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LIGHT SPECTRUM PREFERENCE IN THE EUROPEAN EEL *ANGUILLA ANGUILLA* (L.)

Wojciech Kuliński, Ewa Styczyńska-Jurewicz***

*Marine Biology Center, Polish Academy of Sciences, Gdynia, Poland
**Institute of Biology and Environmental Protection, Pomeranian Pedagogical Academy, Słupsk, Poland

ABSTRACT. This paper reports the results of a supplementary study to research conducted previously on the stimulating effect of defined spectral ranges of light on the growth rate of the European eel *Anguilla anguilla* L. The aim was to study the eel's potential selectivity and behavioral preference for defined light band wavelengths which are recognized as optimal colors. Eel specimens from a wild population were acclimatized in a laboratory for six months under natural daylight conditions. Five randomly selected specimens were then held in an aquarium divided into four compartments. Each compartment was irradiated for 7 h daily with tungsten bulb light that was transmitted through a glass filter of a specific transmission band (white, red, violet and green). The fish could enter any of the compartments and stay in them at will. The intensity of irradiance measured at the central point of each compartment was maintained at a standard level. During the 105-day experiment, 61 records of fish distribution in the particular compartments were obtained. Individual preferences for definite colors were estimated statistically. The eels gathered twice as frequently in the compartments irradiated with violet and green light than in those irradiated with white or red. The tendency for them to congregate in groups was also significantly higher in violet and green light than in white or red ($P < 0.001$). The lighting preferences are considered to be optimal for the biology of this species.

Key words: EUROPEAN EEL (*ANGUILLA ANGUILLA*), LIGHT SPECTRUM, BEHAVIORAL PREFERENCE

INTRODUCTION

Every animal species has its own optimal range of light wavelength and intensity which is most favorable for its life (Reiter 1994). Fishes also distinguish colors and display specific differences in sensitivity to wavelength (Thorpe 1978, Head and Malison 2000). Spectral sensitivity in fishes depends to a certain degree on environmental factors (temperature), age, particular differences in the anatomy of the light detecting organ (the retina), as well as on endogenous physiological factors such as some hormones, mostly melatonin (Mc Farland and Loew 1983). This sensitivity is correlated with changes in the quantitative proportions of particular visual pigments. It also depends to some degree on seasonal variation in solar irradiance and corresponding seasonal changes in the spectral composition of light penetrating the aquatic environment (Muntz and Wainwright 1978, Forster 1981, Lythgoe and Partridge 1991).

Various fish species see and prefer to stay in light waves of a definite length (color), depending on the photochemical properties of the physiological visual process and on the ability to synthesize a suitable visual pigment. In most cases, the pigment is a retinoid bound to a protein and has a definite light absorbency which determines the sensitivity of the fish eye (Stell and Harosi 1976, Cameron 1982, Neumeyer 1984, Byzov et al. 1998). Deep-sea fishes in the Atlantic Ocean which live at depths of 500-4000 m have visual pigments whose maximal absorbency falls within a relatively short wavelength range of 468-494 nm (Douglas et al. 1998). According to data reviewed by Losey et al. (1999), teleosts may have as many as 3-4 types of photosensitive cones with different spectral response in their retinas. Kobayashi (1962) reported two different sized cones (long and short) in the eel retina. The response of the retina cones and rods depends upon both light intensity and wavelength (Ali 1992, Wang and Mangel 1996).

The aim of the present study was to test the supposed preference for defined spectral ranges in the European eel *Anguilla anguilla* (L.). Previous studies on the effect of light spectrum on the growth of eel (Kuliński and Styczyńska-Jurewicz 1993) indicated that eel held in green and violet light had better growth rates than those held in white or red. Therefore, the working hypothesis of the present study was that eels would select, visit and demonstrate a preference in the above mentioned "optimal" lighting if the experiment provided them with the opportunity to choose a suitable spectral range.

