

Vision in Tunas and Marlins

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Abstract

To obtain a fundamental knowledge of the vision of tunas and marlins the brains were observed morphologically, and the retinae were examined histologically and electrophysiologically. Tunas and marlins have an extremely well developed optic tectum indicating that vision is very important to them. The S-potentials recorded from the retinae showed that tunas and marlins are probably color-blind. The retinae has cones (predominantly twin cones) in parallel arrangement, 3 layers of horizontal cells, no fovea nor well-developed area. Dense retinal tapetum was found in the bigeye tuna. Visual acuity determined from cone density ranged from 0.3 to 0.5, which is the highest among fishes. It is believed that the retinae of these fishes are advantageous for movement perception, and that their eyes are well adapted to the low light levels in the lower limits of their vertical distribution (ca. 500m). Sight feeding was confirmed by experimental fishing by longlines with inedible artificial lures.

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I. INTRODUCTION

Tunas and marlins widely inhabit oceanic and coastal waters in the Pacific, Indian, and Atlantic Oceans, and are of high commercial value. To predict changes in their distribution and abundance, systematic scientific work has been conducted, mostly as oceanographic investigations in fishing grounds. Such work began in Japan in the early 1930's, and in the USA in the early 1950's, since then these nations and others have been increasingly involved. The activities were reviewed by BLACKBURN (1965), NAKAMURA (1965), KAWAI (1969), SUDA *et al.* (1969), SHINGU (1970), and UDA and NAKAMURA (1973). At the same time, subsistence and commercial fishermen have worked to devise and improve tuna fishing methods and gears. Only a few similar attempts have been made by fishery scientists because of the difficulties involved in, for example, repeated experimental operation in the field.

Although oceanographic investigations have not contributed so much to fishery, they have elucidated a great many aspects in pure oceanography, such as currents and hydrographic conditions in fishing grounds. Owing to the accumulation of experimental and commercial catch data, fish population dynamics has become a subject of great interest, and estimates of resources therefrom have become increasingly more reliable (SUDA, 1970, 1974; HAYASHI *et al.*, 1972; HAYASHI, 1974; LAUREC and LE GALL, 1975).

The seasonal and monthly horizontal distribution of tunas and marlins is now well known from commercial and experimental fishing all over the world. The vertical ranges have also been determined, by means of specially-designed deep sea lines and fish finders, to extend from the surface down to 500 m or so (NAKAGOME, 1958; SHIBATA and NISHIMURA, 1969; SAITO *et al.*, 1970; YUKINAWA *et al.*, 1972; SAITO, 1975; IWASA, 1978; HISADA and MORITA, 1980; KYU, 1980; MIYAKI, 1980). The maximum depths of distribution of the various species are summarized in Table 1.1. The finding of such a deep vertical range is very interesting to vision researchers. While light intensity is fairly strong at the water surface in tropical areas, ambient light is extremely limited below 200 m. Evidently, tunas and marlins have eyes specially adapted to such optic environments.

Knowledge about the behaviour and sensory physiology of fishes is very important to fishery. In this paper, we report on vision in tunas and marlins, from histological and electrophysiological studies and experimental confirmatory fishing.

There are many variations in the nomenclature of tunas and marlins, but we used the following for the species in the present study.

Japanese name	English name	Scientific name
Kihada	Yellowfin tuna	<i>Neothunnus albacora</i> (LOWE)
Mebachi	Bigeye tuna	<i>Parathunnus, sibi</i> (TEMMINCK & SCHLEGEL)
Binnaga	Albacore	<i>Thunnus alalunga</i> (BONNATERRE)
Kuromaguro	Bluefin tuna	<i>Thunnus thynnus orientalis</i> (TEMMINCK & SHLEGEL)
Makajiki	Striped marlin	<i>Makaira mitsukurii</i> (JORDAN & SNYDER)

Kurokajiki	Pacific blue marlin	<i>Malaira mazara</i> (JORDAN & SNYDER)
Shirokajiki	Black marlin	<i>Istiomax indicus</i> (CUVIER)
Mekajiki	Broadbill swordfish	<i>Xiphias gladius</i> LINNÉ

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Table 1.1. Records of the maximum range of vertical distribution in tunas and marlins determined by fish finder or fishing line. (after KAWAMURA *et al.*, 1981)

Species	Maximum depth in meters	Fishing ground	Method	Author
Yellowfin tuna	200	South China Sea	Fish finder	SHIBATA and NISHIMURA (1969)
	500 or more	Indian Ocean	do.	YUKINAWA <i>et al.</i> (1972)
	150	West Pacific	Fishing line	NAKAGOME (1958)
	200	East Pacific	do.	KYU (1980)
	250	Middle Pacific	do.	MIYASAKI (1980)
	278	South Pacific	do.	IWASA (1978)
Bigeye tuna	300	East Pacific	Fish finder	SHIBATA and NISHIMURA (1969)
	500 or more	North Pacific	do.	YUKINAWA <i>et al.</i> (1972)
	380	South Pacific	Fishing line	SAITO <i>et al.</i> (1970)
	245	Middle Pacific	do.	SAITO (1975)
	250	West Pacific	do.	HISADA and MORITA (1979)
Albacore	380	South Pacific	Fishing line	SAITO (1975)
	334	do.	do.	IWASA (1978)
	500 or more	Indian Ocean	Fish finder	YUKINAWA <i>et al.</i> (1972)
Bluefin tuna	400 or more	North Pacific	Fish finder	SHIBATA and NISHIMURA (1969)
Striped marlin	340	South Pacific	Fishing line	SAITO <i>et al.</i> (1970)
	200	East Pacific	do.	KYU (1980)
	193	South Pacific	do.	IWASA (1978)
Pacific blue marlin	250	Middle Pacific	Fishing line	MIYAKI (1980)
Black marlin	180	East Pacific	Fishing line	KYU (1980)
Broadbill swordfish	380	South Pacific	Fishing line	SAITO (1975)
	240	West Pacific	do.	HISADA and MORITA (1979)

II. IMPORTANCE OF VISION AS INFERRED FROM BRAIN PATTERN

The fish brain differs considerably both in its outer form and in the inner structure according to taxon or ecological group. Studies of the brains of many kinds of fish have revealed that their behavioural characteristics are reflected in the structure of their brains. This finding has been important in the study of the correlation between function and structure of the brain (TSUGE *et al.*, 1968). Attempts have been made to infer fish behaviour from brain structure (UCHIHASHI, 1953; OGAWA, 1967, 1968; OZAWA and TSUKAHARA, 1973; KAWAMURA, 1979 a). In this study, we infer the importance of vision in tunas and marlins from the structure of their brains.

MATERIALS and METHODS

Materials were obtained on board Kagoshima-Maru, training boat of the Faculty of Fisheries, Kagoshima University, in the Indian Ocean in 1978. Fish were captured by longline and their heads were fixed in 10% formalin for more than 25 days before dissection in the laboratory. The fishes examined were yellowfin tuna, bigeye tuna, and albacore.

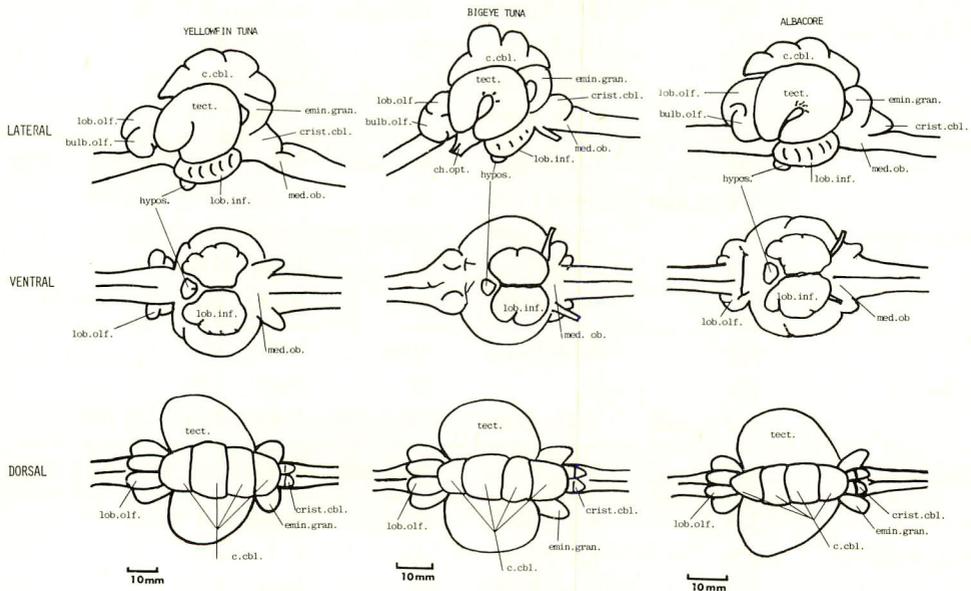


Fig. 2. 1. The outer brain forms of three tunas.

Abbreviations in the figures

bulb.olf.....	olfactory bulb	lob.olf.....	olfactory lobe
c.cbl.....	corpus cerebelli	lob.fac.....	facial lobe
ch.opt.....	optic chiasma	lob.inf.....	inferior lobe
crist.cbl.....	crista cerebelli	lob.vag.....	vagal lobe
emin.gran.....	eminentia granularis	med.ob.....	medulla oblongata
hypos.....	hypothysis	tect.....	optic tectum

albacore, striped marlin, and Pacific blue marlin.

RESULTS

Tuna. There is no significant difference in the outer form of the brains of these tunas as shown in Fig. 2. 1.

The telencephalon consists of olfactory bulb and olfactory lobe, neither of which is as well developed as those of nocturnal fishes such as catfish and eel which are known to have highly sensitive chemo-perception. The optic tectum is extremely well developed and has the largest volume. The corpus cerebelli, dorsal to the optic tectum, is likewise large and is separated into four parts by three deep grooves. The medulla oblongata consists of eminentia granularis, crista cerebelli, facial lobe, and vagal lobe. The latter two are small.

Marlin. There is no significant difference in the outer brain form between the two marlins, but both differ markedly from the tunas (Fig. 2. 2).

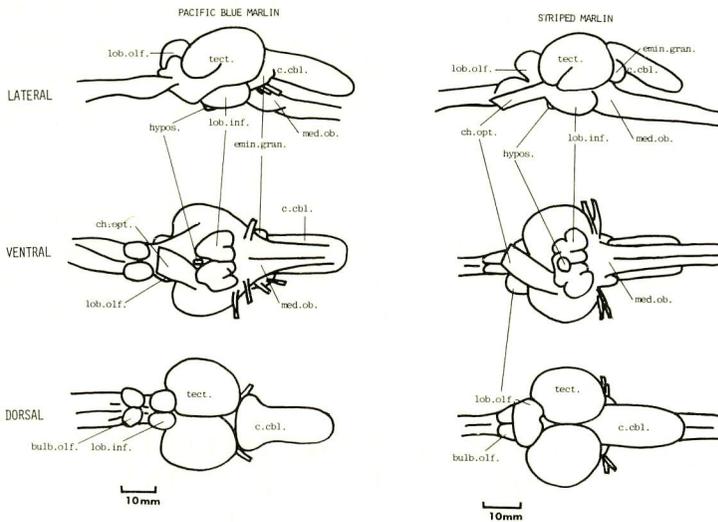


Fig. 2. 2. The outer brain forms of two marlins. Abbreviations as in Fig. 2. 1.

The telencephalon consists of olfactory bulb and olfactory lobe, neither well developed. The optic tectum and the corpus cerebelli are equally well developed. The eminentia granularis is less developed than in the tunas; the facial and vagal lobes are also small.

DISCUSSION

The extremely well developed optic tectum in the tunas and marlins studied indicates that vision is very important to these fishes. Bluefin tuna has been reported by TSUGE *et al.* (1968) also to have well developed optic tectum, corpus cerebelli,

and eminentia granularis. The development of the optic tectum and corpus cerebelli in fish shows the importance of movement perception in feeding (UCHIHASHI, 1953; TSUGE *et al.*, 1968).

VAN WEEL (1952) and TESTER *et al.* (1954) observed the reaction of yellowfin tuna and little tuna to extracts of food and to chemical substances in a pond and in the sea. The fishes responded to some of the stimuli in the pond but not in the sea. KOYAMA (1957) used inedible lure permeated with squid oil in tuna longline fishing, and NAKANO (1969) tried to allure albacore with minced fish meat. Neither of them got the expected response. These show that tunas do not have sensitive chemical perception. This conclusion is supported by the finding that tunas do not have well developed olfactory lobes and facial lobes. The same could be said about marlins.

Development of the corpus cerebelli provides for highly active swimming in fish. Tagging experiments revealed that bluefin tuna and albacore migrate from coastal waters of Japan across the Pacific to the west coast of USA and back (CLEMENS and FLITTNER, 1969). It is well known that striped marlin and Pacific blue marlin migrate latitudinally across the equator (UEYANAGI, 1954; NAKAGOME, 1985; ANRAKU and YABUTA 1959). Tunas and marlins have very strong swimming power (WALTER and FIERSTINE, 1964). It is often observed with fish finder that tunas go up and down the vertical range of 200-300 m at very high speed. Based on an echo trace of the fish finder, MORITA and YAMANAKA (1974) reported a vertical swimming speed of 4.6 km/h in yellowfin tuna. This active swimming is reflected well in the extremely well developed corpus cerebelli of tunas and marlins.

According to UCHIHASHI (1953), fish with well developed eminentia granularis and crista cerebelli has a nocturnal habit. Tunas can be fished at night, although the efficiency is lower than in daytime (WATABE, 1958; TSUKAKOSHI, 1979); stomach contents show that they feed even at nighttime (KUME and MORITA, 1966). Since marlins do not have well developed eminentia granularis and crista cerebelli, their activity is probably limited to daytime.

III. VISUAL ACUITY AS INFERRED FROM HISTOLOGY ON RETINA

An animal's habit is well reflected in its eyes (WALLS, 1942). O'CONNELL (1963) noted that differences in number and size of various retinal structures in fishes, when considered along with various other features, suggest certain functional differences. From a comparative study on retinae of various fishes, not only the function of retinal elements but also the animal's habit can be deduced. KAWAMURA and TAMURA (1973) and KAWAMURA (1976) discussed the correlation between histological features of retinae and the habits of teleosts. In this study, the retinae of tunas and marlins were observed histologically, and visual axis and visual acuity were determined from cone density.

MATERIALS and METHODS

The fishes studied were bigeye tuna, yellowfin tuna, bluefin tuna, albacore, striped

marlin, Pacific blue marlin, black marlin, and broadbill swordfish. Two sizes of bluefin tuna were used: a young one (52 cm fork length) obtained by trolling in the coastal waters off Kagoshima in 1980, and an adult which has been reared from a young stage in a fish cage in the Bohnotsu Bay and supplied by Bohnotsu Cho. The other fishes were captured alive by longline on board Kagoshima-Maru in the Indian Ocean in 1978 and 1979.

