マグロ･カジキ類の色覚と分光感度

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Color Vision and Spectral Sensitivity in Tunas and Marlins[*1]

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To determine the presence of color vision in tunas and marlins, S-potentials were recorded from the isolated retinae of yellowfin tuna, bigeye tuna, albacore, striped marlin, Pacific blue marlin, and black marlin. No chromaticity type S-potential was recorded. This finding indicates that these fishes are probably color-blind. The distribution of relative amplitude at each stimulus wavelength obtained from the records showed that the maximum sensitivity is at wavelengths between 492 and 522 nm in albacore and between 458 and 492 nm but closer to 492 nm in the others.

Dependence on vision in tunas and marlins is well known[1,2]. While it is very common among tuna fishermen to use colorful lures shaped like squid or fish, color vision and shape discrimination in tuna are not known. A great many fishermen and fisheries biologists have attempted, and failed to find more effective fishing baits or artificial lures for tuna or marlin line fishing. One reason why their attempts have not always been successful is the lack of adequate information on behaviour and sensory physiology of these fishes.

It has been shown that the S-potential is a good indicator of spectral sensitivity and color vision in fish[3,4] and has in fact been found useful in studies on many teleosts and sting ray[4–10]. We conducted the present study to determine the presence of color vision in tunas and marlins, with the use of electrophysiological technique.

Materials and Methods

The experiments were carried out in May–July 1975, 1978 and 1979 on boarding the Kagoshima Maru, the training boat of the Faculty of Fisheries, Kagoshima University. The species studied were the yellowfin tuna *Neothunnus albacora,* bigeye tuna *Parathunnus sibi,* albacore *Thunnus alalunga,* striped marlin *Makaira mitsukurii,* Pacific blue marlin *Makaira mazara* and black marlin *Istiomax indicus.* Specimens were captured alive by long-line in the Indian Ocean.

S-potentials were recorded from the isolated retinae of the fish. The procedure and apparatus for recording S-potential have been described previously[8]. A glass capillary microelectrode filled with 3 M KCl was used as the recording electrode. The electrical potentials were amplified, displayed on a cathode-ray oscilloscope and photographed for later analyses. The photostimulator employed was designed to produce 11 colored light (almost monochromatic) of equal energy for all wavelengths. The apparatus was placed on a rubber cushion to minimize the vibration due to the engine. The eye without sclera was so soft that the recording was much disturbed by the pitching and rolling of the boat, so in 1979, S-potentials were recorded from retinae cut into small pieces around 3 cm in diameter.

Results

S-potentials are classified into two major types from their response pattern to spectral light. Those responding only with hyperpolarization to all wavelengths of light are called the "luminosity type ' (L-response); those in which the polarity is wavelength-dependent are called the "chromaticity type" (C-response).

In yellowfin tuna, we observed and recorded responses of about 500 cells from the retinae of

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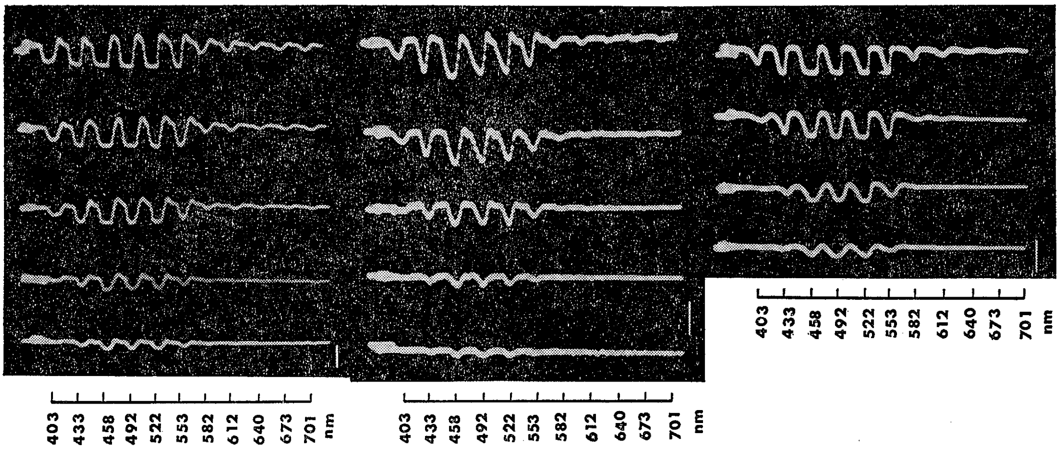

Fig. 1. Spectral responses of S-potential for three tunas, arranged in order of decreasing stimulus from top to bottom. Left, yellowfin tuna; middle, bigeye tuna; right, albacore. Calibration, 10 mV.