MATERIAL AND METHODS

Yellow stage eels (ca 40 cm long) from a wild population were caught in the Vistula River and then acclimatized to laboratory conditions for six months. The eel were held in aerated aquaria in natural solar lighting transmitted through a window and were trained to take food served with forceps. They were fed once daily. The food consisted of thawed pieces of beef spleen (Bieniarz et al. 1978). All unconsumed food was immediately removed from the aquarium. After acclimatization, five specimens (the minimum number which permits statistical estimations) were selected at random and held in an experimental aquarium located in a dark room. The 50-liter aquarium was divided into four separate compartments by solid, wooden walls. Each compartment was irradiated with a different light beam - white (total VIS), green (λ max. 520

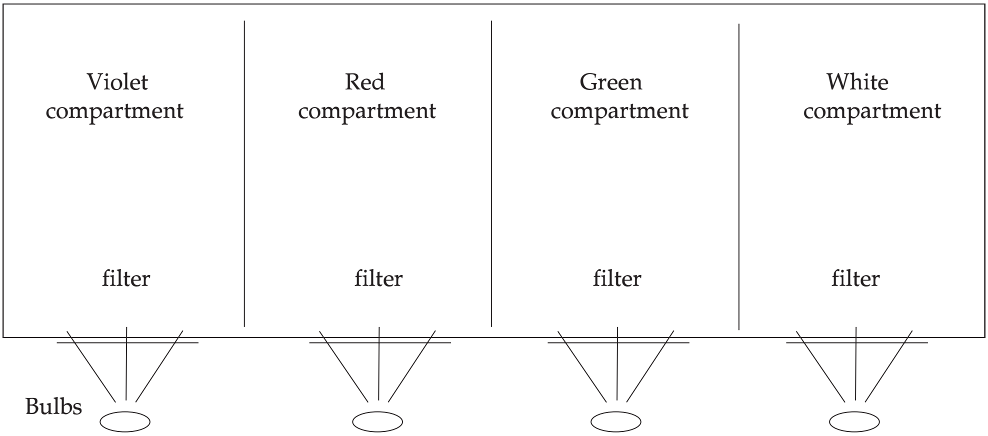

Fig. 1 Lighting scheme in the experimental aquarium.

nm), violet (λ max. 380 nm) and red ($\lambda > 700$ nm). The light from tungsten bulbs was transmitted through Jena glass filters mounted on the transparent wall of each compartment (Fig. 1). The transmission spectra of the filters are shown in Fig. 2. Either 70 or 150 W tungsten bulbs were mounted at an adjustable distance from the filters to maintain the transmitted light intensity at a standard level, as follows:

$$3\ 10^{17} \text{ quanta m}^{-2} \text{ s}^{-1} = 4.98\ \mu\text{E m}^{-1} \text{ s}^{-1}$$

The underwater irradiance measured in the central point of each compartment was adjusted to this standard level (chosen on the basis of our previous experiments) using a Sonopan FF-O1 phytophotometer. The fishes were free to swim around, change place and enter different compartments of the aquarium (Fig. 1).

During the 105-day period (March 23 to July 5), the frequency of how often the eels chose to be in a given compartment was recorded randomly; 61 such observations were performed. All manipulations (serving food and/or frequency counting) were conducted very quietly under low intensity red lighting switched on in the dark room just long enough to complete the task so as not to disturb the eel.

The frequency with which the eel chose to be in the differently irradiated compartments and the distribution of individual preferences for light color were evaluated statistically with the χ^2 test, and the frequency of groups was evaluated using the G independence test (Statistica).