Photographs were made at right angles to the eye surface to determine the direction of the sighting groove of the pupil. Then the heads of the specimens were cut. The eyes were enucleated (parts of the cornea at the temporal and dorsal regions were removed as marks for orientation) and fixed in BOUIN's solution for a few days, and transferred into 70% ethanol.

For the histological examination, each retina was divided into 33 regions as shown in Fig. 3. 1. After routine dioxan-paraffin embedding, tangential and cross sections ($6\ \mu$) were made. Photomicrographs were taken. The cones in $0.01\ \text{mm}^2$ of each region were then counted. The cone ellipsoids and visual cell nuclei in a $230\ \mu$ stretch of retina were counted and their ratios (nuclei-cone ratio) were calculated. For detailed observation, the retinae were dehydrated in dry ice (TANAKA, 1980), sputtered with gold, and processed for scanning electron microscopy.

To determine the presence of retinal tapetum, the sections were observed under a polarizing microscope. In addition, the pigment epithelium was carefully removed together with the choroid from the fresh eye, pressed on paper, dried in the air, sputtered with gold, and then observed under the scanning electron microscope.

The minimum separable angle, or visual acuity, was calculated from the density of the cones in the retinal region in which the highest cone density was observed, the assumption being that image lines can be only be resolved when they fall on cones separated by at least one unstimulated cone (TAMURA, 1957). This angle is

$$\sin \alpha = 1 / F [0.1 (1 + 0.25) \times 2 / \sqrt{n}]$$

where α is the minimum separable angle in radians, F is focal distance of the lens, which is 2.55 times the radius of the lens (MATTHIESSEN'S ratio), 0.25 is the degree of shrinkage during the histological procedure, n is number of cones (single and twin cones) per $0.01\ \text{mm}^2$.

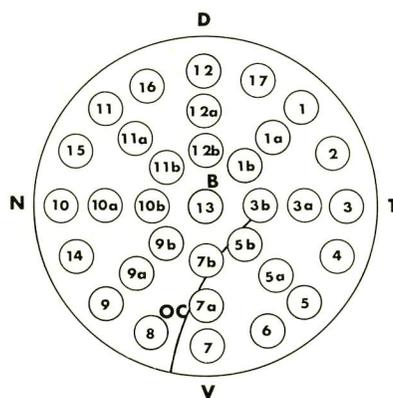


Fig. 3. 1. Regions of the retina for which cone density measurements were made. B, bottom; D, dorsal; N, nasal; T, temporal; V, ventral; OC, optic cleft.

RESULTS and DISCUSSION

Topographical distribution of cones. Photomicrographs of tangential and cross

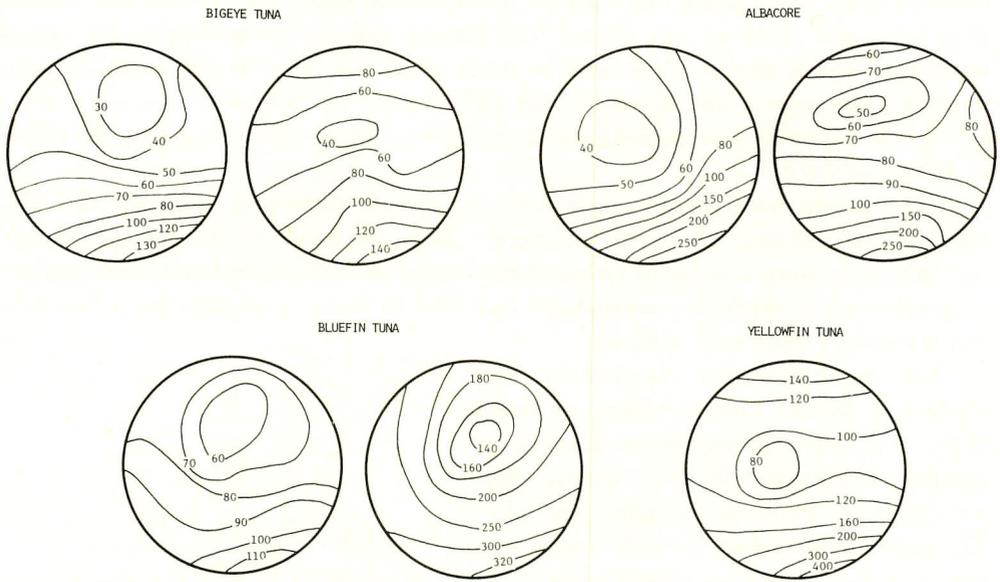


Fig. 3. 2. Cone (sum of twin and single cones) density topography in tunas. Areas of equal density are delineated.

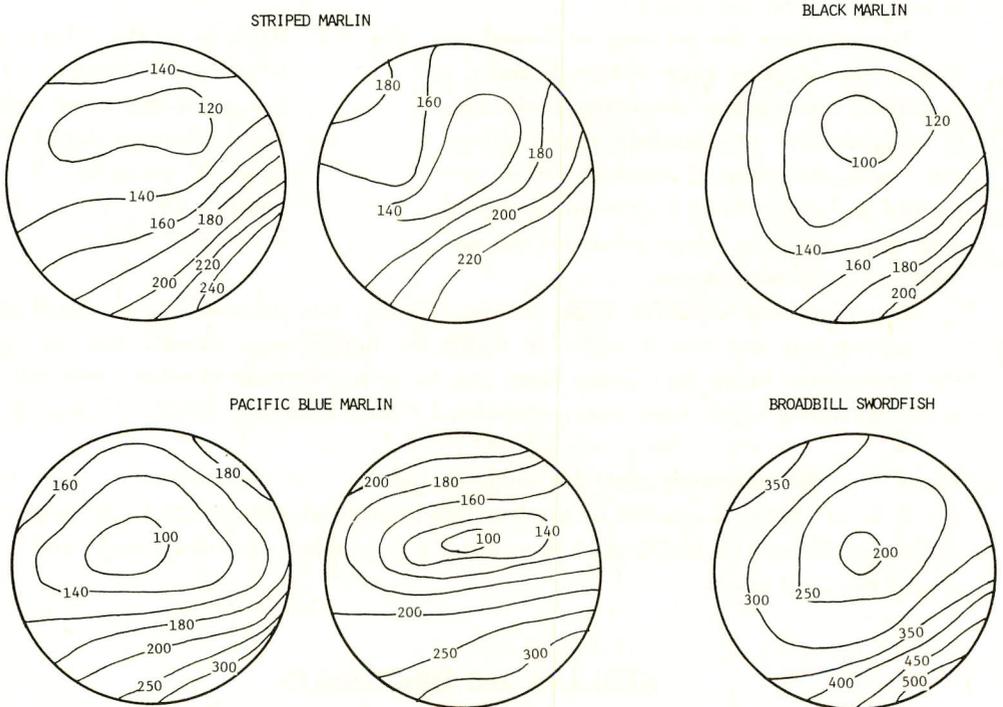


Fig. 3. 3. Cone density topography in marlins. As in Fig. 3. 2.

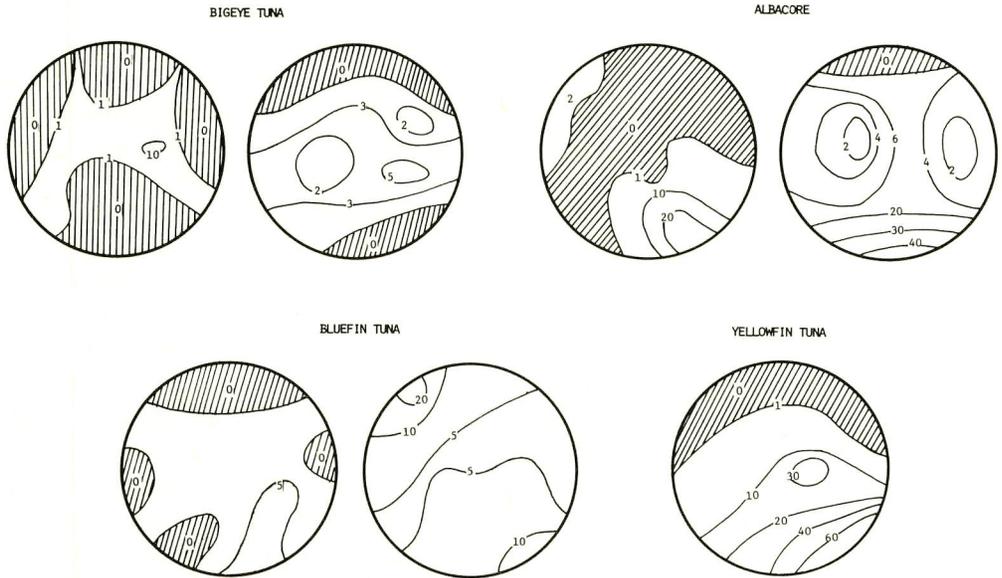


Fig. 3. 4. Single cone density topography in tunas. Hatched area shows retinal part where single cones were absent.

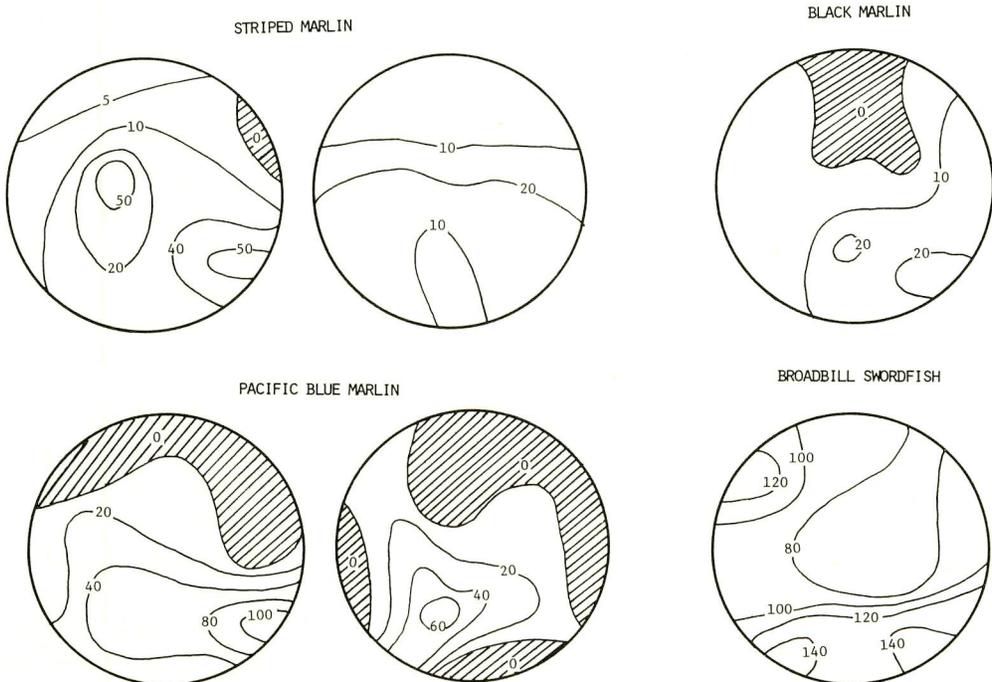


Fig. 3. 5. Single cone density topography in marlins. As in Fig. 3. 4.

sections of selected tetinal regions are shown for each species in Plates 1-8. Density and size of cones varied with species and retinal regions; cone densities are given in Appendix table 1. The highest cone density was in the ventral retinal region in tunas and in the ventro-temporal region in marlins. Tamura and Wisby (1963) made similar findings. Topographies of cone density distribution are shown in Figs. 3. 2. and 3. 3.

Twin cones were present throughout the retinae of all species studied. While many single cones were found in the retina of broadbill swordfish, they were virtually absent, particularly from the dorsal retinal regions of other fishes especially bigeye tuna. The topography of single cone density in each species is shown in Figs. 3. 4 and 3. 5.

TAMURA (1957) and LYALL (1957) conducted a histological study of the retinae of many marine teleosts and found that twin cones (or double cones) were most numerous in deep-water fishes, and suggested that twin cones were intermediate between single cones and rods in sensitivity. Their suggestion was supported by ENGSTRÖM (1963), ANCTIL (1969), SOMIYA and TAMURA (1971), KAWAMURA and TAMURA (1973), and now by this study. The measurement of angular distribution of underwater radiance revealed that the downward component is predominant even at depths of 400 m (JERLOV, 1968). Presumably, the rare appearance of single cones at the dorsal retinal region is an adaptation of the tunas and marlins to such an angular distribution of underwater radiance. Additionally, the nuclei-cone ratio (Fig. 3. 6 and Appendix table 2) is higher in the dorsal than in the ventral part of the retina; the higher ratio

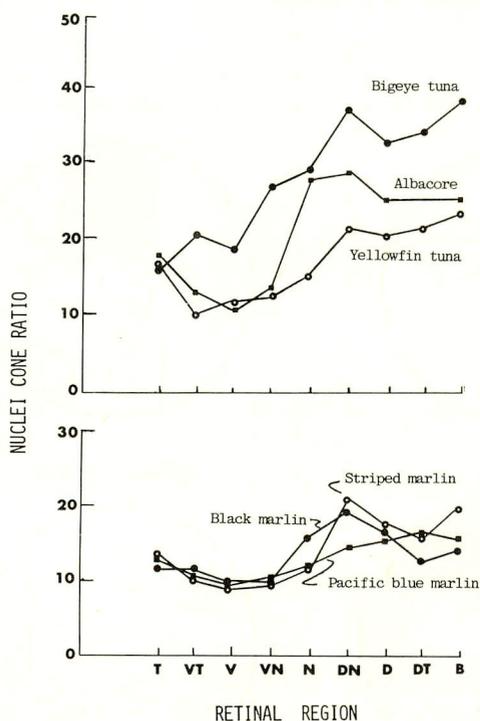


Fig. 3. 6. Visual cell nuclei-cone ratio in each retinal region for tunas (upper) and marlins (lower).

means more numerous rods. The distribution of single cones and rods in the retina seems to harmonize well with the angular distribution of the relative energy of underwater radiance at great depths.

Young bluefin tuna has more numerous single cones than the adult, suggesting a shallower habitat for the former. In support of this is the fact that young bluefin tuna are captured not by deep set longline but by trolling in surface water. Young broadbill swordfish also have relatively numerous single cones, again suggesting a change in depth of habit with growth.

SCHWASSMANN (1968) observed that the retinal fovea in kelp bass appears along the direction of the sighting groove of the pupil. Examining the relationship between the direction of the sighting groove and the cone density topography in the tunas and marlins in this study, we found that the oval-shaped pupil and its sighting

groove are directed upwarp and slightly nasalward, except in striped marlin and Pacific blue marlin, which have a triangular pupil with the sighting groove directed nasalward not in harmony with cone density topography (Plate 9). This suggests different visual behaviour of the striped marlin and Pacific blue marlin from the others.

Visual acuity. Vision is most acute when tunas look upward and marlins fore-upward. The direction of lens movement in accommodation shifts slightly forward (TAMURA and WISBY, 1963). The minimum separable angle was calculated for the retinal region where the highest cone density was observed and shown in Table 3. 1.

