THE SPECTRAL SENSIBILITY OF THE SUN-FISH AS EVIDENCE FOR A DOUBLE VISUAL SYSTEM

BY HARRY GRUNDFEST*

(From the Laboratory of Biophysics, Columbia University, New York)

(Accepted for publication, March 14, 1932)

INTRODUCTION

Most fish, like most other vertebrates, possess an anatomically duplex retinal system, composed of rods and of cones (Schultze, 1866; Wunder, 1925). The Duplicity Theory, proposed in 1894 by von Kries, postulates that animals which have such an anatomically double retinal system show this physiologically by the presence of two types of photosensory behavior. This hypothesis is based, in part, on the work of Schultze (1866), Hering and Hillebrand (Hillebrand, 1889), and of Koenig (1894), and also follows a suggestion made by Parinaud in 1881 (see Tschermak, 1929). According to the Duplicity Theory, which is applied to all vertebrates, the rods are responsible for vision at low intensities of illumination while the cones are functional at the higher intensities. Subsidiary to this hypothesis is the further one that cone vision in the lower vertebrates may also be accompanied by color perception.

Tschermak (1929) justly observes that "decisive weight must be given only to physiological arguments (in favor of the Duplicity Theory), especially those indicating different visibility functions in dim and in bright vision, and not to histological data, since the findings of comparative anatomy are not always unequivocal . . . ." It was, however, precisely on the physiological arguments that opposition to the Duplicity Theory was maintained for many years by von Hess (general summary, 1922). Hess' attack was along two lines. He believed that the lower vertebrates and especially fish possessed, at all intensities, the same spectral sensibilities as those found in totally

* Fellow in Biology, National Research Council.
color-blind humans and in normal human dim vision. Furthermore, Hess maintained that the lower vertebrates showed an inability to discriminate colors.

There is evidence (Grundfest, 1932) showing that the sensibility of *Lepomis* to very dim spectral lights is determined by the absorption spectrum of its own visual purple and therefore does not correspond to the visibility curve of human color-blinds. This is entirely contrary to Hess' first argument. His second position has been made untenable by the evidence of Sumner (1911), Mast (1914), and especially of von Frisch and his students (review by von Frisch, 1925). These investigators have presented proof in a number of different ways that fish can discriminate colors.

These two types of evidence, while they remove the objections of Hess, do not settle the problem raised by the Duplicity Theory as to the presence of a dual photosensory system. However, von Frisch (1924) has shown that color discrimination in fish is possible only at intensities that are well above the threshold for brightness perception. Furthermore, Bauer (1910) has found that fish exhibit the Purkinje phenomenon. Since Koenig and Ritter (1891) have shown that this effect, in man, is due to the difference in the spectral sensibilities of the rods and cones, the results of von Frisch and of Bauer are strong evidence to show that two different retinal mechanisms also occur in fish. Up to the present, however, no quantitative evidence has been available. It is my purpose in making the present measurements to supply this lack, and to show quantitatively that in the case of the sun-fish *Lepomis* the visibility function at high spectral intensities is different from that obtained for low, thus affording direct proof that the eye of the sun-fish is a duplex mechanism in the sense postulated by the Duplicity Theory.

**Method**

In a previous paper (Grundfest, 1932) I have reported measurements on the sensibility of the sun-fish to very dim monochromatic lights. Those data were obtained by using as an index the "rheotropic" response of an individual animal to an object moving in its visual field. Measurements were made of the relative energies of various spectral beams which just enable the animal to discriminate a pattern composed of alternate bars and spaces. Such discrimination is evidenced by the orienting response of the fish to a movement of the pattern. In
the present work the spectral visibility function at higher intensities has been
determined in the same way by a suitable modification of this method.

The pattern used for measuring the dim-visibility function was composed of
rather large vertical bars and spaces, since it was desired to study the vision of the
animal as close to the threshold intensities as possible. The present measurements
however are concerned with a brightness level several hundred times above the
threshold. A pattern, to be just discriminable at these intensities, must be com-
posed of very fine elements, as has been shown for the human eye by Koenig (1897).
This relation between light intensity and visual acuity has been further developed
by Hecht (1928) and extended to apply to all visual systems composed of a large
number of unitary receptors (Hecht and Wolf, 1929).