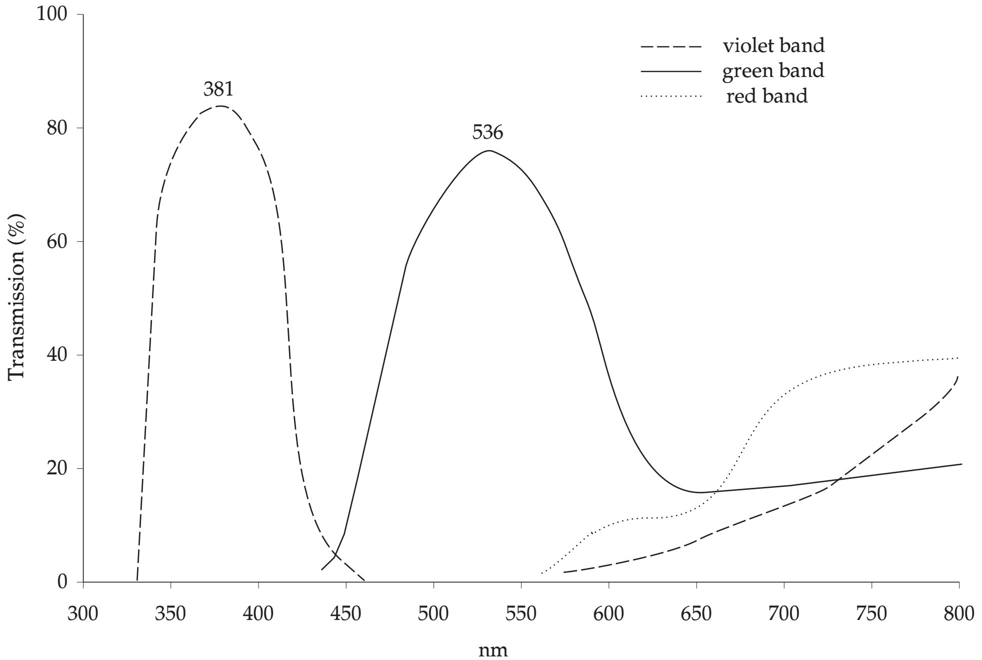

Fig. 2. Spectral ranges of the light transmitted through the filters used in the experiment. All the glass filters transmit some amount of long waves.

RESULTS

The χ^2 test showed that frequencies in particular compartments differed significantly ($\chi^2 = 28.757$; $P < 0.001$), Table 1, Fig. 3 .

TABLE 1

Frequency of eel specimens in particular lightings (61 registrations)

Color of lighting	Violet	Green	Red	White
Number of specimens registred in a comparment	106	93	50	56

The frequency of groups (i.e. the occurrence of 2-5 specimens in a compartment) analysed with the G independence test was significantly different ($P < 0.001$) in compartments irradiated with violet and green light in comparison to those with white or red lighting. A two-specimen group was observed in violet light 17 times and in green 22 times. However, an absence of eel was recorded 26 times in red light, while in