Table 3. 1. Size of fish, cone density, focal distance of lens, and minimum separable angle in tunas and marlins studied.

Species	Forklength in cm	Retinal region of highest cone density	No. of cones in 0.1 mm square	Diameter and focal distance of lens in mm		Minimum separable angle in minutes and (visual acuity)
Yellowfin tuna	105	Ventral	406	16.3	20.78	2.06 (0.49)
Bigeye tuna	111	do.	148	22.0	28.05	2.52 (0.40)
	139	do.	135	25.4	32.39	2.27 (0.44)
Albacore	97	do.	265	19.8	25.25	2.09 (0.48)
	105	do.	262	20.4	26.02	2.04 (0.49)
Bluefin tuna	120	do.	115	17.6	22.44	3.57 (0.28)
	52	do.	324	10.2	13.01	3.67 (0.27)
Striped marlin	175	do.	217	16.3	20.78	2.81 (0.36)
	175	Ventro-temporal	245	16.3	20.91	2.63 (0.38)
Pacific blue marlin	157	Ventral	304	15.7	20.02	2.46 (0.41)
	150	Ventro-temporal	385	15.2	19.38	2.26 (0.44)
Black marlin	190	do.	208	17.2	21.93	2.27 (0.37)
Broadbill swordfish	54	do.	492	9.3	11.86	3.27 (0.31)

These values range about 2 to 4 minutes in arc (about 0.3 to 0.5 in visual acuity). NAKAMURA (1967) trained yellowfin tuna to discriminate between vertically and horizontally striped images and obtained maximum visual acuity value of 0.274, which is less than that obtained here, 0.49. While we determined acuity at the ventral retinal region, NAKAMURA presented the striped image to be discriminated in front of the fish and the visual acuity was measured at the temporal retinal region. Our value for the temporal retinal region is 0.23 which is close to 0.274. It is believed from the visual axis that tunas and marlins probably see objects from below as silhouetting targets.

Cone arrangement. Most teleost retinae contain single and twin (or double) cones and these are frequently arranged to form a regular cone mosaic.

Twin cones in tunas form a regular mosaic of rows in parallel arrangement. A few single cones appear randomly among them (Plates 1-4) but not in the dorsal part of the retina. The long axes of the cross section of the twin cones were oriented in concentric circles relative to the retinal periphery in albacore, yellowfin, bigeye,

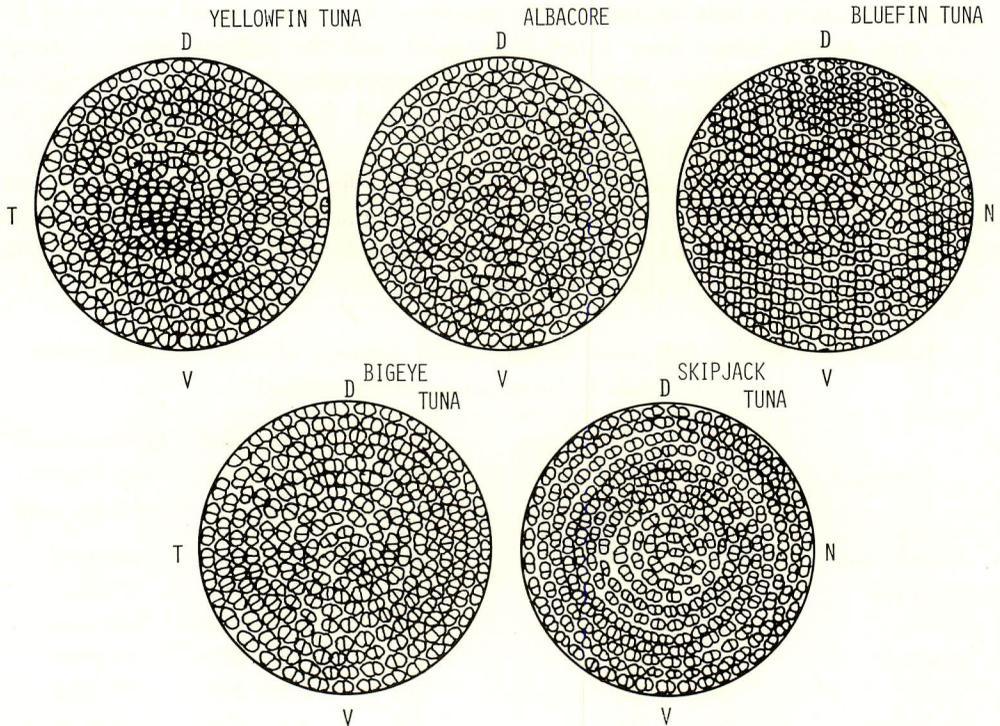


Fig. 3. 7. Cone arrangement in the retinae of five tunas.

and skipjack and parallel to the equator in bluefin. (Fig. 3. 7).

The twin cones were also in regular mosaic in marlins. In most of the retinal regions, cones were arranged in parallel rows, but a quadrangular mosaic was present in the ventro-temporal part behind the optic cleft of the retina (Plate 5-8).

Cone mosaic patterns reflect to a great extent the degree to which the fish relies upon vision. LYALL (1957) believed that cone patterns improve the perception of movement. The most regular mosaics are found in species feeding on fast-moving prey. Based on the finding that the square mosaic occurs in the ventral part of the retina and the rows in the dorsal part, ENGSTRÖM (1963) suggested that the square mosaic is predominant in acute vision. This was supported by KAWAMURA and TAMURA (1973). The regular arrangement of twin cones in parallel rows as well as the presence of 3 layers of large horizontal cells indicate the importance of movement perception in tunas and marlins.

Retinal tapetum. As TSUKAKOSHI (1979) observed, the eye of bigeye tuna captured at night shines brightly as shown in Fig. 3. 8. Observation with the polarizing microscope revealed a dense tapetum lucidum in the pigment epithelium layer. The tapetum material was square to rectangular in shape (Plate 10). No eyeshine nor tapetum lucidum was observed in the other tunas and marlins examined.

The tapetum lucidum is considered to act as a mirror, reflecting the light back and thus increasing the effectiveness of photoreceptors, the retina bearing this having predominance in dim light vision (WALLS, 1942).

Species which live deep tend to have large eye, which allows a further increase in

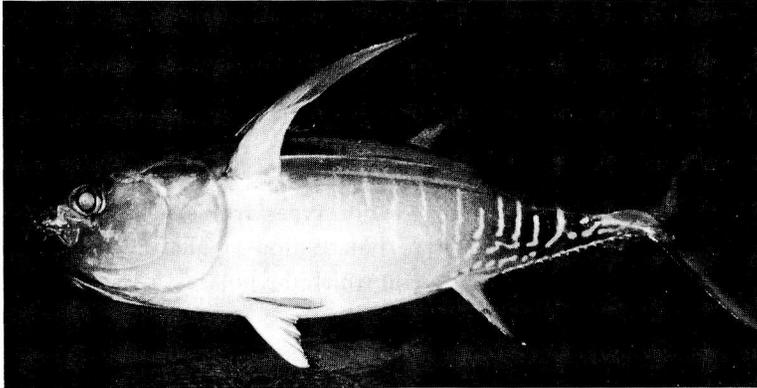


Fig. 3. 8. Bigeye tuna photographed on deck ; note bright eyeshine.

sensitivity. The bigeye tuna has the largest eye among the tunas (TSUKAKOSHI, 1979), indicating a corresponding higher efficiency in dim light at extreme depths and at night. It was also observed that the outer segment of the cone was ramified in bigeye tuna (Plate 11). Such a ramified outer segment could be a special adaptation for increased sensitivity, or perhaps an artifact of the histological procedure. The retina of bigeye tuna should be observed further under various histological treatments to confirm the ramification.

IV. COLOR VISION AND SPECTRAL SENSITIVITY

Dependence of tunas and marlins on vision was discussed above. While it is very common among fishermen to use colorful lures shaped like squid or fish, color vision and shape discrimination in tunas and marlins have not been demonstrated. Pelagic fishes have retina with cones which are responsible for color vision, but not all of them have color vision (TAMURA *et al.*, 1972). We conducted an electrophysiological study to determine the presence of color vision in tunas and marlins, using the S-potential as an indicator of spectral sensitivity and color vision (KAWAMURA *et al.*, 1981).

MATERIALS and METHODS

The experiments were carried out in May-July 1975, 1978, and 1979 on board Kagoshima-Maru. The species studied were the yellowfin tuna, bigeye tuna, albacore, striped marlin, Pacific blue marlin, and black marlin. Specimens were captured alive by longline in the Indian Ocean.

S-potentials were recorded from the isolated retinae of the fish. The procedure

and apparatus for recording S-potential were described by KAWAMURA (1979 b). A glass capillary microelectrode filled with 3M 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 lights (almost monochromatic) of equal energy for all wavelengths.

RESULTS and DISCUSSION

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

Table 4.1. Number of specimens and cells from which S-potentials were recorded.

Species	No. of specimens	No. of cells
Yellowfin tuna	23	519
Bigeye tuna	20	464
Albacore	10	189
Striped marlin	3	67
Pacific blue marlin	5	120
Black marlin	5	165

In yellowfin tuna, we observed and recorded responses of 519 cells from the retinae of 23 fish (Table 4.1). All responses showed simple hyperpolarization at all wavelengths, and no C-response, even from the inner horizontal cells. Similar results were obtained in the other species. Fig. 4.1 shows 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.

The spectral sensitivity was estimated from the distribution of the relative amplitude. From Figs. 4.2 and 4.3, it can be said that the maximum spectral sensitivity is between 458 and 492 nm in yellowfin tuna, bigeye tuna, and the three marlins and 492-522 nm in the albacore.

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 (1957) analysed catch records of tuna trolling and showed that there was in fact no preference for any color nor form of lure. It is wellknown that the species studied could be captured by line at night, although the efficiency is lower than in daytime (WATANABE, 1958). The stomach contents of captured fish show that these fishes are active even at night (KUME and MORITA, 1966). The

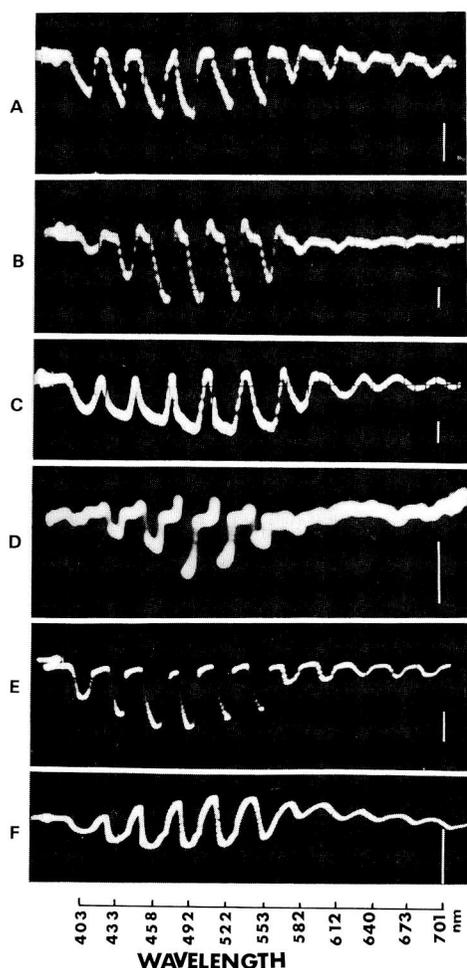


Fig. 4.1. Spectral responses of S-potential for three tunas and three marlins. A, yellowfin tuna; B, bigeye tuna; C, albacore; D, striped marlin; E, black marlin; F, Pacific blue marlin.

depth. SVAETICHIN and MACNICHOL (1958) 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 distribution of these fishes extend from the surface down to 500 m or so. The difference in the sensitivity maximum in albacore can not be explained on the basis of the spectral characteristics of the environment, as NIWA (1976) had done for two groups of freshwater ugui, because the vertical range of distribution of albacore overlap with those of the other five species. According to SAITO (1979), albacore feeds more actively in deep waters. There thus must be a phylogenetic explanation for this observed difference.

The absence of color vision seems not a serious handicap for tunas and marlins,

fishes; body color patterns, considered to have some meaning in interspecific or intraspecific communication (STRASBURG, 1961; MAGNUSON, 1965), are not particularly colorful. Since these fishes inhabit great depths as shown in Table 1.1, their visual habitat is presumably far from colorful. All these behavioural features and observations seems to agree with the electrophysiological fact-color blindness. Agreement is also shown by the study of MUNZ and MACFARLAND (1977). 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.* (1972) 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 JERLOV (1970), water acts as a monochromator for blue light, and the spectral distribution curves for clear water are peaked in blue light. From the spectral sensitivity determined by electroretinograms in many fishes, KOBAYASHI (1962) 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

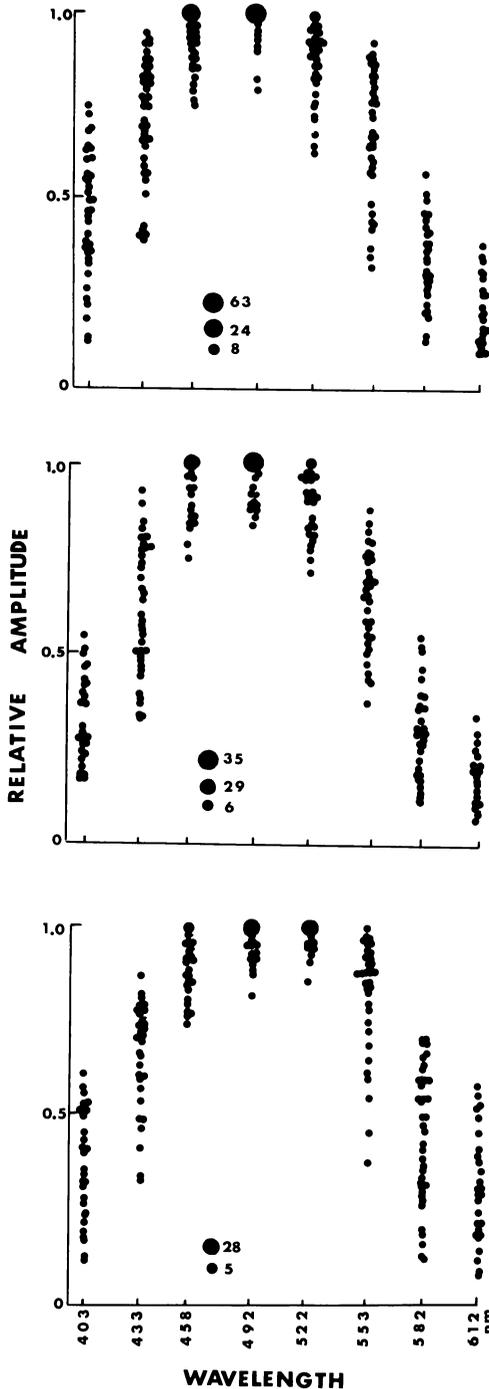


Fig. 4.2. Distribution of relative amplitude of response at each stimulus wavelength for tunas. Numbers beside larger circles show the frequency. Top, yellowfin tuna; middle, bigeye tuna; bottom, albacore. (after KAWAMURA *et al.*, 1981)

when considered along with other features such as histological characters of their retina and ambient light in their habitat. In the depths, sensitivity is most important and color vision has no value. Even at the surface, they might see underwater objects from below not as colored targets but as silhouettes.