Koenig pointed out that the relation between visual acuity and intensity in-
volves two functions. At low visual acuities and the correspondingly low intensi-
ties, discrimination is accomplished by the rods, while at the higher acuities it is
performed by the cones. The use in these experiments, of a fine pattern corre-
sponding to a high visual acuity makes possible, therefore, measurements of the
sensibility of the sun-fish to spectral lights of intensities far above the threshold.
Since the data are obtained in the same way as those for very dim illuminations,
the results of the two measurements are strictly comparable and it is possible to
decide whether the visual system of \textit{Lepomis} is composed of two functional entities.

\textit{Apparatus}

The experimental arrangement is shown diagrammatically in Fig.
1, and is a modified form of the apparatus described in my previous
paper (Grundfest, 1932). Light from a 500 watt concentrated-fila-
ment lamp illuminates a piece of opal glass, thus furnishing an evenly
radiating source of light. By means of a lens the light from the opal
plate, after passing through 4 cm. of water in a cell, is focussed on a
neutral wedge so that its intensity may be varied continuously. Be-
yond the wedge the light spreads out, being helped in this process by
a negative lens, and is reflected upward by a mirror so as to fall on the
inside of a hollow, truncated 45° cone made of plaster of Paris. From
here the light is diffusely reflected inward through the movable screen
pattern toward the fish which is in a cylindrical glass jar. The glass
jar, the screen pattern, and the plaster of Paris cone rest on a glass-
topped table as shown in Fig. 1.

The movable pattern in the previously mentioned work (Grund-
fest, 1932) was made of a cylinder composed of rather large metal bars.
These gave a very low visual acuity, and made the minimal illumina-
tion at which the fish could discriminate the moving pattern also
very low. The movable patterns in the present experiments consist of fine wire in order that the visual acuity and the corresponding illu-

minations should be much higher than the threshold. Two screens have been made by taping vertically on the outside of a hollow glass cylinder lengths of fine wire spaced about 6-8 mm. apart. The di-

Fig. 1. Diagrammatic arrangement of the apparatus.
ameter of the wire used for Screen A is 0.2 mm. and for Screen B it is 0.1 mm. Discrimination of these patterns corresponds to visual acuities of 0.06 and 0.12 Snellen units respectively.

A spectroscope used as a source of monochromatic radiation does not deliver the high intensities required for the discrimination by the fish of these patterns. Wratten monochromatic filters Nos. 71A to 76 have therefore been employed in conjunction with the 500 watt lamp. They are inserted in the path of the light after the neutral wedge and the spreading lens. The transmissions of these filters were measured with a Koenig-Martens spectrophotometer. The energy distribution of a 1,000 watt lamp was determined by means of a Hilger constant deviation spectrometer, a Hilger linear thermopile, and a Leeds and Northrup type HS galvanometer. The 500 watt lamp used was so similar in color temperature to the 1,000 watt lamp, that I considered the energy distribution in the spectrum of the two as identical for the present purposes.

The relative energy transmitted by the filters in conjunction with the lamp has then been calculated in the following way. The transmission of each filter at any wave-length was multiplied by the relative energy emitted by the lamp at that wave-length. These values were plotted for each filter and the relative areas of each curve measured planimetrically. These areas correspond to the relative total energy obtained from the lamp and the filter. The abscissa at the center of gravity of each curve has been taken as the wave-length of the beam. Table I gives the data for the six filters.

In these calculations, it has been arbitrarily assumed that wave-lengths longer than 700 mp are not effective in the vision of Lepomis. The areas and centers of gravity of filters 71A and 72 have accordingly been calculated on that basis. The visibility function of one animal (5NS) has been determined at very low illuminations with the present arrangement but using the large stripes corresponding to the low visual acuity. This served to test the last assumption as well as the general permissibility of using the rather broad spectral beams obtainable with filters.

The results are shown in Table II. Included in Table II, in the last column, are comparable values taken from my previous work with Lepomis (Grundfest, 1932). The values are secured from the curve
representing the average of thirteen animals, measured with narrow spectroscopic bands, and not with broad filters. It is evident that the results obtained from Animal 5NS by means of Wratten filters resemble closely those previously gotten with the more elaborate apparatus using a spectrometer. The wave-length of maximum effectiveness is near 540 m\(\mu\), about where it was found previously; more-

### TABLE I

Energy transmission of six Wratten filters in conjunction with a 500 watt, concentrated-filament Mazda lamp.