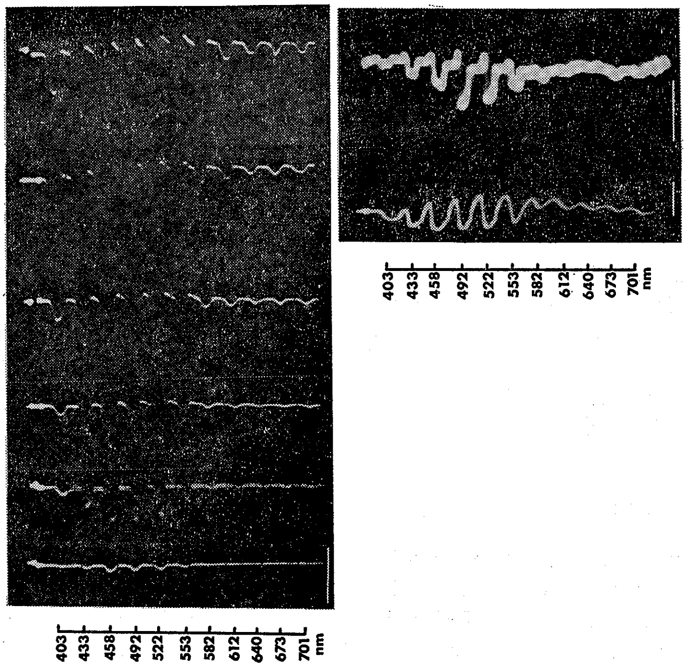

Fig. 2. Spectral responses of S-potential for three marlins. Left, black marlin; right upper, striped marlin; right lower, Pacific blue marlin. Calibration, 10 mV.

21 fish. All responses showed simple hyperpolarization at all wavelengths and no C-response. We investigated not only the outer horizontal cells but also the inner cells, said to be responsible for the C-response. There just was no C-response. Similar results were obtained in the other species. Figs. 1 and 2 show the spectral responses recorded in the six species. The amplitude of response was higher at blue and blue-green decreasing toward either side of the spectrum, more remarkably toward the longer wavelengths.

We estimated the spectral sensitivity from the distribution of the relative amplitude obtained from the records in 1979. It is common to base the spectral sensitivity on the amplitude-intensity for various wavelengths, but we had to consider the