V. Attempts to Confirm the Importance of Movement Perception in Feeding

It was estimated from the brain pattern and retinal structure of the fishes studied that movement perception is the most important in feeding. Moreover, commercial fishermen have observed that rough sea conditions increase the efficiency of tuna long-lines, i.e. catch is increased. Presumably, the rough sea tosses the gear about and the motion of hooked bait stimulates the movement perception of fishes. To clarify the observed relationship between catch and sea conditions, catch records were analysed.

Data Used

The Kagoshima-Marui has done tuna longline fishing in the Indian Ocean since 1960 to train students and do experiments in the fishing grounds shown in Fig. 5.1. Catch data and sea and weather conditions during the operations were recorded every four hours in the ship's logbook. The

relationship between the wave scale (set by the Central Meteorological Observatory of Japan, see Table 5.1) and the hook ratio (number of hooked tuna and marlin to number of hooks used) was examined using 9 logbooks in 1960-'62, '67, '71, '74, '75, '77, and '79, involving 154 operations excluding those for gear and lure experiments.

Results and Discussion

Fishing on Kagoshima-Maru was

Table 5.1. Relationship between wave scale and wave height

Wave scale	Wave height (m)
0	0
1	0 to less than 0.5
2	0.5 to less than 1
3	1 to less than 2
4	2 to less than 3
5	3 to less than 4
6	4 to less than 6
7	6 to less than 9
8	9 to less than 14
9	14 or more

Table 5.2. Annual fluctuation of mean hook ratio.

Year	Hook ratio	
	Mean	Range
1960	3.89	1.70-6.30
1961	5.15	0.37-11.77
1962	4.05	1.14-7.25
1967	2.32	0.70-4.25
1971	3.70	0.00-8.40
1974	2.08	0.80-4.60
1975	1.84	0.00-4.27
1977	2.95	0.30-6.50
1979	2.63	0.56-6.10

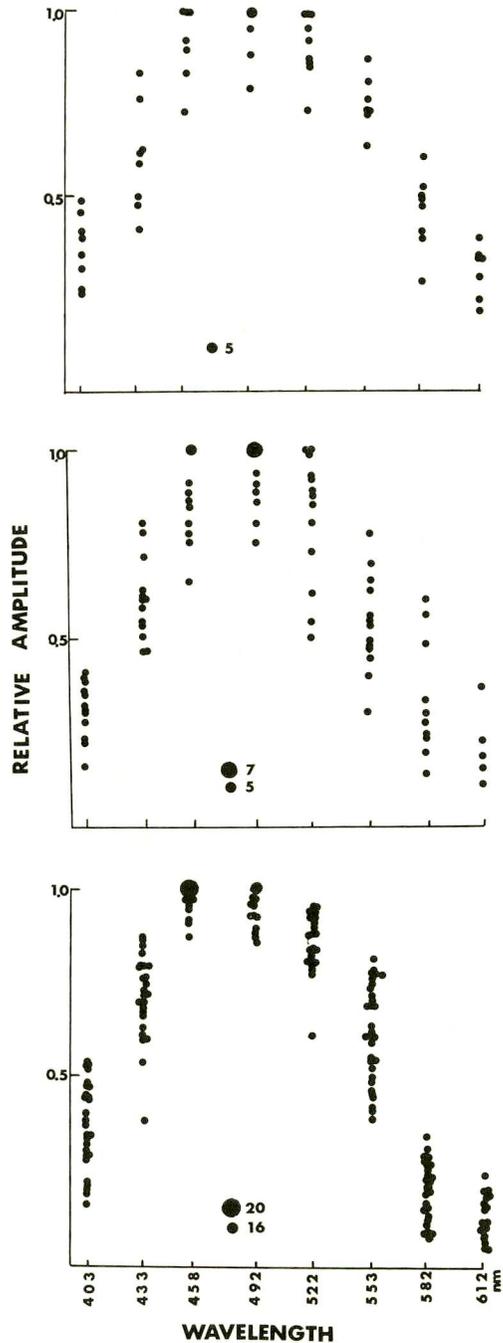


Fig. 4.3. Distribution of relative amplitude of response at each stimulus wavelength for marlins. Top, Pacific blue marlin; middle, striped marlin; bottom, black marlin. (after KAWAMURA *et al*, 1981)

repeated 10 to 23 times in one cruise and the catch data for many years were pooled to deduce a reliable relationship between the wave scale and hook ratio. This was done after it was ascertained that the annual catch fluctuations did not noticeably affect the hook ratio (Table 5.2).

Fishing was done during wave conditions 1 to 5, and the hook ratio varied from 0 to 11.77. Plotted together, no correlation appears (Fig. 5.2).

Japanese fishermen believe that motion of the baited hooks is the most important factor in attracting fish; this belief was experimentally supported by TAMURA (1952). While fish will be attracted more by moving bait than by still bait, increase in wave scale evidently does not increase the catch efficiency. According to YAMANE (1979).

the amplitude of vertical motion of a float with sinker is much smaller than that of a regular wave. Even when the floats move with high amplitude, due to the rheology of the kuremona line used (TANIDA, 1980), the tension caused by the floats' motion at the upper part of the float line is probably absorbed in the successive sections. Thus in such small waves examined here, float motion probably caused no motion of the bait submerged in 80-140 m waters.

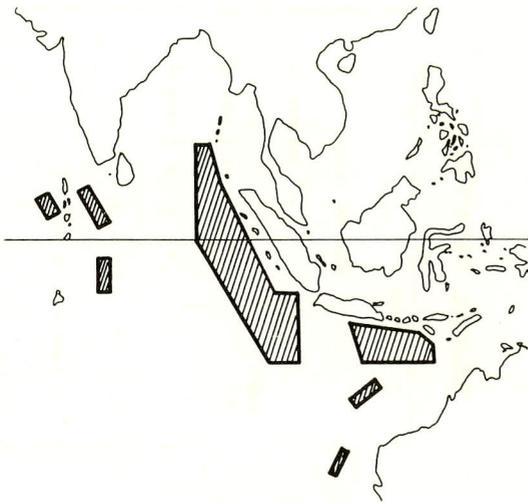


Fig. 5. 1. Fishing grounds in the Indian Ocean where longline fishing was carried out by Kagoshima-Maru.

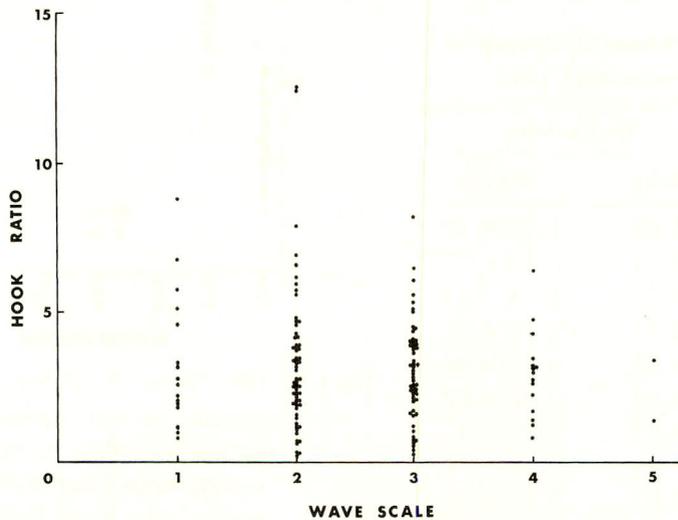


Fig. 5. 2. Distribution of hook ratio by wave scale.

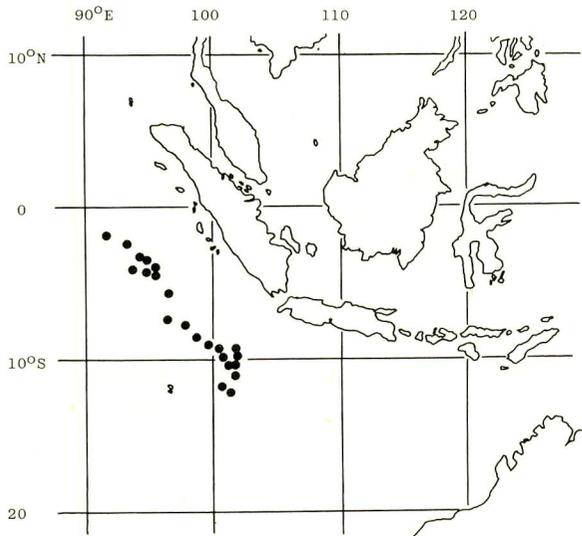


Fig. 6. 1. Positions of experimental fishing by longline with inedible artificial lure in the Indian Ocean

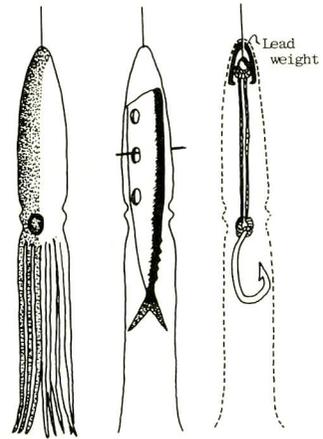


Fig. 6. 2. The inedible artificial lure used (left) showing saury inside (middle) and hook and lead weight inside (right).

VI. LONGRINE FISHING WITH INEDIBLE ARTIFICIAL LURE

Artificial inedible lures have long been used in trolling for tunas and marlins, but only recently in longline fishing. The experimental use of artificial lures, edible and inedible ones, in tuna longline fishing has been done in Japan (KOYAMA, 1957; ASARI, *et al.*, 1965; Faculty of Fisheries, Hokkaido University, 1966; Kanagawa Prefecture Fisheries Experimental Station, 1969; YADA *et al.*, 1969; TSURUDOME, 1970; HARADA and KONAGAYA, 1971; KOBAYASHI, 1975), mostly without success. We tried again to use inedible artificial lure in tuna longline because it is a convenient method to determine the role of vision in the feeding of tunas and marlins.

MATERIALS and METHODS

The experiment was done by the Kagoshima-Marui in the fishing grounds in the Indian Ocean (Fig. 6. 1) from May to July, 1979. The lures were made of soft vinyl chloride shaped and colored like a squid 30 cm long and 3.5 cm wide with a lead weight of 30 g. The lures were attached to hooks as shown in Fig. 6. 2. Additionally, lures stuffed with saury (Fig. 6. 2B) were used to test for the effect of chemical sense of the fish no catch. Frozen saury was used as control bait. The longline used was of common construction and one basket had 5 hooks (IMAI, 1972), and 200 baskets were used in a day. A group of 5 baskets was considered as a unit. The units were arranged in various ways (Fig. 6. 3) during the 22 operations made. In the first and second operation, 4 units of lure baskets were arranged at one end

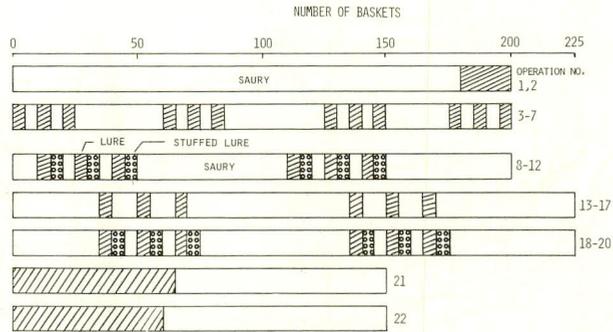


Fig. 6. 3. Arrangement of units of lure, saury bait, and stuffed lure on the experimental tuna longline. Each unit consists of 5 baskets each of 5 hooks.

Table 6. 1. Number of hooks used.

Operation No.	Saury	Lure	Stuffed lure
1	900	100	—
2	900	100	—
3	700	300	—
4	700	300	—
5	700	300	—
6	700	300	—
7	700	300	—
8	700	150	150
9	700	150	150
10	700	150	150
11	700	150	150
12	700	150	150
13	790	185	—
14	790	185	—
15	790	185	—
16	790	185	—
17	790	185	—
18	790	185	150
19	790	185	150
20	790	185	150
21	425	325	—
22	450	300	—
Total	15995	4555	1200

of the line for practice in the use of the lure. In the 21st and 22nd operation, 13 and 12 units of lure basket were arranged in succession as a preliminary to next year's experiments. Therefore, the analysis was made on the catch from the 4th arrangement in the 3rd to the 20th operation.

RESULTS and DISCUSSION

Three kinds of tuna and six kinds of marlin were captured in the baskets analysed (Table 6.2). Many of the lures were slightly or seriously damaged (Plate 12)

Table 6.2. Number of hooks tested and number of fish captured.

Species	Saury	Lure	Stuffed lure
Number of hooks tested	1750	1500	1200
Yellowfin tuna	73	14	6
Bigeye tuna	18	0	2
Albacore	8	1	0
Striped marlin	1	0	0
Pacific blue marlin	4	0	0
Black marlin	1	1	0
Sailfish	1	0	1
Shortbill spearfish	2	0	0
Broadbill swordfish	3	0	1

probably due to biting by fish other than tuna or marlin since no fragment of the lure was found among the gut contents of the tunas and marlins captured.

The lure was always turned inside out or inverted where tuna or marlin was hooked (Plate 12). It was very difficult to invert the lure by hand and it must have taken the fish a great deal of power to do it. The inverted lure gives valuable insight on the motion of the fish after being hooked.

As the catch of the units was poor, mostly 0 or 1, catches obtained in one arrangement were summed up for two fixed positions of the units: saury-unit-adjacent-to-lure-unit and saury-unit-adjacent-to-stuffed-lure-unit. Thus, results for 30 pairs of saury and lure units, and 12 pairs of saury and stuffed lure units were statistically tested (Tables 6.3 and 6.4). As the frequency distribution of longline catch was not normal, catches and differences in catch were normalized by a transformation using the logarithmic formula $\text{Log}(N + 2)$ where N is the actual catch or difference.

The catch with lure was significantly less than that with saury ($t=3.648$, $df=48$, $0.001 < p < 0.005$). However, the catch with lure was same as that with stuffed lure ($t=0.646$, $df=20$, $0.50 < p$). From these results, it can be said that while the catch with lure was poorer than with saury bait, tunas and marlins can be captured by inedible lure, and that there is no apparent effect of chemical sense on the catch.

These findings suggest that tunas and marlins feed mainly by sight.

Using the same lure as in our experiment, MIYAKI (1980) obtained a better catch although 63% of it was bigeye tuna which have highly sensitive eyes (see above). The maximum depth at which his lure was submerged was calculated as 225 m based on the catenary curve of the longline used. His result shows that tunas feed by

Table 6.3. Comparison of catch between saury and lure.