<table>
<thead>
<tr>
<th>Filter No.</th>
<th>Central wave-length (m\mu)</th>
<th>Relative energy transmitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>451</td>
<td>1.00</td>
</tr>
<tr>
<td>75</td>
<td>491</td>
<td>2.05</td>
</tr>
<tr>
<td>74</td>
<td>533</td>
<td>2.05</td>
</tr>
<tr>
<td>73</td>
<td>577</td>
<td>2.38</td>
</tr>
<tr>
<td>72</td>
<td>612</td>
<td>1.33</td>
</tr>
<tr>
<td>71A</td>
<td>660</td>
<td>5.33</td>
</tr>
</tbody>
</table>

### TABLE II

Relative effectiveness of spectral light of very low illuminations as furnished by Wratten filters and by a spectrometer.

<table>
<thead>
<tr>
<th>Wave-length (m\mu)</th>
<th>Log relative energy Animal 5NS</th>
<th>Relative effectiveness For 5NS with Wratten filters</th>
<th>For 13 animals with spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>451</td>
<td>0.113</td>
<td>22.8</td>
<td>25.0</td>
</tr>
<tr>
<td>491</td>
<td>1.947</td>
<td>33.3</td>
<td>81.0</td>
</tr>
<tr>
<td>533</td>
<td>1.578</td>
<td>78.0</td>
<td>81.0</td>
</tr>
<tr>
<td>577</td>
<td>0.282</td>
<td>15.4</td>
<td>11.5</td>
</tr>
<tr>
<td>612</td>
<td>0.523</td>
<td>8.9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

over, the effective spectral portion seems to be quite narrow, as before. The small number of points at which determinations of such a narrow curve could be made with the present arrangement prevents accurate conclusions; but judging by the agreement of the two results and remembering the range of individual variation possible, it seems extremely likely that the use of filters and the neglect of wave-lengths longer than 700 m\(\mu\) are both legitimate procedures.
The control of intensity is effected by an Eastman Kodak balanced neutral wedge which is 20 cm. long and 3 cm. wide. It has a range of 1:1,000. The wedge, securely mounted in a movable, metal carriage has been calibrated photometrically, in terms of the light transmitted at different parts of the wedge corresponding to different positions of the engraved millimeter scale attached to the mounting of the wedge itself. The relation is such that the logarithm of the light intensity transmitted is a linear function of the distance along the wedge. The position of the scale can be read accurately to 0.1 mm., though in these measurements the readings have rarely been to closer than 1 mm.

Procedure

The animals were kept alive in individual, balanced tanks. They have been obtained from the New York Aquarium, through the courtesy of Mr. Breder.

The experimental procedure followed in the present work is very similar to that already described in my study of the spectral sensibility of the sun-fish at low illuminations (Grundfest, 1932). At the beginning of each experiment, a fish is placed in a clean cylindrical jar which is filled with 250 cc. of filtered tap water. The jar is 9 cm. in inside diameter and the depth of the water is about 4 cm. This tank, containing the animal, is then placed on the cone table in the position shown in Fig. 1, and the fish is allowed to become dark adapted for about 2 hours. At the end of this time measurements are begun.

One of the Wratten filters is placed in the path of the light beam, the wedge is set at its densest point, and a shutter is opened, permitting the light beam to fall on the mirror. The hollow glass cylinder which carries the fine vertical line pattern is rotated in either direction. If the animal does not respond, the intensity of the beam is increased somewhat by moving the wedge out about 5 mm. and the cylinder is again rotated. This procedure is repeated until the animal gives a definite orienting reaction. The light is again dimmed by moving the wedge in a few mm. By gradual search the setting of the wedge is determined at which the animal just responds. This scale reading is recorded to the nearest mm. on the wedge scale and the measurement repeated. Then another set of measurements is made for a different Wratten filter in the same way, and the process con-
tinued until all the filters have been tested. There is no regular order in which the filters are used. The time required for a complete experiment is about 1½ hours, exclusive of the adaptation period.

The readings secured are transformed into energy values by the calibrations. These values—as log E—are plotted against their respective wave-lengths, and a smooth curve is drawn through them in order to secure the most effective wave-length. The reciprocal of the energy corresponding to this minimum is given a value of 100 per cent, and the relative percentage effectiveness of the other parts of the spectrum are calculated from it by dividing the energy at the maximum by the energy required at the other wave-lengths.

