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SPECTRAL COMPOSITION OF THE LIGHT OF THE LANTERN-FISH, *MYCTOPHUM PUNCTATUM*

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(Text-figs. 1–3)

Relative spectral emission curves are available for the lights of many invertebrate animals, but none exists for fish. It seems likely that many bony fish use their photophores to signal to one another. Information about the spectral composition of fish luminescence is desirable to permit comparisons with the spectral sensitivities of fish eyes, to enable calculations to be made of luminous intensities, and to allow estimates to be made of the rate of attenuation of such lights in sea water. To further these ends, measurements were made of the spectral composition of the luminescence of the lantern-fish, *Myctophum punctatum*.

MATERIAL AND METHODS

The lantern-fish *Myctophum punctatum* Rafinesque is a pelagic species that executes diurnal migrations to the surface at dusk. Specimens were collected by R.V. 'Sarsia' at three stations: 46° 57′ N., 60° 58′ W., 4 June 1959; 46° 42′ N., 6° 09′ W., 5 June 1959; 47° 01′ N., 5° 55′ W., 7 June 1959. The fish were attracted to the side of the ship at twilight by means of a floating lamp submerged just below the surface. They were caught in hand-nets and transferred to a container of sea water on deck. Myctophids do not survive long in captivity, and the animals were used as soon as possible after capture.

Myctophids possess a series of photophores on the lower surface of the head and trunk. These light up spontaneously, and bright luminous flashes are also evoked by tactile stimulation of the fish.

The spectral composition of the light was determined by means of coloured filters and photomultiplier tubes (Fig. 1). The fish was placed in a black vessel which fitted into a black box. Above the box was a round aperture. Over this aperture was placed a thin cover-glass at 45° to the vertical axis. One photomultiplier (vertical) was placed directly over the cover-glass and the aperture; a second photomultiplier (horizontal) was placed at right angles to the vertical axis at one side of the cover-glass so as to catch reflected light from the latter. Between the cover-glass and the photomultiplier there was a disc, capable of being rotated, and containing a series of coloured filters which could be interposed between the cover-glass and the vertical photomultiplier. The vertical photomultiplier detected the light which passed through the filters; the horizontal photomultiplier monitored the light intensity for each recording made with the other photomultiplier.

The photomultipliers were E.M.I., types nos. 6685 (vertical) and 6260 (horizontal). Both types are most sensitive in the blue region of the spectrum, and sensitivity falls off rapidly above 500 mμ. The spectral sensitivity of photomultiplier tube type no. 6685 was determined by the National Physical Laboratory; the spectral sensitivity curve is given elsewhere (Fig. 2, Nicol, 1958*a*).

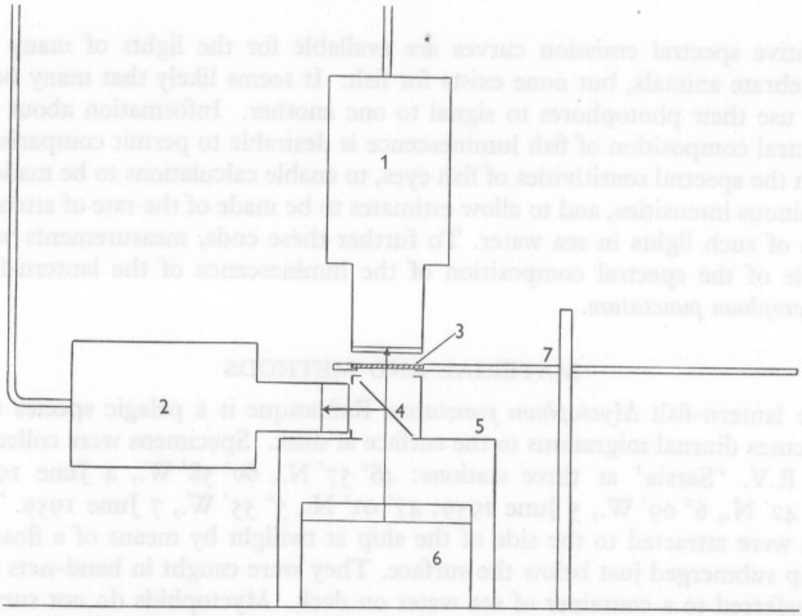

Fig. 1. Diagram of apparatus. 1, vertical photomultiplier type no. 6685. 2, horizontal photomultiplier type no. 6260. 3, filter. 4, cover-glass. 5, black box. 6, black vessel, holding sea water to contain the fish. 7, rotating disc. Arrows indicate light-paths.