Operation No.	Saury	Lure	Difference
	7	0	7
	8	2	6
	6	1	5
	5	0	5
	3	3	0
3-7	4	0	4
	9	3	6
	2	0	2
	3	0	3
	4	0	4
	3	0	3
	3	1	2
	9	1	8
	3	0	3
	9	2	7
	2	0	2
	1	0	1
8-12	3	1	2
	11	0	11
	2	0	2
	0	0	0
	4	0	4
	5	0	5
	1	0	1
	2	0	2
	0	0	0
18-20	2	1	1
	0	1	1
	0	0	0
	0	0	0
Total	111	16	95
Mean	3.70	0.53	3.17
Confidence limit of mean difference at 99.9% level: 1.272 - 5.068			

Table 6.4. Comparison of catch between lure and stuffed lure.

Operation No.	Stuffed lure	Lure	Difference
	1	1	0
	1	0	1
	1	2	-1
	1	0	1
	2	0	2
8-12 and	3	1	2
18-20	1	0	1
	0	0	0
	0	1	-1
	0	1	-1
	0	0	0
	0	0	0
Total	10	6	4
Mean	0.83	0.50	0.33
Confidence limit of mean difference at 90% level: -0.065 - 0.725			

sight even at such depths. SAITO *et al.* (1970) recorded an albacore hooked at 207 m using a depth meter attached to a branch line; he also captured albacore, bigeye tuna, striped marlin, and broadbill swordfish at depths of 335-382 m with a specially-designed experimental vertical longline.

Fishermen using lure in tuna longline fishing at present report that they get almost the same hook ratio with lure as with fish bait. It has been shown that inedible lures effectively stimulate sight feeding by fishes. If this gear and its operation could be improved, lures could completely take the place of fish bait, and costs could be minimized since lures can be used repeatedly.

VII. CONCLUSION

We have thus shown that tunas and marlins are visual animals; their brain and eye-retinal structure all point to this. The visual-optical apparatus of these fishes is designed to adapt to the low light levels in the lower limits of their vertical distribution. Object recognition seems to be by preception of movement and of contrast with the background, more than of color or form vision. The importance of movement perception in feeding is clear from trolling operations from surface to deep water (tens of meters). A good catch can not be expected with stationary lures; motion attracts the fish. In tuna longlines set in deep water, motion is somewhat precluded. It is a challenge to fishermen and fishery scientists to develop a way to keep tuna longlines in some form of motion that the fish can appreciate.

Body form and color pattern of prey is important to its predators. Presumably,

this should hold true for tunas and marlins. It is thus worth investigating how these fishes recognize their prey or their predators, given the apparent absence of color vision determined presently. Such study should help us design an artificial lure which is visually effective.

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Appendix table 1. Cone density (number of twin and single cones in 0.01 mm^2) of each retinal region. The fork length of specimen is shown in parenthesis. TC, twin cone; SC, single cone, Sum, sum of twin and single cones.

Retinal region	Yellowfin tuna (105 cm)				Bigeye tuna (149 cm)				Bigeye tuna (111 cm)			
	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC
1	133	0	133	0	44	0	44	0	55	0	55	0
2	109	0	109	0	44	0	44	0	54	0	54	0
3	90	0	90	0	37	0	37	0	65	3	68	0.05
4	96	8	104	0.08	39	1	40	0.03	67	3	70	0.04
5	298	73	371	0.24	86	0	86	0	116	0	116	0
6	310	66	376	0.21	105	0	105	0	—	—	—	—
7	366	40	406	0.11	135	0	135	0	148	0	148	0
8	246	26	272	0.11	78	1	79	0.01	86	8	94	0.09
9	157	10	167	0.06	63	1	64	0.02	54	3	57	0.06
10	105	6	111	0.06	43	0	43	0	53	3	56	0.06
11	107	0	107	0	45	1	46	0.02	75	0	75	0
12	146	0	146	0	42	0	42	0	93	0	93	0
13	79	10	89	0.17	35	1	36	0.03	84	4	88	0.05
14	54	1	55	0.02	40	0	40	0	—	—	—	—
15	101	0	101	0	47	0	47	0	66	0	66	0
16	136	0	136	0	39	0	39	0	84	0	84	0
17	146	0	146	0	39	1	40	0.03	85	0	85	0
1a	94	3	97	0.03	35	1	36	0.03	62	2	64	0.03
1b	84	3	87	0.04	31	2	33	0.06	54	2	56	0.04
3a	87	9	96	0.10	29	1	30	0.03	46	2	48	0.04
3b	80	27	107	0.34	28	15	43	0.54	40	3	43	0.08
5a	178	41	219	0.23	62	0	62	0	—	—	—	—
5b	138	14	152	0.10	51	2	53	0.04	56	5	61	0.09
7a	210	32	242	0.15	94	0	94	0	111	3	114	0.03
7b	115	11	126	0.10	50	0	50	0	118	0	118	0
9a	118	5	123	0.04	57	0	57	0	62	3	65	0.05
9b	93	8	101	0.09	48	1	49	0.02	41	2	43	0.05
10a	81	6	87	0.07	47	1	48	0.02	51	2	53	0.04
10b	73	3	76	0.04	35	1	36	0.03	—	—	—	—
11a	71	0	71	0	29	0	29	0	46	3	49	0.07
11b	75	3	78	0.04	29	1	30	0.03	37	2	39	0.05
12a	80	1	81	0.01	30	0	30	0	57	4	61	0.07
12b	83	3	86	0.01	33	0	33	0	48	1	49	0.02

Continued from p.29

Albacore (105 cm)				Albacore (97 cm)				Bluefin tuna (52 cm)				Bluefin tuna (120 cm)				Striped marlin (175 cm)			
TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC
74	0	74	0	65	2	67	0.03	144	2	146	0.01	71	2	73	0.03	129	6	135	0.05
59	0	59	0	78	2	80	0.03	213	2	215	0.01	73	1	74	0.01	155	9	164	0.06
58	0	58	0	62	3	65	0.05	131	2	133	0.02	64	0	64	0	218	16	234	0.06
53	1	54	0.02	85	5	90	0.06	188	1	189	0	63	4	67	0.06	218	27	245	0.07
73	7	80	0.10	121	20	141	0.17	200	14	214	0.07	92	4	96	0.04	215	30	245	0.12
221	22	243	0.10	161	28	189	0.17	314	10	324	0.03	97	3	100	0.03	215	15	230	0.14
242	20	262	0.08	225	40	265	0.18	286	9	295	0.03	107	8	115	0.08	198	9	207	0.07
168	1	169	0.01	155	35	190	0.23	296	4	300	0.01	88	1	89	0.01	154	11	165	0.05
95	0	95	0	84	18	102	0.21	294	9	303	0.03	90	0	90	0	155	17	172	0.05
44	2	46	0.05	78	5	83	0.06	180	9	189	0.05	95	0	95	0	115	19	134	0.17
49	2	51	0.04	56	6	62	0.11	195	32	227	0.16	63	0	63	0	117	7	124	0.06
45	0	45	0	53	3	56	0.06	173	5	178	0.03	59	0	59	0	115	6	121	0.05
42	1	43	0.02	60	5	65	0.08	193	6	199	0.03	58	1	59	0.02	113	22	135	0.19
63	0	63	0	89	6	95	0.07	187	2	189	0.01	80	1	81	0.01	119	20	139	0.17
57	0	57	0	57	4	61	0.07	238	10	248	0.04	86	1	87	0.01	125	7	132	0.06
45	0	45	0	146	0	146	0	182	4	186	0.02	74	0	74	0	160	4	164	0.03
61	0	61	0	65	0	65	0	176	5	181	0.03	75	0	75	0	136	6	142	0.03
60	0	60	0	—	—	—	—	154	3	157	0.02	54	3	57	0.06	127	2	129	0.02
40	0	40	0	42	2	44	0.05	138	3	141	0.02	64	1	65	0.02	123	9	132	0.07
52	0	52	0	68	3	71	0.04	163	6	169	0.04	65	1	66	0.02	156	23	179	0.15
44	1	45	0.02	48	8	56	0.17	156	6	162	0.04	72	4	76	0.06	132	30	162	0.29
63	6	69	0.01	156	0	156	0	191	7	198	0.04	93	6	99	0.07	170	18	188	0.11
47	0	47	0	—	—	—	—	167	6	173	0.04	71	1	72	0.01	156	16	172	0.10
128	25	153	0.20	—	—	—	—	281	5	286	0.02	79	4	83	0.05	155	10	165	0.06
100	16	116	0.16	90	9	99	0.10	150	6	156	0.04	69	4	73	0.06	146	10	156	0.06
71	1	72	0.01	—	—	—	—	181	5	186	0.03	76	0	76	0	148	13	161	0.09
59	0	59	0	65	4	69	0.06	168	4	172	0.02	63	2	65	0.03	135	14	149	0.10
40	0	40	0	49	4	53	0.08	172	4	176	0.02	79	2	81	0.03	111	32	143	0.29
42	0	42	0	48	4	52	0.08	147	5	152	0.03	60	2	62	0.03	104	32	136	0.31
38	0	38	0	60	2	62	0.03	173	5	178	0.03	58	1	59	0.03	102	6	108	0.06
38	0	38	0	48	2	50	0.04	164	3	167	0.02	63	2	65	0.03	118	9	127	0.08
40	0	40	0	57	6	63	0.11	176	4	180	0.02	65	0	65	0	114	5	119	0.04
42	0	42	0	45	1	46	0.02	118	3	121	0.03	50	1	51	0.02	99	8	107	0.08

Continued from p. 30

Striped marlin (175 cm)				Pacific blue marlin (157 cm)				Pacific blue marlin (150 cm)				Broadbill swordfish (54 cm)				Black marlin (190 cm)			
TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC	TC	SC	Sum	SC/TC
184	0	184	0	160	0	160	0	181	0	181	0	170	82	258	0.48	105	13	118	0.12
225	0	225	0	180	0	180	0	174	0	174	0	168	92	260	0.55	111	10	121	0.09
158	46	204	0.29	203	0	203	0	138	7	145	0.05	170	83	253	0.49	123	16	139	0.13
165	50	215	0.30	289	21	310	0.09	282	103	385	0.37	320	155	475	0.48	144	26	170	0.18
158	40	198	0.25	-	-	-	-	198	64	262	0.32	342	150	492	0.44	185	14	199	0.08
165	0	178	0	260	0	260	0	240	37	277	0.15	300	135	435	0.45	194	14	208	0.07
207	10	217	0.05	304	0	304	0	232	30	262	0.13	272	120	392	0.44	160	16	176	0.10
158	18	176	0.11	225	55	280	0.24	157	42	199	0.27	288	140	428	0.49	136	8	144	0.06
203	16	219	0.08	196	49	245	0.25	165	21	186	0.13	186	90	276	0.48	137	8	145	0.06
140	0	140	0	192	0	192	0	119	20	139	0.15	208	95	303	0.46	143	5	158	0.04
180	4	184	0.02	230	8	238	0.04	235	0	235	0	238	110	348	0.46	137	2	139	0.02
139	4	143	0.03	210	0	210	0	164	0	164	0	201	98	299	0.49	123	0	123	0
136	6	142	0.04	126	23	149	0.18	91	6	97	0.07	136	70	206	0.52	105	5	110	0.05
136	7	143	0.05	196	0	196	0	143	19	162	0.13	198	98	296	0.50	139	7	146	0.05
-	-	-	-	196	14	210	0.09	218	0	218	0	252	123	375	0.49	140	2	142	0.02
175	0	175	0	188	0	188	0	156	0	156	0	196	95	291	0.49	131	0	131	0
160	5	165	0.03	190	0	190	0	192	0	192	0	168	80	248	0.48	120	3	123	0.03
136	13	149	0.10	118	2	120	0.02	101	0	101	0	168	85	253	0.51	103	5	108	0.05
148	18	166	0.12	113	3	116	0.03	92	3	95	0.03	151	77	228	0.51	91	0	91	0
156	15	171	0.10	139	3	142	0.02	128	0	128	0	155	75	230	0.48	103	7	110	0.07
183	24	207	0.13	135	10	145	0.07	101	7	108	0.07	150	70	220	0.47	106	5	111	0.05
-	-	-	-	150	44	194	0.29	117	58	175	0.50	280	140	420	0.50	95	12	107	0.13
146	48	194	0.33	168	63	231	0.38	91	50	141	0.55	204	94	298	0.46	88	10	98	0.12
221	0	221	0	189	68	257	0.36	140	68	208	0.49	290	138	428	0.48	148	20	168	0.14
143	36	179	0.25	118	37	155	0.31	120	54	174	0.45	241	122	363	0.51	94	13	107	0.14
116	28	144	0.24	-	-	-	-	100	47	147	0.47	180	93	273	0.52	83	8	91	0.10
104	32	136	0.31	108	52	160	0.48	93	49	142	0.53	172	84	256	0.49	104	2	106	0.02
123	48	171	0.39	96	55	151	0.57	95	25	120	0.25	182	90	272	0.50	105	4	109	0.04
113	52	165	0.46	84	43	127	0.51	87	10	97	0.16	168	81	249	0.48	112	0	112	0
116	0	116	0	145	0	145	0	109	3	112	0.03	156	73	229	0.47	110	3	113	0.03
123	48	171	0.39	98	0	98	0	95	6	101	0.06	154	73	227	0.47	107	0	107	0
132	4	136	0.03	137	0	137	0	115	0	115	0	174	83	257	0.48	97	0	97	0
125	8	133	0.06	107	0	107	0	88	3	91	0.03	160	78	238	0.49	95	0	95	0