TABLE III
Relative energy (log E) and relative effectiveness (Eff.) of spectral lights of high intensities for stimulation of *Lepomis*. Data on four animals—3NS, 4NS, 5NS, and 6NS.

<table>
<thead>
<tr>
<th>Wave-length (μ)</th>
<th>Screen A</th>
<th>Screen B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3NS</td>
<td>4NS</td>
</tr>
<tr>
<td>Log E</td>
<td>Log E</td>
<td>Log E</td>
</tr>
<tr>
<td>Eff.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>451</td>
<td>2.303</td>
<td>2.351</td>
</tr>
<tr>
<td>491</td>
<td>2.191</td>
<td>2.413</td>
</tr>
<tr>
<td>533</td>
<td>1.383</td>
<td>82.6</td>
</tr>
<tr>
<td>577</td>
<td>1.343</td>
<td>90.6</td>
</tr>
<tr>
<td>612</td>
<td>2.043</td>
<td>18.1</td>
</tr>
<tr>
<td>660</td>
<td>2.828</td>
<td>3.0</td>
</tr>
</tbody>
</table>

RESULTS
In order to make these measurements of quantitative significance, it is necessary to observe one important precaution. Koenig and Ritter (1891) have obtained visibility curves intermediate in shape between that of the rods and that of the cones, merely by using an
intermediate brightness level in their measurements. This effect, indeed, is the basis of their explanation for the Purkinje phenomenon. It is therefore important to ascertain that the measurements with...

![Graph](https://via.placeholder.com/150)

**Fig. 2.** Cone visibility function for Animal 6NS determined at two brightness levels. The solid circles are for a visual acuity of 0.06; the clear circles for a visual acuity of 0.12. In the former case the points have been raised 0.2 units on the log E ordinates to permit superposition of the two sets at 577 μm.

*Lepomis* are made at an intensity level which assures the determination of the cone curve alone and not of an intermediate condition.

It is for this purpose that the pattern of Screen B was made. The
visual acuity corresponding to it is twice that of Screen A, and therefore demands still higher illuminations in order to be resolved by the animal's eyes. Animal 6NS was measured with both screens. The data are given in Table III, and are plotted in Fig. 2. The curves obtained in both cases are identical if allowance is made for the higher intensity level in the measurements with the finer screen. This is shown in Fig. 2 where a constant is added to the values of log E for

![Graph of Cone visibility functions of Animal 5NS (clear circles) and 4NS (filled circles). The latter values are raised by 0.45 unit on the log E ordinates. The upper figure is obtained from the average log E curve.](image-url)
Set A (filled circles). This constant is so chosen that one point in each set (double circle, 577 m\(\mu\)) becomes identical; its value is 0.2 unit on the log E scale. The clear circles are the values obtained with Screen B. Both sets of data give the same visibility curve, showing

![Graph showing cone visibility](image)

**Fig. 4.** Cone visibility (clear circles) of Animal 3NS. The solid circles are the data for Animal 8 (Grundfest, 1932, Fig. 6, lower half) shifted 30 m\(\mu\) toward the red.

that the measurements made with Screen A represent the cone visibility function and not an intermediate condition.

Using Screen A only, I measured three other animals in addition to Animal 6NS. The measurements are all given in Table III. Several sets of measurements have been made with Animal 5NS. They are shown in Fig. 3 together with the data for 4NS (which have been raised 0.45 unit in the figure). This curve is much narrower than
that for 6NS and probably represents a condition comparable to that found in most measurements on the rod visibility function. The data for Animal 3NS are of particular interest and will be discussed fully in the following section. They are plotted in Fig. 4 (clear circles). The visibility curve for this animal is much broader and more regular than those of the other animals.

In every case, the wave-length of maximum efficiency at high illuminations is further to the red than is the corresponding maximum for vision at low illuminations. The previous work with *Lepomis* showed the dim vision maximum to be at 540 m\(\mu\). As can be seen from the figures the maximum for high illuminations does not occur at the same wave-length in all the animals. In the case of Animal 3NS it is 30 m\(\mu\), and in the case of the other animals it is 60 m\(\mu\) further toward the red than is the maximum for the rod visibility function. The reason for this difference will be discussed later. At present, it is important only to note that the difference between the visibility curves at the two intensity levels clearly shows that there are two photosensory systems in *Lepomis* each having a different sensibility to spectral lights. One of these systems is responsible for dim vision and is presumably composed of the rods. The other system is predominantly active in bright illumination, and probably is composed of the cones. It will be recalled that a similar difference in the position of the maximum of the cone and of the rod visibility curves is also found in human vision.