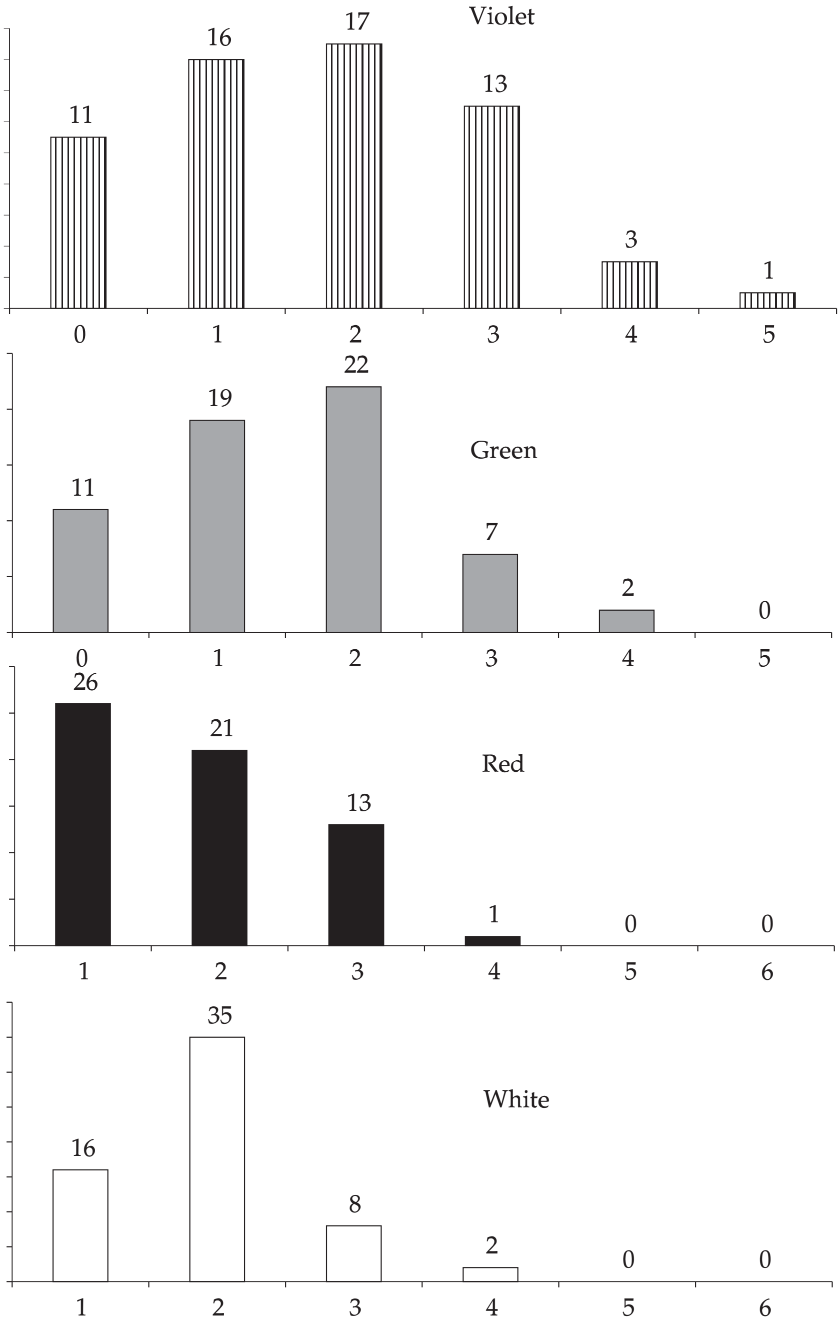

Fig. 3. Distribution of fish frequencies in separate compartments. Bars and numbers at the top shows how frequently they were registred in different lightings: no specimens (0), single (1) or groups of (2, 3, 4, 5) specimens.

white light single specimens were noted as frequently as 36 times. Groups consisting of four specimens occurred in violet and green light three and two times, respectively. A group of five was recorded once in violet light.

Thus, a behavioral preference for violet and green light was evident in the experimental eels indicating that these light bands are optimal and suit well the biological requirements of this species at the yellow stage of development.

DISCUSSION

At the yellow stage, feeding eels have a prevalence of the most sensitive visual pigments at wavelengths of 501-502 nm (rhodopsin) and 523 nm (porphyropsin). The green light prevailing in eutrophicated marine and inland waters is absorbed well by both pigments (Jerlow 1978). Another visual pigment with a shorter wave absorbency (chrysopsin -λ max. 482 nm) is prevalent in silver eel which migrate to spawn in clean, deep seas (Dartnall 1962, Kobayashi 1962, Beatty 1975).

According to Losey et al. (1999), many teleosts could also have an UV-absorbing pigment (λ max. 360 nm). However, as far as we are aware, its presence in the eel has not been documented as yet. The strong preference of the eels in the present study for the short wavelength violet light might be linked to this UV-absorbing pigment with a slightly extended range of absorbency, which included part of our violet band (see Fig. 2).