Each photomultiplier was connected to a cathode-ray oscilloscope through a d.c. amplifier. Vertical deflexions of the spot on the face of the tube were photographed on moving paper. Current for the photomultipliers was provided by two stabilized power packs. Noise was filtered off by means of a 0·1 μF condenser placed across the input of each oscilloscope.

Filters were Chance OX 1 (u.v.), OV 1 (purple), and Ilford 601 (violet), 602 (blue), 603 (blue-green), 604 (green), 605 (yellow-green), 606 (yellow), 607 (orange), 608 (red), 609 (deep red). The spectral transmission of these filters was measured in a spectrophotometer. Representative transmission curves may be found in manuals of Chance Bros., Ilford Ltd., and curves for $S_\lambda T_\lambda$ (sensitivity of photomultiplier type no. 6685 × transmission of the filters) in a previous paper (Nicol, 1957).

A lantern-fish was introduced into the box and stimulated by gently squeezing it. The response through a given filter and the monitored response were recorded, and this procedure was repeated several times with each of the filters. A fish flashed repetitively under this treatment, and each record showed a number of flashes, some of optimal size for measurement, some too bright and off screen, and some very small and difficult to measure. Representative records are shown in Fig. 2. The deflexions obtained with filters transmitting long wavelengths, viz. 606, 607, 608 and 609, were small and difficult or impossible to measure.

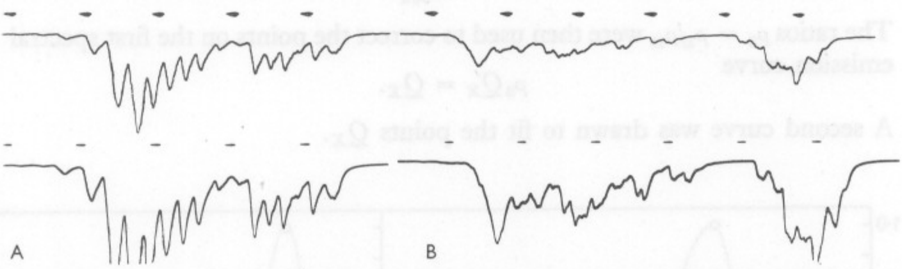

Fig. 2. Recordings of luminous responses. A, two left-hand records. Above, response recorded through filter 603, below, monitored response. B, two right-hand records. Above, through filter 602, below monitored response. Downward deflexions of traces are luminous responses. Time scale 1/sec.

The extent of the deflexions on each record, when possible, was measured. The records obtained with the monitoring photomultiplier were used to correct the records obtained with the filters and the vertical photomultiplier, so as to compensate for differences in the intensities of the response. All records obtained with filters were thus scaled to the same initial intensity. Means of the corrected records for each filter were determined. Let these values be R_X, where X refers to a given filter.

Curves were plotted for the products of the sensitivity of photomultiplier type no. 6685 (S_λ) times the transmission of the filters (T_λ), against λ. The area of each of the curves is

$$\eta_X = \int_{320}^{700} S_\lambda \, T_\lambda \, d\lambda.$$

The mean representative wavelength for each curve was estimated from the vertical axis bisecting the area ('centre of gravity' of the curve).

Relative spectral emission at the representative mean wavelength for each filter was calculated from

$$R_X/\eta_X = Q'_X.$$

From the values for Q'_X a spectral emission curve was constructed (first approximation). Let the relative spectral energy levels on the curve be E'_λ. With these values, a correction was applied to compensate for the wide transmission bands of the filters. A further series of curves was constructed for $E'_\lambda S_\lambda T_\lambda$

$$\zeta_X = E'_\lambda S_\lambda T_\lambda.$$

Ratios were then obtained for each filter

$$\rho_1 = \zeta_X/\zeta_{602}.$$

Similar ratios were determined for measured responses

$$\rho_2 = \frac{R_X}{R_{602}}.$$

The ratios $\rho_3 = \rho_2/\rho_1$, were then used to correct the points on the first spectral emission curve

$$\rho_3 Q'_X = Q_X.$$

A second curve was drawn to fit the points Q_X.