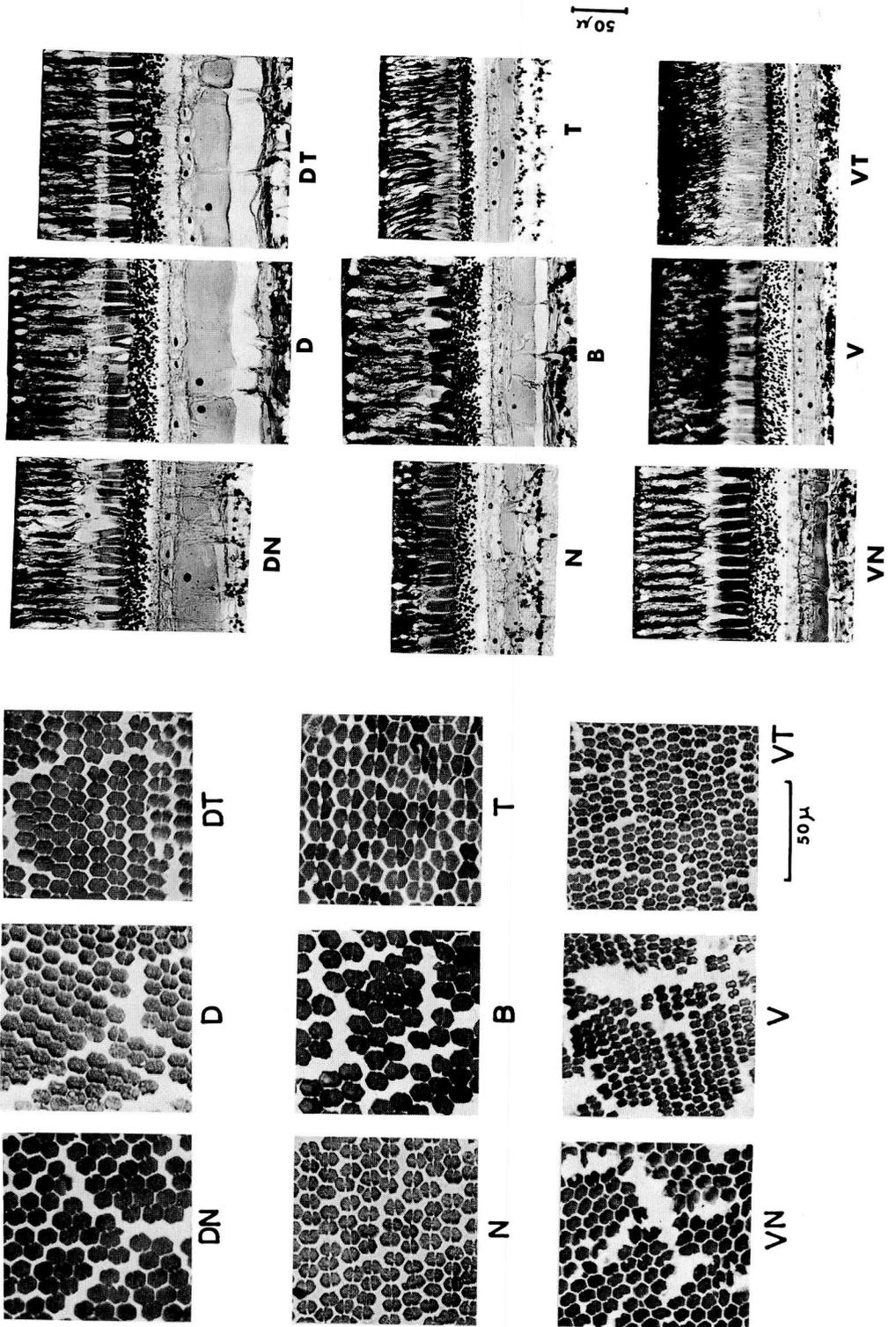
Appendix table 2. Number of visual cell nuclei and cones found in $230\ \mu$ of the cross section ($6\ \mu$), and their ratios for tunas (upper) and marlins (lower). Figures in parentheses show number of single cones.

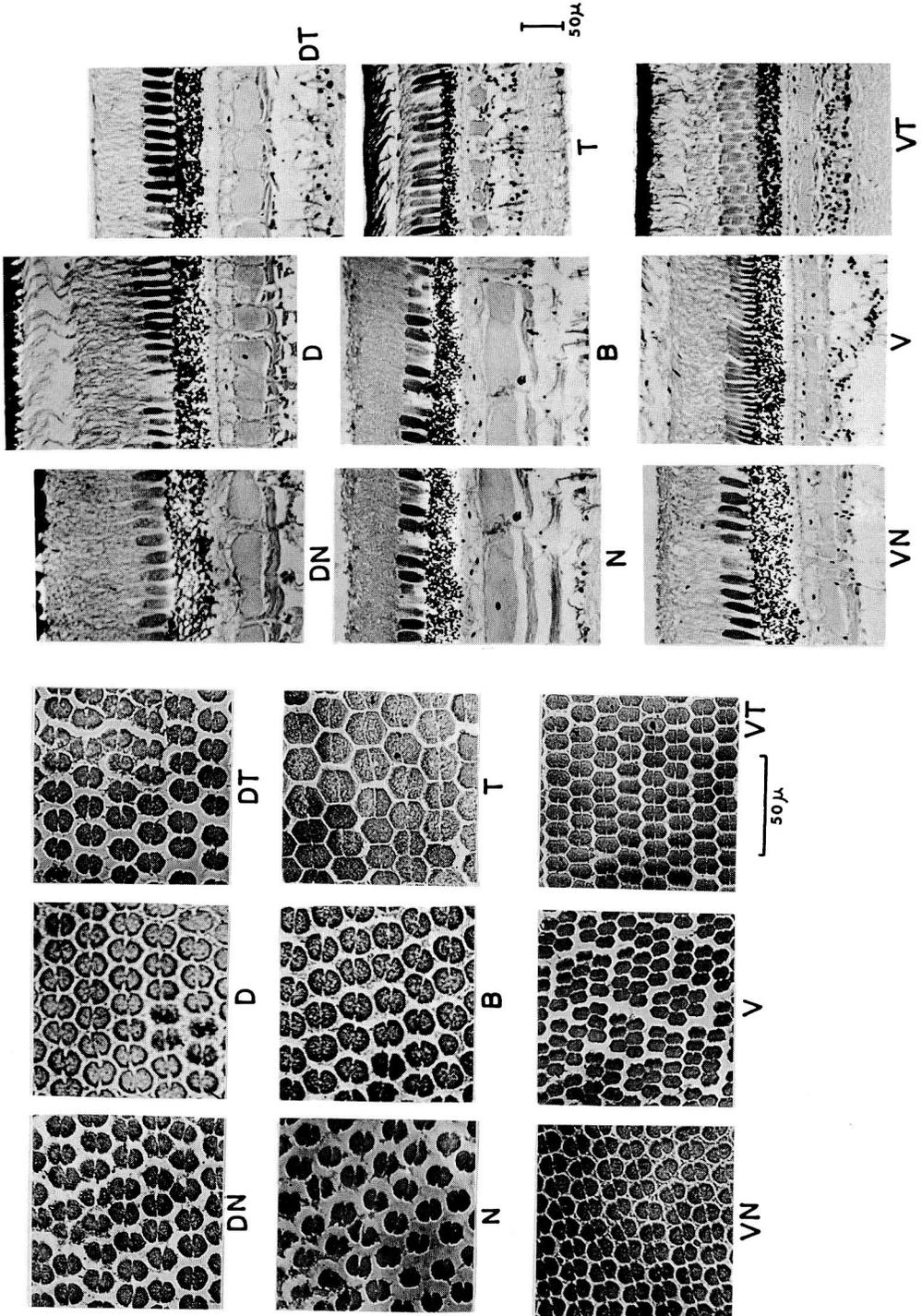
Retinal region	Yellowfin tuna (105 cm)			Bigeye tuna (149 cm)			Albacore (105 cm)		
	Cone	Nucleus	Ratio	Cone	Nucleus	Ratio	Cone	Nucleus	Ratio
Temporal	21	366	17.43	19	330	17.36	17(1)	331	18.39
Ventro-temporal	34	359	10.57	28	592	21.14	23(1)	316	13.17
Ventral	35	420	12.00	33	599	18.15	27	307	11.37
Ventro-nasal	31	398	12.93	20	553	27.65	21(1)	361	14.36
Nasal	25	401	15.76	21	627	29.86	17	480	28.24
Dorso-nasal	20	447	22.35	19	716	37.68	14(1)	437	29.13
Dorsal	21	434	20.67	22	732	33.27	16(1)	433	25.46
Dorso-temporal	23	499	21.70	17	591	34.76	17	425	25.00
Bottom	20	484	24.20	17	658	38.71	19(2)	537	25.57

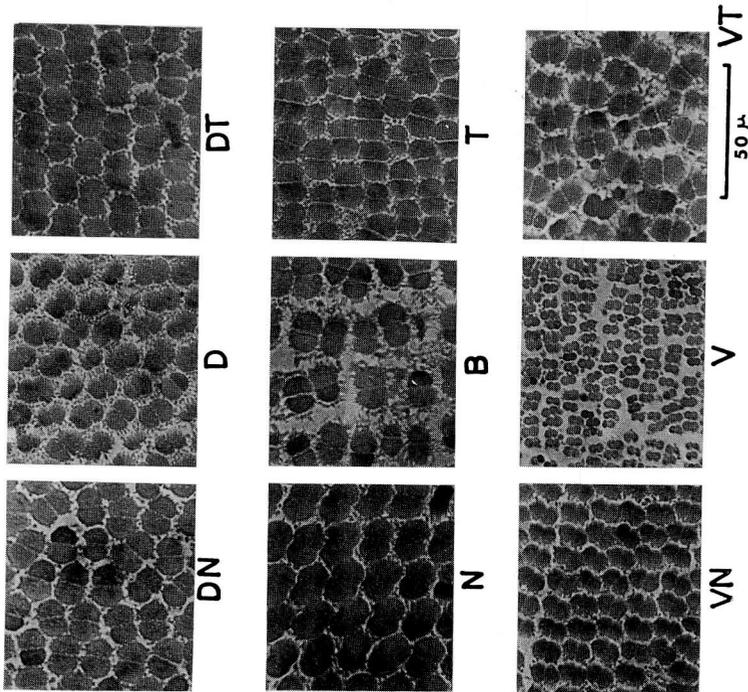
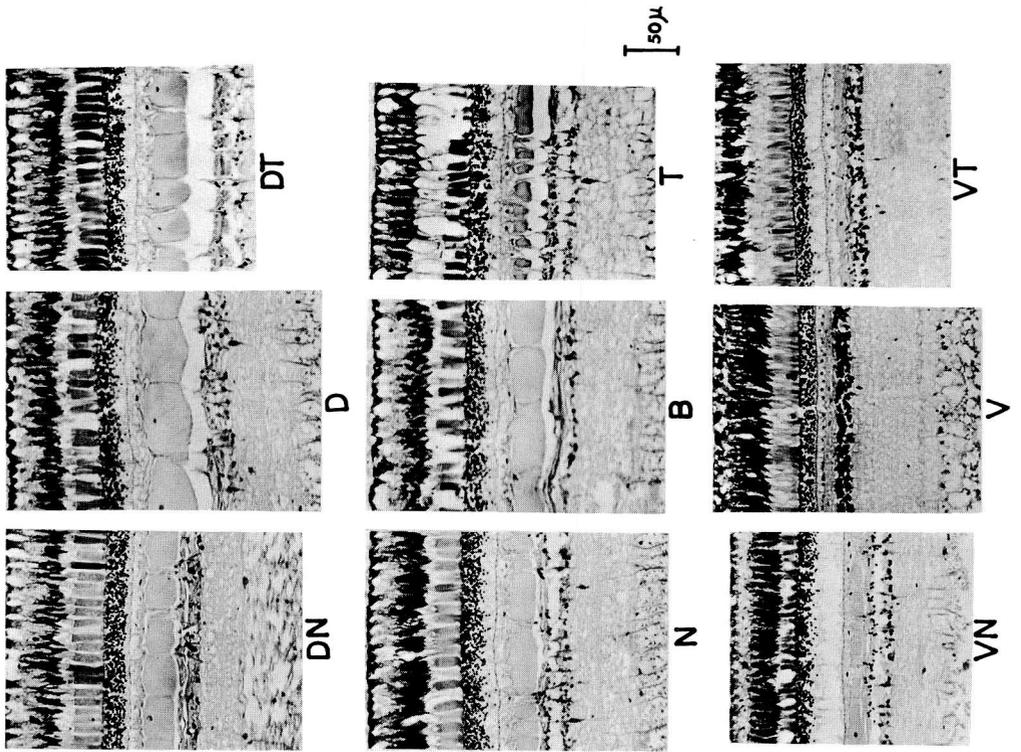
Retinal region	Striped marlin (175 cm)			Pacific blue marlin (150 cm)			Black marlin (190 cm)		
	Cone	Nucleus	Ratio	Cone	Nucleus	Ratio	Cone	Nucleus	Ratio
Temporal	34	448	13.18	34	394	11.59	35	472	13.49
Ventro-temporal	41	415	10.12	33	385	11.67	39	390	10.00
Ventral	41	400	9.76	34	336	9.88	40	387	9.68
Ventro-nasal	34(1)	377	10.77	28(3)	315	10.16	36	359	9.97
Nasal	33	389	11.79	27(3)	455	15.69	27(2)	346	11.93
Dorso-nasal	28	592	21.14	28	547	19.54	29	423	14.69
Dorsal	24	430	17.92	26	437	16.81	28	496	15.71
Dorso-temporal	35	565	16.14	34	434	12.76	33	543	16.46
Bottom	31	615	19.84	21	305	14.52	30	473	15.77

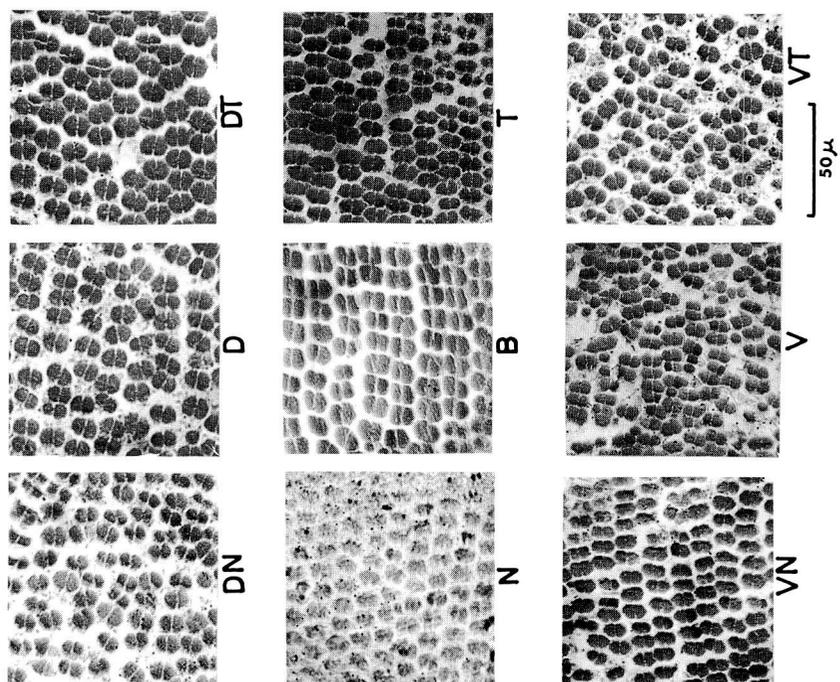
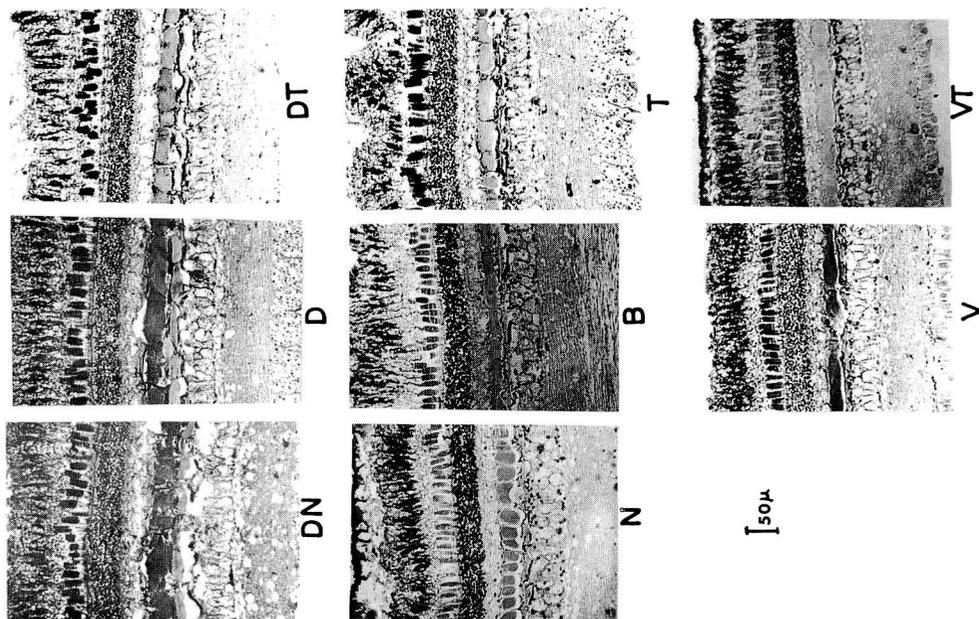
Explanation of Plates