**DISCUSSION**

In comparing the visibility curve of *Lepomis* at low illuminations with the absorption spectrum of its visual purple, it was found (Grundfest, 1932) that the visibility curve is very much narrower than the absorption curve. To account for this difference in the shape of the two curves I have suggested the hypothesis that the eye of *Lepomis* contains, in addition to visual purple, two light-absorbing, but not light-sensitive, pigments. These act as spectral filters and distort the shape of the visibility curve out of agreement with the form demanded by the absorption spectrum of the visual purple. One of these pigments is not identified but it is suggested that the second may be carotin. The first is assumed to be relatively fixed in quantity while
the concentration of carotin is known to vary with the physiological condition of the animal. Among the evidence presented for this hypothesis have been the visibility curves of one animal (No. 8) which were taken several weeks apart. The first of these curves 8I closely approached on the short wave side the curve predicted from the absorption spectrum of fish visual purple. On the right side of the maximum it agreed with the curves found for the other animals. Two later measurements showed a gradual change in the left portion of the visibility curve until the entire function became similar to that obtained with the other twelve animals. From these data it was concluded that the visibility function at low illuminations tends toward agreement with that demanded by the absorption spectrum of the visual purple when the complications produced by the light absorbing pigments are eliminated.

This interpretation can also be applied to the data here given on the cone visibility function. Though a quantitative treatment of the variations in the visibility function is not possible, certain points may be cleared up. For example, in one case we can compare the rod and the cone visibility curves in an approximate way. This comparison can be made between the data for Animal 3NS (cone visibility) and for 8I (rod visibility) given in full detail in my previous paper. The comparison is shown, graphically, in Fig. 4. The clear circles represent the cone function data of 3NS while the filled circles are the rod data of 8I. In the latter case, the wave-lengths have been increased by 30 m$m\nu$ while the two arbitrary log $E$ scales have been made equal by adding 0.6 unit to the rod values. As mentioned above the data for Animal 8I have been found to approach the theoretical rod visibility function on the short wave-length side of the maximum. Remarkably good agreement is evident between the two sets of data, considering that, in one case, broad filter bands and, in the other, very narrow spectral bands have been used.

This agreement must not, however, be pressed too closely. I believe it indicates clearly that the undistorted cone curve is similar to the rod curve but shifted toward the red. The magnitude of the shift cannot be safely stated from these measurements, since it is assumed that there is still present one pigment which distorts the long wave portions of both curves. The absorption spectrum of this pigment most
likely does not change in the two cases and an error is introduced by moving the rod curve to coincide with the cone data. The shift is certainly 30 m\(\mu\) and most probably greater, because the remaining pigment would tend to distort the point of maximum efficiency, moving it toward the short wave end. Unfortunately the rod function of 3NS, which could have furnished material for an adequate comparison, was not determined.

The foregoing indicates that the cone visibility function of *Lepomis* is similar to its rod function but shifted toward the red. The rod curve is determined by the absorption spectrum of visual purple. It therefore seems likely that the form of the cone curve is also fixed by a photosensitive substance whose absorption spectrum is similar to that of visual purple but displaced some 30–60 m\(\mu\) toward the red. As I have mentioned above, this same relation occurs also between the rod and cone systems of man; Honigmann (1921) finds a similar behavior in the case of the fowl.

The visual purple found in fish, however, is different from that of the hen and the human (Koettgen and Abelsdorff). We are therefore confronted with an interesting situation. On the one hand, we know that rod vision is mediated in fish by one kind of visual purple and in the other vertebrates by a second type. On the other hand, the cone visibility curve of each group is similar in form to its particular rod curve and both types of cone curves are displaced in the same direction relative to their rod curves. Is there any relation between the sensitive substances responsible for rod and for cone vision, which would account for the similarity in the shapes of their visibility curves and also for the similar displacement which each cone function undergoes with respect to its corresponding rod function? It is of course conceivable that these results are purely fortuitous. However, it must be remembered that the simultaneous occurrence of two coincidences is fairly rare. Yet this is exactly what must be assumed upon such a theory. According to this view we find two vertebrate groups having different visual purples. In each of these groups has arisen an independent cone photosensitive substance.\(^1\) The first co-