The second light perception organ in the eel, as in other fishes, is the pineal gland (epiphysis or the "third eye") which functions mostly as a neuroendocrine organ. One of its products, the hormone melatonin, is closely linked to the biological clock and is responsible for the diurnal and seasonal regulation of physiological circadian rhythmicity (Nowak et al. 1989, Bolliet et.al. 1994, Pickard and Tang 1994, Popek et al. 1997). A simple behavioral method used in the present study did not permit conclusions to be drawn regarding the potential involvement of the pineal gland in the distinct spectral preference observed in the eel. The answer to this question requires a separate study and the application of methods used routinely in fish endocrinology. Nevertheless, some data in the literature suggest that the foregoing approach was appropriate. According to Kezuka et al. (1988), melatonin may influence spectral sensitivity in carp and goldfish. Other light-absorbing regions in fish are probably some layers of the skin. The main photosensitive region is the side line canal, located between the epithelium and the scales. Neuromasts, or sensory cubs, occur in this canal (Lager et al. 1977). Since the eel does not have any visual pigment to absorb red light, it is possible that the only receptors able to respond to red and infrared irradiance occur in the skin (detected by fish most probably as a thermal cue). In the present study this cue was undetectable due to the method used. Nevertheless, the frequency with which the eel visited the red light chamber remained 100% lower than that in the violet or green ones (Table 1). Similarly, no preference was observed for the total VIS range (white light). The former contains a certain share of violet and green beams, but perhaps the intensity of the preferred bands in the total VIS spectral range in this study was too low to evoke a behavioral response in the eel.

The formation and distribution of fish groups analysed with the G test showed that the eels were not only able to select an optimal light color, but they also exhibited a tendency to stay longer in it. The behavioral preference of green and violet spectral ranges documented in the present study confirmed the importance and suitability of these light bands for biological fitness and the natural life requirements of the eel. The experience of our previous studies, which detected the stimulating effects of the above light colors on food consumption and somatic growth in European eel (Kuliński and Styczyńska-Jurewicz 1993, Kuliński 2000), allows us to recommend violet and/or green lighting in intensive eel aquaculture conducted in a limited space.

CONCLUSIONS

1. Yellow stage eels detect, select and exhibit a preference for violet (λ max 380 nm) and green (λ max. 536 nm) light bands.
2. The frequency with which the fish exhibited a preference for red and white light was lower by 100%.
3. The experiment proved that violet and green light bands are optimal and suit the biological requirements of the eel well.

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STRESZCZENIE

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W uzupełnieniu wcześniej przeprowadzonych badań nad stymulującym wpływem światła zielonego i fioletowego na wzrost węgorza europejskiego, *Anguilla anguilla* L., przeprowadzono eksperyment, który miał wykazać, czy w świetle zróżnicowanym pod względem długości fali istnieje u węgorza wybiórczość w stosunku do pewnych barw tego światła. W akwarium z węgorzami wydzielono 4 przedziały, pomiędzy którymi ryby mogły się swobodnie przemieszczać. Każdy z przedziałów był oświetlany światłem o innej długości fali (czerwonym, fioletowym, zielonym i białym) dzięki transmisji przez szklane filtry nałożone na ściankę akwarium. Stosowano fotoperiod: 7 godz. światła / 16 godz. ciemności. W ciągu 105 dni dokonano ogółem 61 losowo przeprowadzonych rejestracji przebywania w spektralnie różnym oświetleniu 5 osobników losowo wybranych z aklimatyzowanej w laboratorium dzikiej populacji. Dane uzyskane z rejestracji częstotliwości przebywania ryb w poszczególnych przedziałach o różnych barwach oświetlenia wskazują na wyraźną preferencję behawioralną węgorzy w stosunku do światła fioletowego i zielonego. W oświetleniu fioletowym i zielonym węgorze przebywały częściej i dużo częściej tworzyły liczniejsze zgrupowania niż w oświetleniu białym i czerwonym. Test χ^2 oraz G test (niezależności) wykazały wysoce istotne statystyczne różnice we frekwencji ryb w preferowanych barwach światła (fioletowej i zielonej) w porównaniu ze światłem białym i czerwonym ($P < 0{,}001$). Proponowane jest praktyczne zastosowanie wyników w akwakulturze węgorza.

CORRESPONDING AUTHOR:

Prof. dr. hab. Ewa Styczyńska-Jurewicz
Instytut Biologii i Ochrony Środowiska
Pomorska Akademia Pedagogiczna
ul. Arciszewskiego 22B
76-200 Słupsk