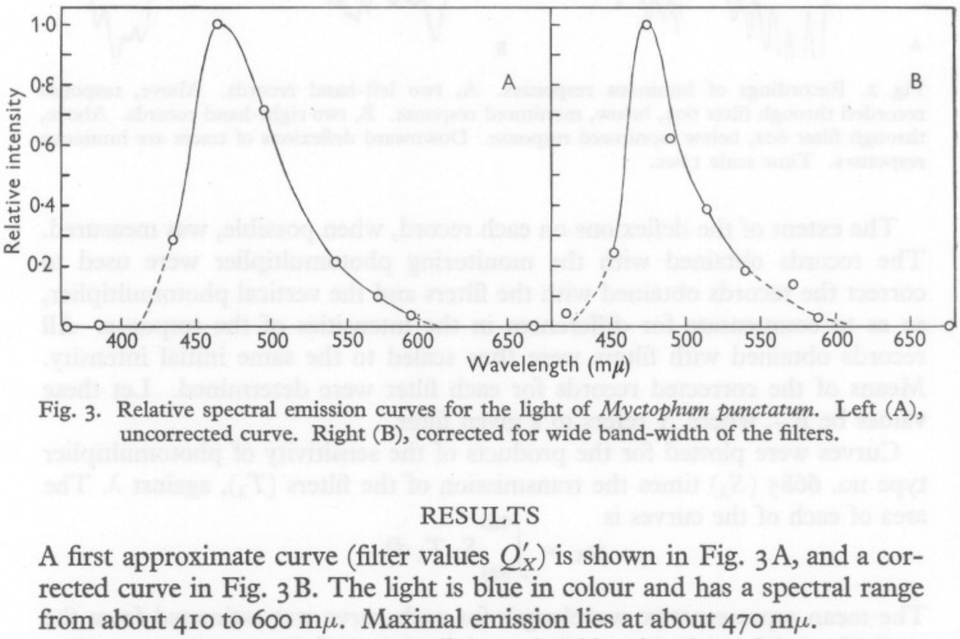

Fig. 3. Relative spectral emission curves for the light of *Myctophum punctatum*. Left (A), uncorrected curve. Right (B), corrected for wide band-width of the filters.

RESULTS

A first approximate curve (filter values Q'_X) is shown in Fig. 3A, and a corrected curve in Fig. 3B. The light is blue in colour and has a spectral range from about 410 to 600 mμ. Maximal emission lies at about 470 mμ.

These results pertain only to the light emitted by the photophores. Myctophids also possess a special light-organ, known as the 'caudal gland', on the caudal peduncle. The 'caudal gland' lights up independently of the other photophores. Its light appears blue to the eye; determination of the spectral composition was not attempted.

DISCUSSION

The lights of luminous fishes have been variously described as white, blue, blue-green, green or yellow. The majority appear to be blue or blue-green (Harvey, 1955). It is likely that several quite dissimilar chemiluminescent mechanisms are involved in the production of light by different fishes, and it is not unexpected that the lights should have different spectral characteristics. *Mycotophum* produces light intracellularly, within photophores. *Searsia*, a deep-sea species, releases a blue-green luminous secretion (Nicol, 1958*b*). *Malacocephalus laevis*, believed to owe its light to luminous bacteria, has a blue-green luminescence. Luminous bacteria, cultured from this fish, emit light having a spectral range of 430–638 mμ, and a maximum at 510 mμ.

Elsewhere I have given estimates of the intensity of the light of *Myctophum punctatum* (Nicol, 1958*b*). According to these estimates, radiant flux ranges from $0{\cdot}1 \times 10^{-9}$ μJ to 52×10^{-9} $\mu W/cm^2$ receptor surface at 1 m distance. Since a relative spectral emission curve for *Myctophum*-light was not then available, the emission curve for blue *Chaetopterus*-light was employed in the calculation. This curve is very similar to that for *Myctophum*-light, and the subterfuge now appears justified.

The photophores of myctophids have specific patterns, and it is not unlikely that they are used as intraspecific signals, during mating, schooling, or other social activities. Denton & Warren (1957) have shown that *Myctophum punctatum*, among other deep sea teleosts, possesses a golden-coloured retinal pigment (chrysopsin). The spectral characteristics of the absorption curve for this pigment are rather similar to those for the spectral emission curve of luminescence.

I wish to thank Dr E. J. Denton for helpful advice, and Mr R. G. Maddock for technical assistance.

SUMMARY

Measurements were made of the relative spectral energy in the light of the lantern-fish *Myctophum punctatum*. Light emission extends from about 410 to 600 mμ, with maximal emission at about 470 mμ.

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