\(^1\) For simplicity, I have neglected the possibility of subdivisions in the sensitive substances. Such subgroups are presumably so closely related that they can be at present considered as behaving like an entity.
incidence arises from the fact that the absorption spectrum of each cone substance is similar to the absorption spectrum of the corresponding visual purple. The second coincidence concerns the fact that each cone curve is displaced along the spectrum with regard to its rod curve in an identical manner. Although such a series of chance occurrences is possible, it seems more likely that the appearance of identical phenomena in two different photochemical systems may be due to one and the same fundamental cause.

With relation to the similar shapes of the human rod and cone visibility curves, Hecht had suggested (Hecht and Williams, 1922) that visual purple is the common photosensory substance of both rods and cones. He explained the displacement of the cone curve toward the red end of the spectrum as due to a difference in the densities and refractive indices of the media in which the visual purple is dissolved. This is an application of Kundt’s rule, which states that the absorption spectrum of a substance dissolved in different media is shifted toward the red in the medium of higher density. Even though Hecht (personal communication) no longer subscribes to this idea, the suggestion in my opinion still merits serious consideration. Such a hypothesis simplifies the problem as to why the different photochemical systems which are present in the eye of man and in fish, respectively, behave in a parallel manner. The answer, according to this hypothesis, is that there are only two different chemical substances which behave in a similar manner because of like relations between the solvent media in their respective rods and cones. The shift of the two cone curves is thus ascribed to a single physical factor, namely the greater density of the solvent media in the cones.

On first glance, there is a serious objection to the view that the photochemical substances of the rods and cones are identical. This arises from the fact that the Young-Helmholtz theory of color vision postulates three distinct cone substances having different absorption spectra, while visual purple is generally assumed to be a single entity. This objection disappears on closer examination. Hecht’s modification of the trichromatic theory (Hecht, 1930) calls for three sensitive substances which have nearly identical absorption spectra and are closely related in chemical composition; they may perhaps even be derived in development from the same precursor. It is the sum of
their absorption spectra which determines the cone visibility function. There is no inherent difficulty in assuming that the rod sensitive substance is also the sum total of these three components. It is immaterial, for present purposes, whether these are assumed to be intimately mixed in each rod, or whether they are supposed to be separated among different rods, as is presumably the situation in the cones. Since the rods differ fundamentally from the cones in that their cerebral termini produce on stimulation an achromatic sensation of brightness, either type of distribution would give the same end result.

The above hypothesis may possibly be submitted to an experimental test. It is assumed that the rods contain, just as do the cones, the three modifications of visual purple. According to modern ideas (Hecht, 1930), color blindness is a condition in which one color sensitive substance is replaced entirely or in part by another. This would mean here that one modification of visual purple is replaced by another. In the case of color-blinds, therefore, the rod visibility curve should undergo modifications similar to those found for the cone luminosity curves. An adequate test of this point involves a series of measurements with a higher degree of precision than was possible in the older data of Koenig (1903). However, it is doubtful whether any significant results could be obtained, because the changes in the visibility function which are to be predicted in color-blinds from Hecht's V-G-R curves are so slight that they easily fall into the range of variability found for normal trichromatic individuals.

In conclusion, I wish to thank Professor Selig Hecht for his help and encouragement during this investigation.

**SUMMARY**

1. An extension of a previously described method makes possible the measurement of the visibility function of *Lepomis* at high intensities of spectral illumination. This is accomplished by determining the relative energies of various spectral beams which will just produce a visual orienting response by the animal to the movement of a pattern composed of fine lines.

2. The function so determined is different from that obtained with a pattern composed of wide bars and spaces at a lower intensity level.
3. This difference furnishes direct and quantitative proof that the eye of *Lepomis* is a physiologically duplex visual system and parallels the known anatomical distinctions between the rods and cones.

4. A comparison of the visibility curves of the two systems indicates that both functions are similar in shape but that the cone curve is shifted to the red.

5. It is suggested that this relation between the two systems, which is also found in the human and the fowl, indicates that the photosensory substance is the same in each case for the rods and cones. According to this hypothesis, the shift of the cone curve is due to a common physical cause which depends on differences in the properties of the solvent media in the cones and in the rods.

BIBLIOGRAPHY


