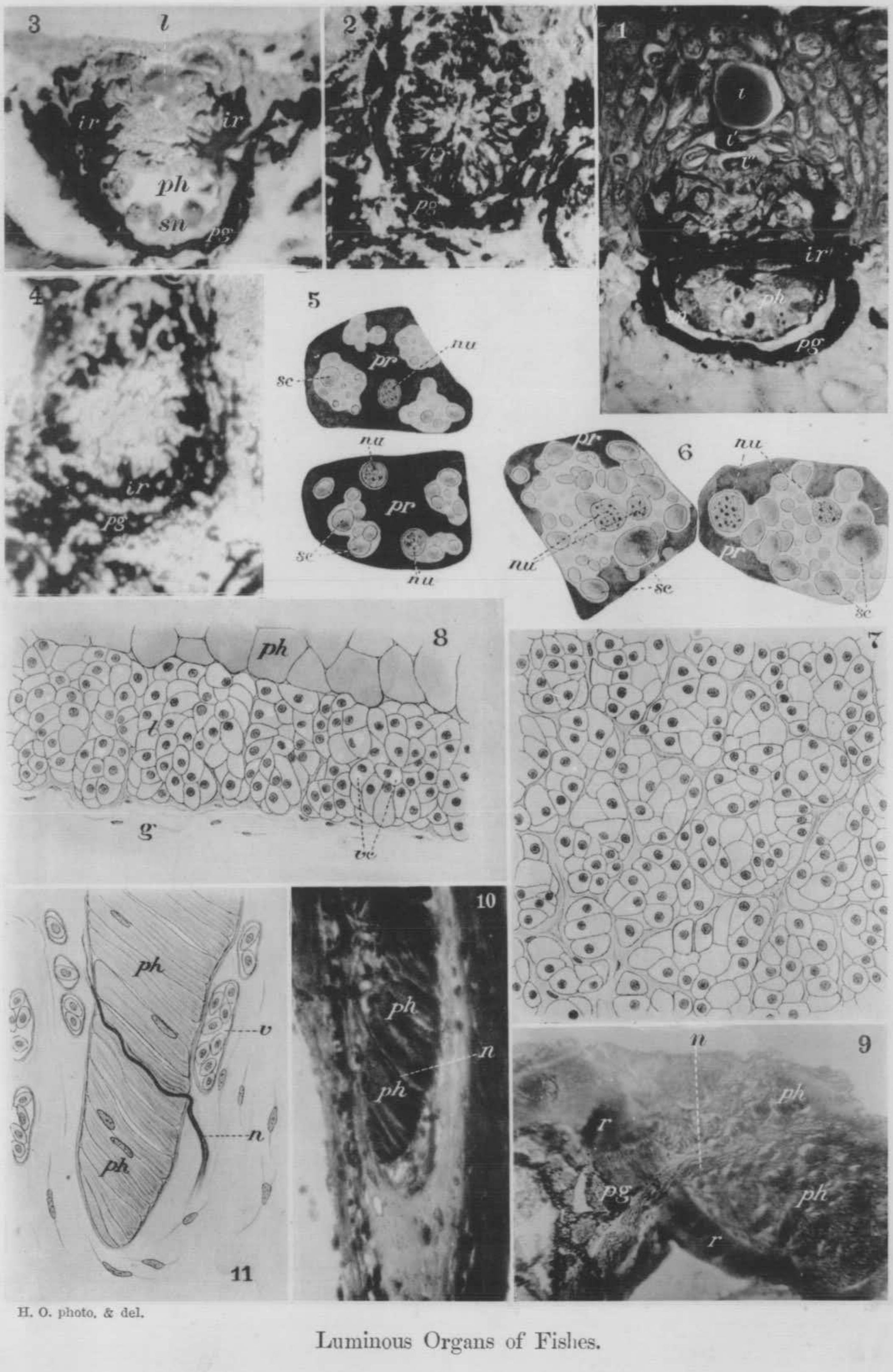
Fig. 8.—Transverse section through a lens of an anteorbital organ of *Maurolicus pennanti.* × 400.

Fig. 9.—An anteorbital organ of *Myctoplum watasei,* showing a nerve; silver impregnation. × 100.

Fig. 10.—Photogenic body of an anterior anal organ of *Myctoplum watasei* showing a nerve entering it, impregnated with silver. × 320.

Fig. 11.—Another section from the same series as the former. × 650.

g—gelatinous connective tissue.
ir—iris.
l—lens.
n—nerve.
nu—nucleus.
pg—pigment layer.
ph—photogenic cell.
pr—cytoplasmic portion.
r—reflector.
sc—secretion product.
sn—blood sinus.
v—blood vessel.
vc—vacuole.



H. O. photo. & del.

Luminous Organs of Fishes.