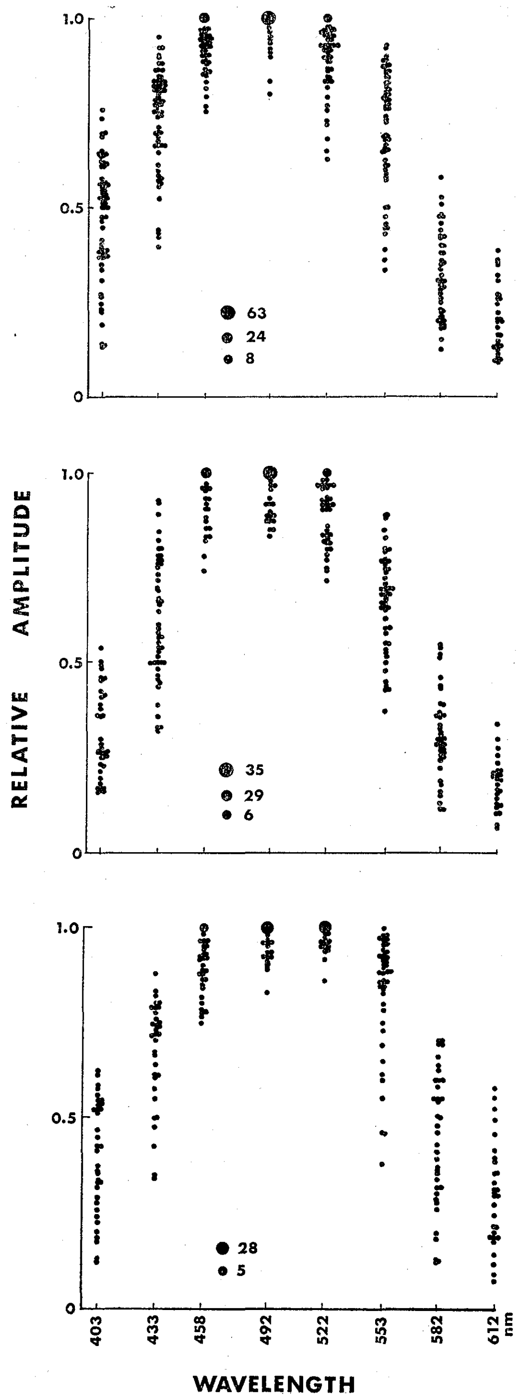

Fig. 3. Distribution of relative amplitude at each stimulus wavelength for tunas. Figures beside larger closed circle show the number of frequency. Top, yellowfin tuna; middle, bigeye tuna; bottom, albacore.

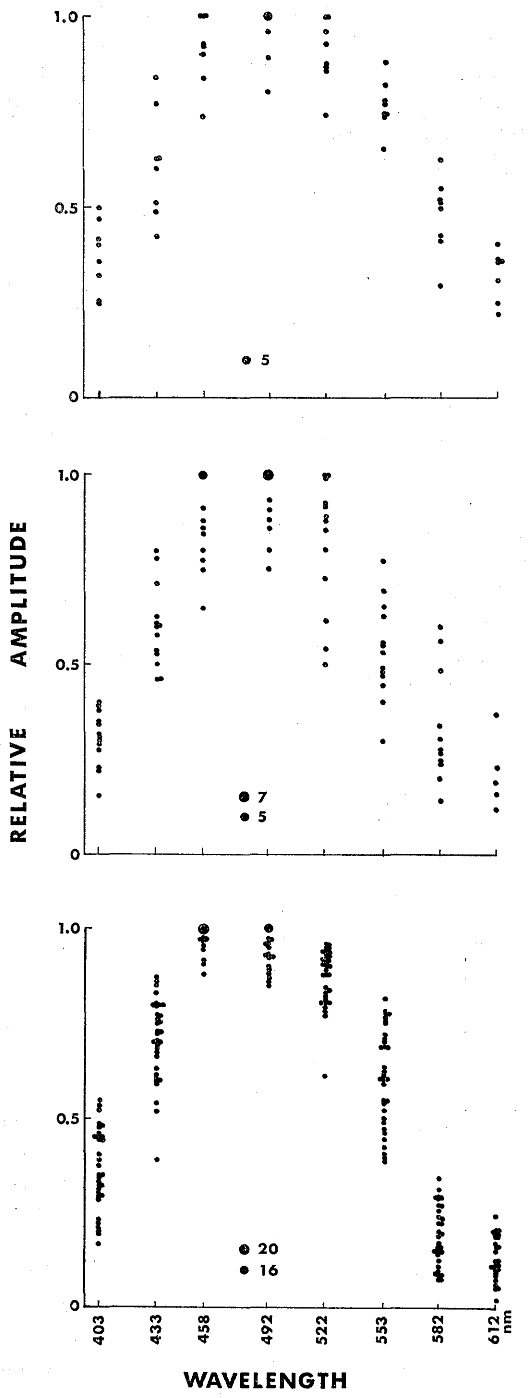

Fig. 4. Distribution of relative amplitude at each stimulus wavelength for marlins. Top, Pacific blue marlin; middle, striped marlin; bottom, black marlin.

effect of boat motion in our records. From Fig. 3 and 4, it can be said that the maximum spectral sensitivity is between 458 and 492 nm, closer to 492 nm in yellowfin tuna, bigeye tuna, and the three marlins. In the albacore, maximum sensitivity shifts to 492–522 nm.