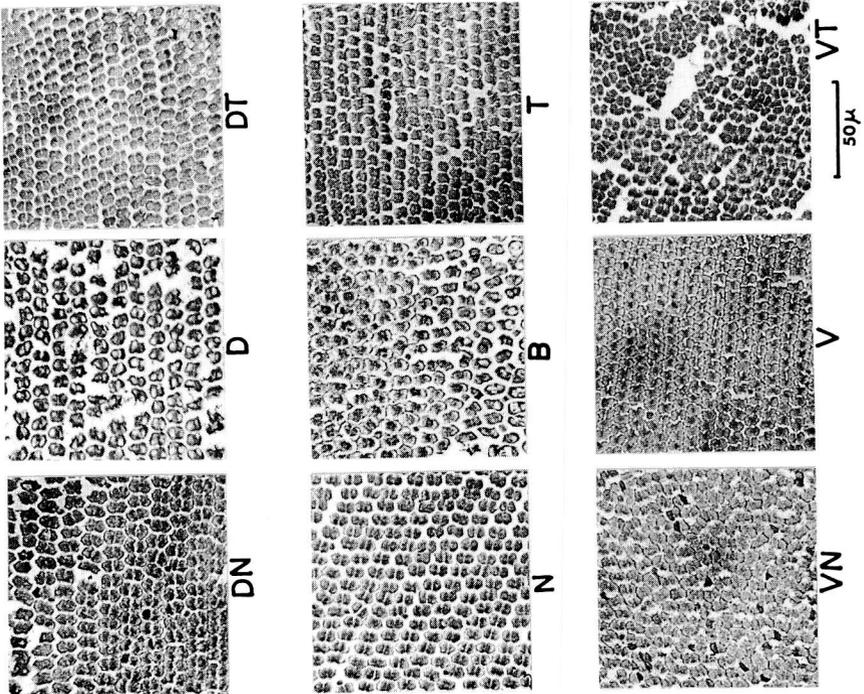
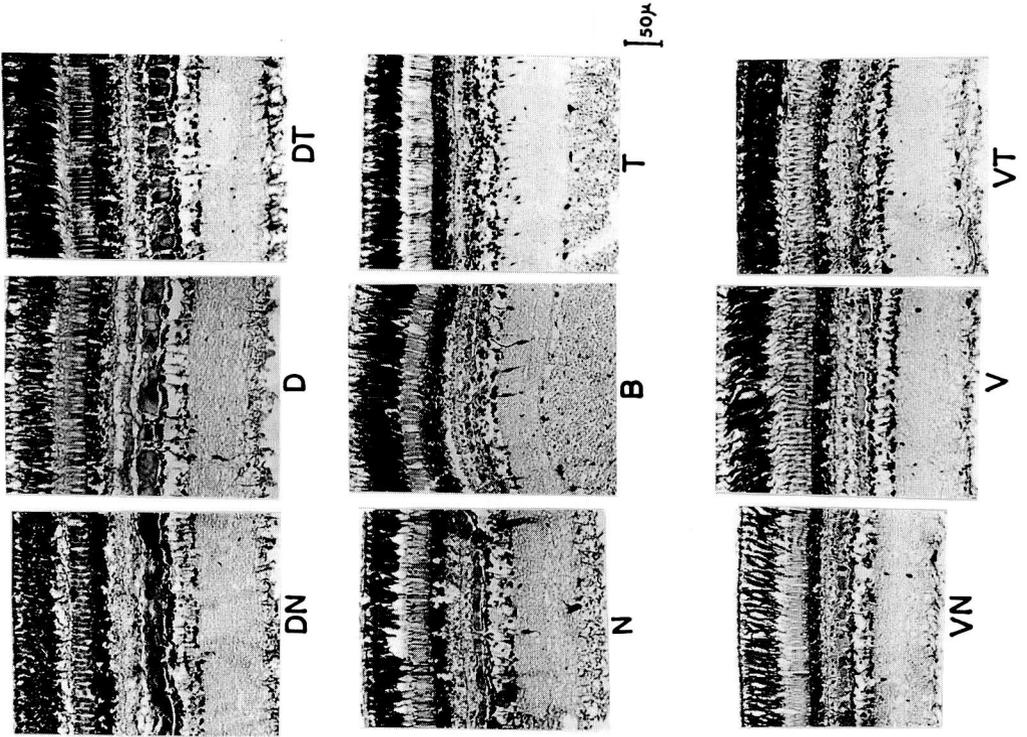
- Plate 1. Yellowfin tuna. Photomicrographs of tangential sections of visual cell layer showing the cone mosaic and cross sections in various retinal regions. Mayer's H.E. stain. B, bottom; D, dorsal; DN, dorso-nasal; DT, dorso-temporal; N, nasal; T, temporal; V, ventral; VN, ventro-nasal; VT, ventro-temporal.
- Plate 2. Bigeye tuna. As in Plate 1.
- Plate 3. Albacore. As in Plate 1.
- Plate 4. Bluefin tuna. Azan stain. As in Plate 1.
- Plate 5. Striped marlin. As in Plate 1.
- Plate 6. Pacific blue marlin. As in Plate 1.
- Plate 7. Broadbill swordfish. As in Plate 1.
- Plate 8. Black marlin. As in Plate 1.
- Plate 9. Photographs showing the shape of pupil and direction of sighting groove. A, yellowfin tuna; B, bigeye tuna; C, albacore; D, striped marlin; E, Pacific blue marlin; F, broadbill swordfish.
- Plate 10. Tapetum lucidum found in the retina of bigeye tuna. A to D, photomicrographs taken with polarizing microscope. Note the light reflected at the retinal tapetum can be seen bright in B and D. E, scanning electronmicrograph showing the retinal tapetum in a pigment epithelium cell.
- Plate 11. Photomicrographs (A and C) and scanning electronmicrographs (B and D) of the cross sections of the retina of yellowfin tuna (upper) and bigeye tuna (lower). Note the ramified outer segment of cone of bigeye tuna (D). Scale, 1 cm = 30 μ .
- Plate 12. Photographs showing the seriously damaged lures (top) and hooked albacore (middle) and skipjack tuna (bottom) with an inverted lure.

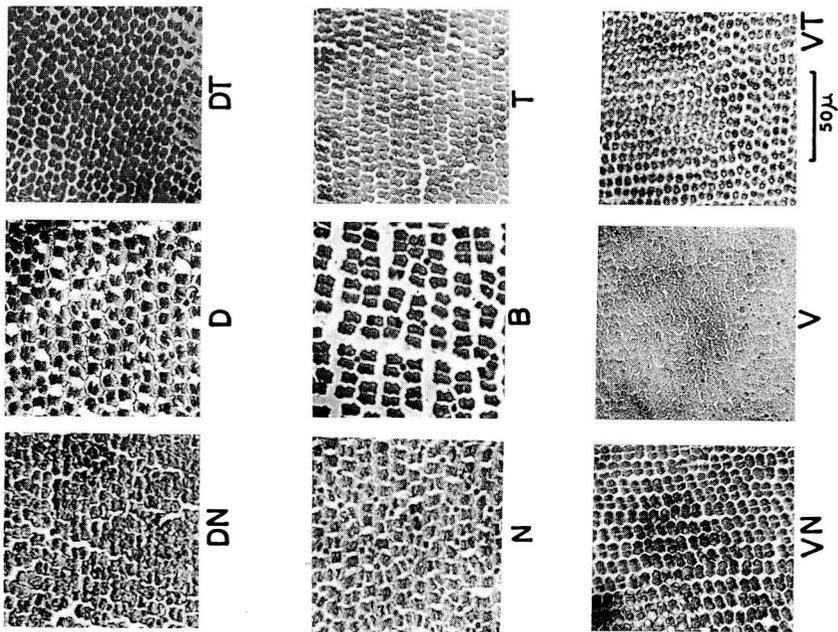
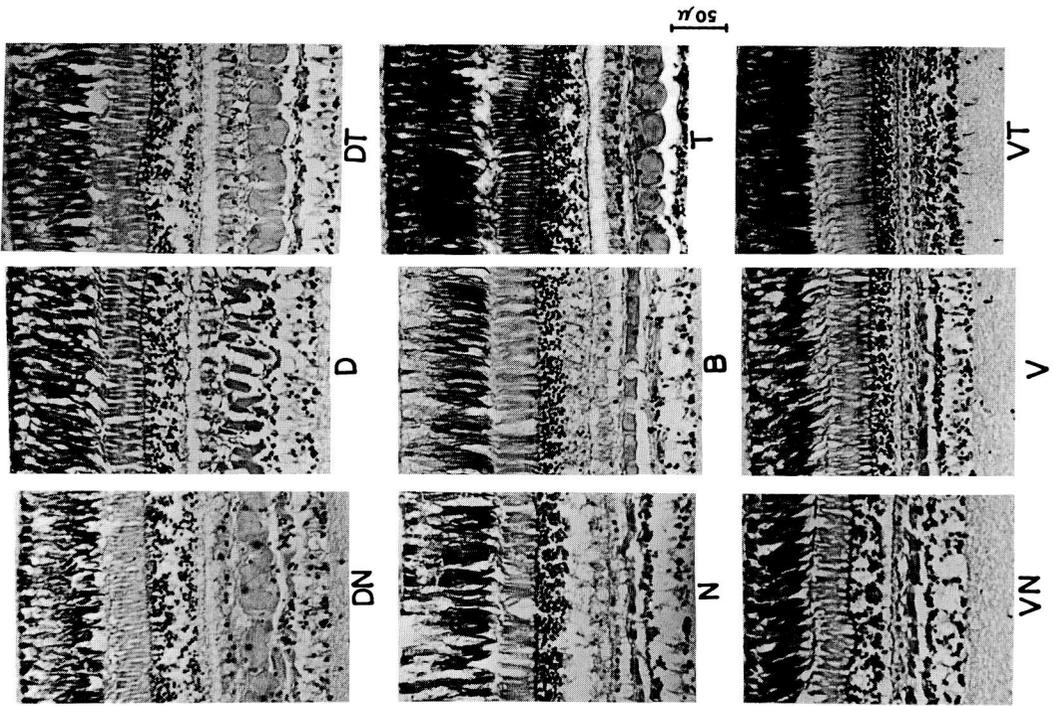


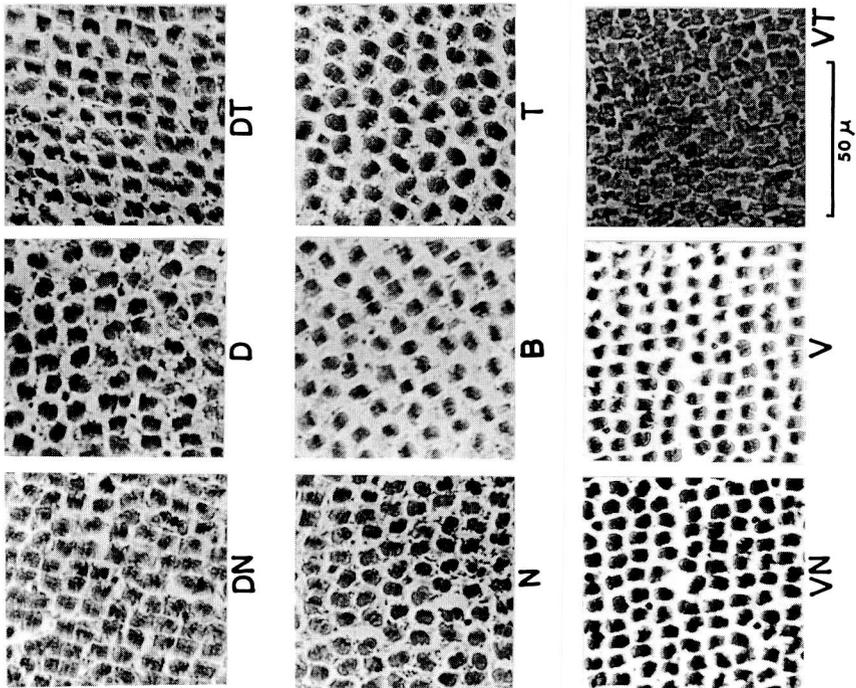
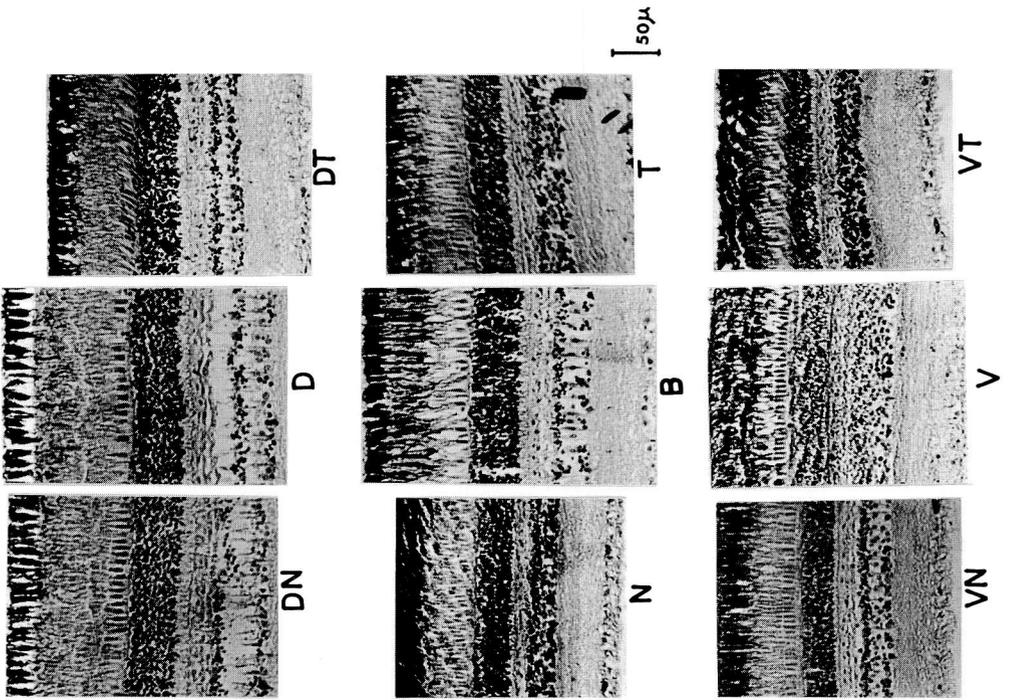


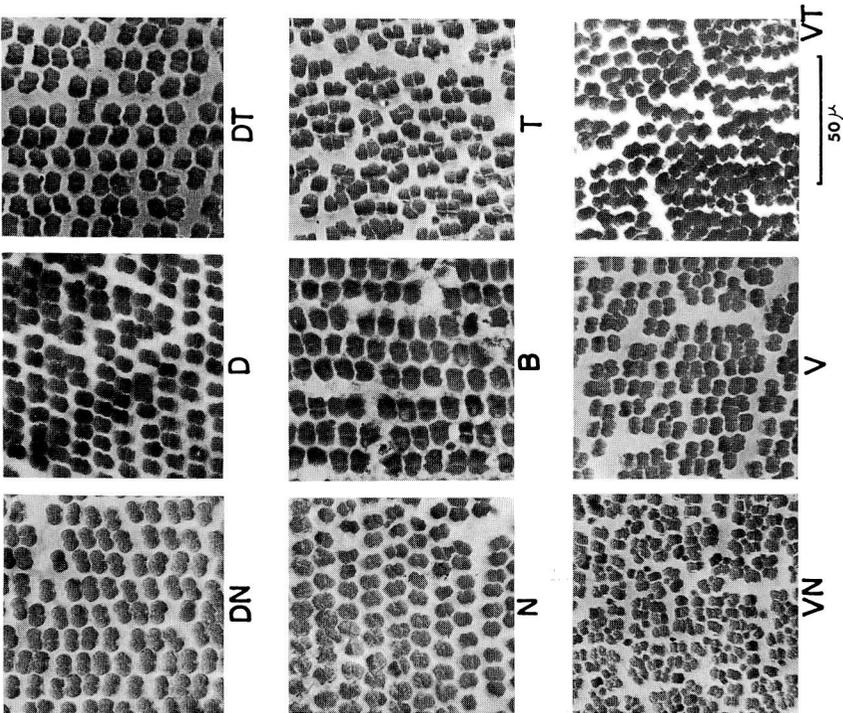
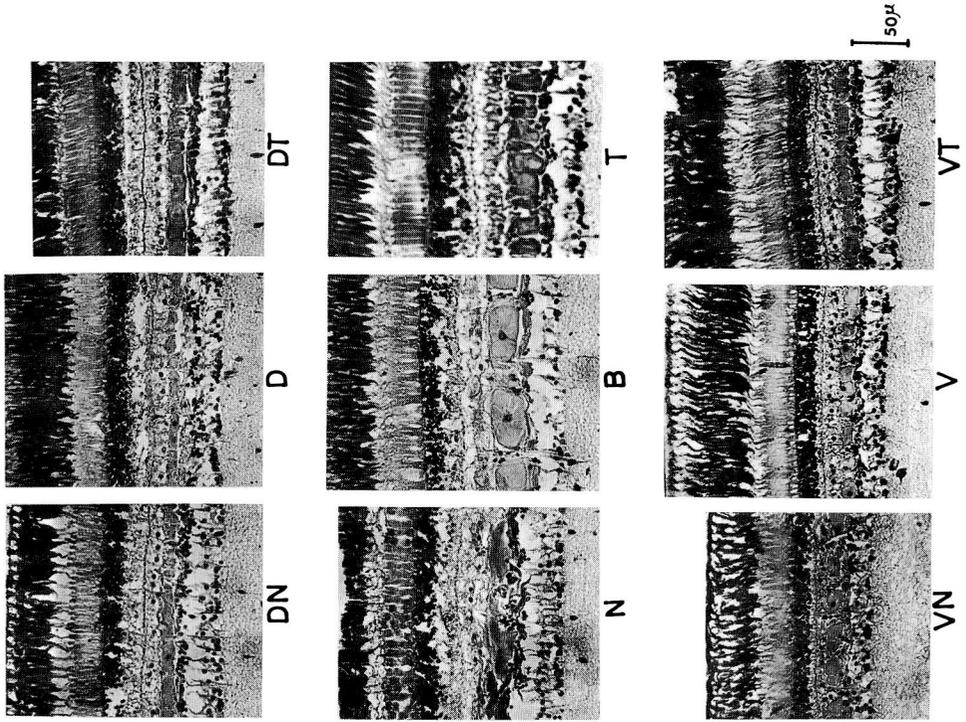


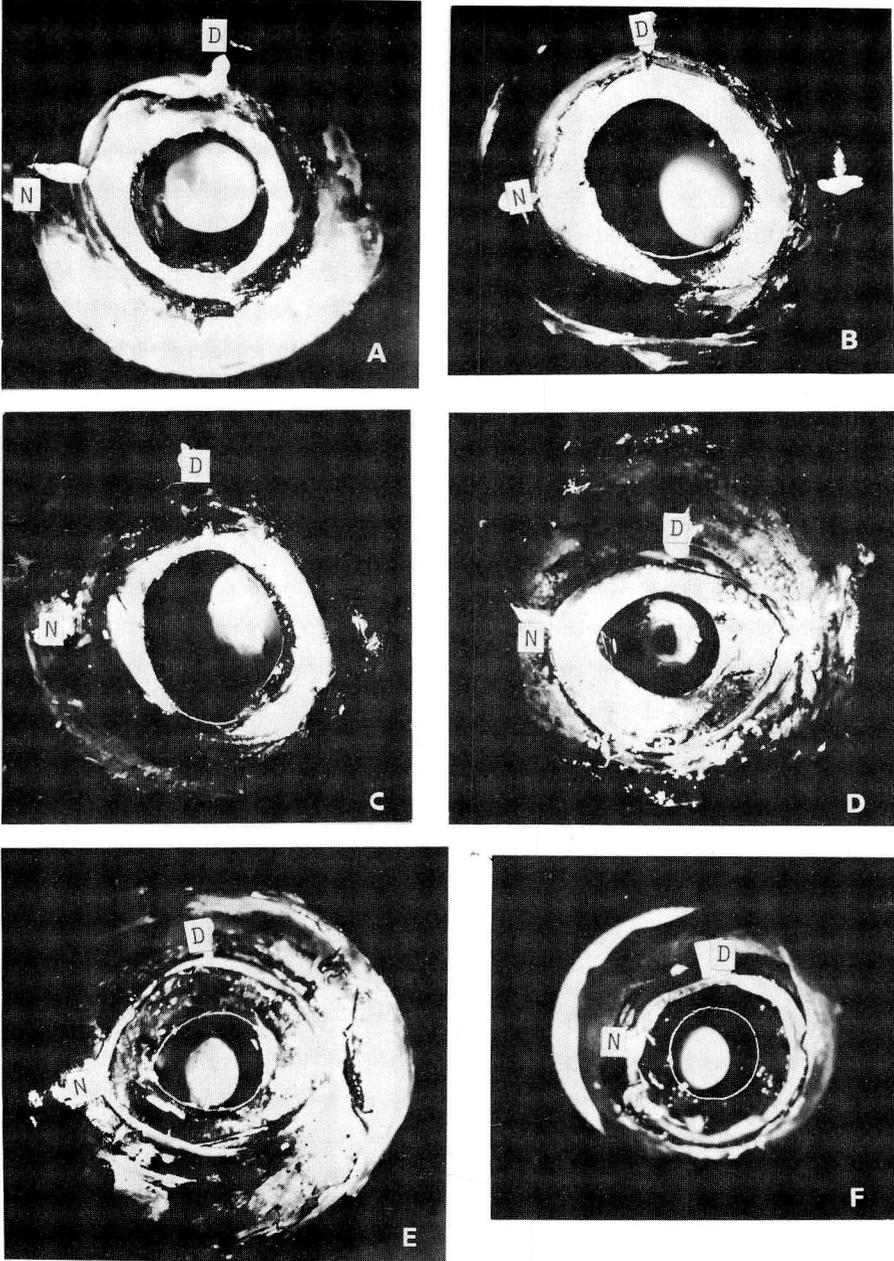


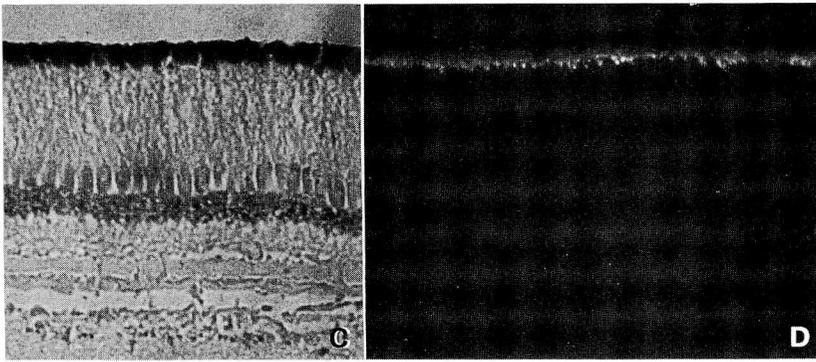
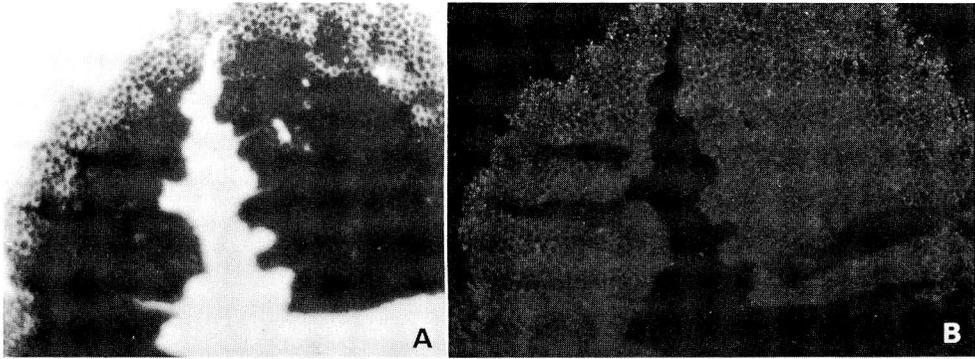




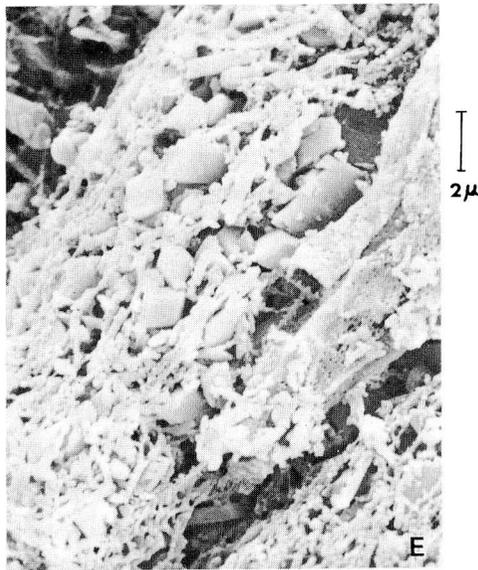


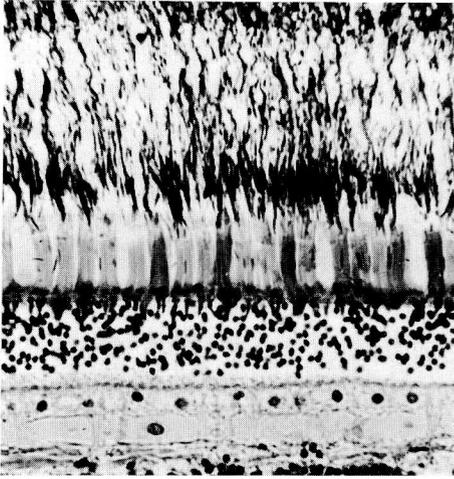




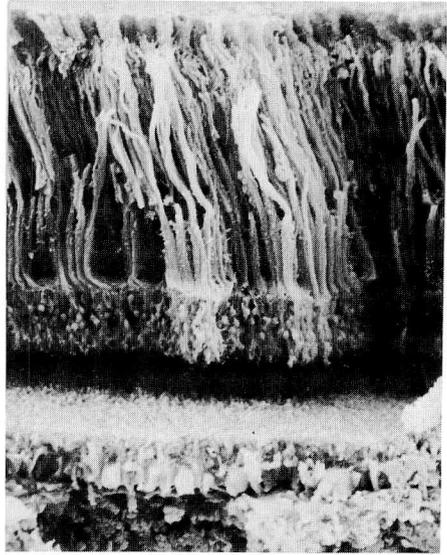


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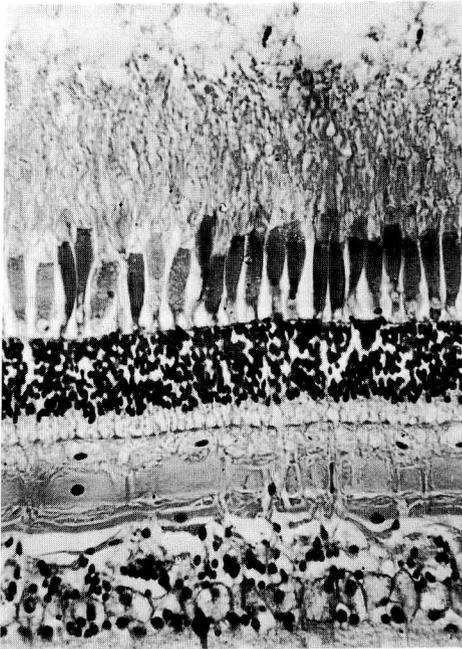




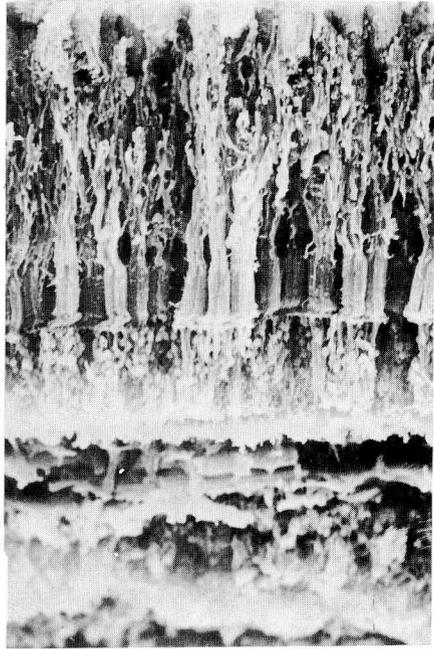
A



B



C



D