Discussion

The absence of C-response, that is, absence of color vision in the tunas and marlins studied is a surprising fact, if only for the fishermen who had tried to use as colorful baits and lures as available and thought they were successful about it. TESTER and NAKAMURA[11)] analysed catch records of tuna trolling and showed that there was in fact no preference for any color nor form of lure. It is well-known that the species studied could be captured by line at night, although the efficiency is lower than in daytime[12)]. The stomach contents of captured fish show that these fishes are active even at nighttime[13)]. The fishes' body color patterns, considered to have some meaning in interspecific or intraspecific communication[14,15)], are not particularly colorful. Since these fishes inhabit great depths, their visual habitat is presumably far from colorful. All these behavioural features and observations seem to agree with the electrophysiological fact—color blindness. Agreement is also shown by the study of MUNZ and MCFARLAND[16)]. They found only a single visual pigment in retinal extracts of wahoo, yellowfin tuna, little tuna, black marlin, and *Makaira ampla.* The total range of λ_{max} in the visual pigments of these fishes was only 482–486 nm. TAMURA *et al.*[1)] recorded S-potentials from skipjack tuna, little tuna, and frigate mackerel; they found no C-response, and concluded that the fishes were color-blind.

According to JERLOF[17)], water acts as monochromator for blue light, and the spectral distribution curves for clear water are peaked in blue light, with the ultra-violet fairly strong even at great depth. From the spectral sensitivity determined by electroretinograms in many fishes, KOBAYASHI[18)] found an obvious correlation between the sensitivity maximum and the maximum depth at which the fishes were found, that is, the sensitivity maximum tended to shift toward the shorter wavelength with increase in depth. SVAETI-

Table 1. Records of the muximum range of vertical distribution in tunas and marlins determined by fish finder or fishing line

Species	Maximum depth in m	Fishing ground	Method	Author
Yellowfin tuna	200	South China Sea	Fish finder	SHIBATA and NISHIMURA[20)]
	500 or more	Indian Ocean	do.	YUKINAWA *et al.*[21)]
	150	West Pacific	Fishing line	NAKAGOME[22)]
	200	East Pacific	do.	KYU[23)]
	250	Middle Pacific	do.	MIYASAKI[24)]
	278	South Pacific	do.	IWASA[25)]
Bigeye tuna	300	East Pacific	Fish finder	SHIBATA and NISHIMURA[20)]
	500 or more	North Pacific	do.	YUKINAWA *et al.*[21)]
	380	South Pacific	Fishing line	SAITO *et al.*[26)]
	245	Middle Pacific	do.	SAITO[27)]
	250	West Pacific	do.	HISADA and MORITA[28)]
Albacore	380	South Pacific	Fishing line	SAITO[27)]
	334	do.	do.	IWASA[25)]
	500 or more	Indian Ocean	Fish finder	YUKINAWA *et al.*[21)]
Bluefin tuna	400 or more	North Pacific	Fish finder	SHIBATA and NISHIMURA[20)]
Striped marlin	340	South Pacific	Fishing line	SAITO *et al.*[26)]
	200	East Pacific	do.	KYU[23)]
	193	South Pacific	do.	IWASA[25)]
Pacific blue marlin	250	Middle Pacific	Fishing line	MIYAKI[24)]
Black marlin	180	East Pacific	Fishing line	KYU[23)]
Broadbill swordfish	380	South Pacific	Fishing line	SAITO[27)]
	240	West Pacific	do.	HISADA and MORITA[28)]

CHIN and MACNICHOL[19] showed the same tendency based on S-potential. Our results agree with these findings. The spectral sensitivity maximum occurs in the blue range for yellowfin and bigeye tuna and the three marlins. The vertical ranges of these species have been determined by means of specially-designed deep sea lines and fish finders and are known to extend from surface down to 500 m or so[20-28] (Table 1). The difference in the sensitivity maximum in albacore can not be explained on the basis of the spectral characteristics of the environment, as NIWA[6] had done for two groups of freshwater ugui *Tribolodon hakonensis*, because the vertical range of distribution of albacore overlaps with those of the other five species. According to SAITO[28], albacore feeds more actively in deep waters. There thus must be a phylogenetic explanation for this observed difference.

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