Optical Characteristics of Snood in Tuna Longline Fishing^{*1}Yoshihiko Nakamura,^{*2} Yoshihiro Kurita,^{*2}
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The luminance and the spectral luminance from different snood materials in tuna longline fishing were measured to compare their optical characteristics with the background luminance constant. The luminance variation coefficient and inherent contrast of the zinc-plated wire were several times larger than that of nylon monofilament. The volumes of stimulation strengths reaching the tuna eye from nylon monofilament and red-colored wire smaller than those from zinc-plated and blue-colored wire were computed using spectral luminance reflectance, spectral irradiance and tuna spectral sensitivity. Since fish detect the presence of fishing gear by visual sense, it is considered that differences in optical characteristics between snood materials should have an effect on the tuna catch rate.

Snood material used in tuna longline fishing is generally zinc-plated wire; however, nylon monofilament is also used. The catch rate of nylon monofilament snood is reported to be better than that of wire snood¹⁾; the higher catch rate is considered to be due to its elasticity which brings about a difficulty for a fish to get free from hooks.^{*4} Moreover, many researchers have studied the characteristics of snood material regarding its handling and durability from the viewpoint of of users.²⁾ In the meantime, fish use no other senses except their visual sense to detect fishing gear when in its vicinity.³⁾ The catch rate, accordingly, relates to visual range of fishing gear and to fish vision. Furthermore, the resolving power of tuna eyes which ranges from 2 to 4 minutes of arc⁴⁾ is far superior to that in other fishes which range from 5 to 10 minutes of arc,⁵⁾ and also the resolving power to a line like a snood is several times more excellent than that with respect to a small target.^{6,7)} A similar phenomenon is also supposed to occur in the case of tuna. Therefore, it is beneficial to study the effect of the snood material on the tuna vision. This paper investigates how the optical characteristics of different snood materials — nylon monofilament, zinc-plated wire and two different

colored wires — influence catches made with such different snood materials.

Measuring Equipment and Method

Materials and Equipment

Four experimental snood materials of different diameters of 10 cm in length were examined (Table 1 and Fig. 1).

Measuring position to the equipment was fixed to be able to measure the luminance of the material under a constant condition in an experimental tank. As shown in Fig. 2 the measuring equipment consisted of two reels, R1 and R2, and four guide rollers G fixed to an iron frame I. They were installed in an experimental tank. The inside of the experimental tank and the equipment were painted with a matt black color except for the front of the tank. Filtrated seawater of 0.1 m^{-1} in attenuation coefficient was poured into the experimental tank up to 30 cm deep.

A white-colored fluorescent lamp, almost flat in spectral distribution, was used to scatter the irradiation from the top of the tank through an opal glass for the lighting in the tank. The illuminance was 4501x at the measuring position

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^{*4} Stated by Mr K. Ashizawa of Shooyoo Co., Ltd. in a conversation at Tokyo Harigane Kogyo Co., Ltd. on November 11, 1989.

Table 1. Diameter of snood materials used in this study

Experimental lines		Diameter (mm)
Nylon monofilament fiber	#80	1.41
	#100	1.65
	#120	1.80
	#150	2.02
	#200	2.35
Zinc-plated wire snood (3+9)	#28	1.60
	#29	1.48
	#30	1.33
	#31	1.23
Zinc-plated wire snood (3×3)	#28	1.54
	#29	1.42
Red-colored wire snood (3+9)	#30	1.33
Blue-colored wire leader (3+9)	#30	1.33

The numbers in parenthesis indicate the number of wire composed of a wire snood respectively.

measured by a small ALM-1 (Alec Electronics) underwater illuminometer.

The luminance was measured by a BM-5 (Topcon) luminance meter mounted with a close-up lens of 0.2 degree of arc in visual angle from the front of the experimental tank. The distance

Fig. 1. Cross section diagram of snood materials used in this study.

between the material and the luminance meter was fixed at 5 cm. The spectral luminance was measured by a SR-1 (Topcon) spectral luminance meter with 0.2 degree of arc in visual angle.

Method

The measurement was carried out in a dark room. The snood materials had been submerged in seawater for 30 minutes before the experiment. The material was coiled up on reel R2 and then one end of the material was led to the other reel R1 through four guide rollers G. Reel R1 was rotated to wind another end of the material every 5 cm in length from reel R2. As the luminance of twisted wire varied by location, the center part of the material was measured by shifting the material vertically. For each material 20 different points were measured. Both of the illuminances in the air and in the water were measured simul-

Fig. 2. Diagrams illustrating the experimental equipment used in this study.

M: luminance meter H: snood material
 O: opal glass I: iron frame
 G: guide roller R: reel of 20 cm in diameter
 L: white-colored fluorescent lamp of 15w

taneously. The seawater in the experimental tank was renewed before each experiment in the morning and in the afternoon to prevent the influence of dust on the luminance.

The spectral luminance reflectance $R(\lambda n)$ is defined as follows:

$$R(\lambda n) = \frac{S(\lambda n)}{P(\lambda n)} \quad (1)$$

where $S(\lambda n)$ and $P(\lambda n)$ are the spectral luminances from the material and the WS-2 (Topcon) standard diffusing reflector. They were measured from 380 nm to 760 nm in 5 nm units of wavelength in the air respectively.

Results and Discussion

Luminance

In this experiment the background luminance was kept constant so that the luminance from the snood materials was used to compare their optical characteristics. Fig. 3 shows examples of luminance measurements on nylon monofilament No. 80, zinc-plated wire (3+9) No. 30 and red-colored wire No. 30 respectively. The thickness of snood materials was nearly equivalent in diameter as shown in Table 1. Nylon monofilament produced luminance of an almost completely flat distribution. In the case of zinc-plated wire (3+9), the luminance and its variation among points were large. At the points of large luminance, unevenness in the zinc plating was observed in some places. This was considered to be due to spotted plating. The luminance of red-colored wire was also rather large and varied from point to point.

Table 2 shows the observed values of mean luminance L (cd/m^2), its standard deviation σ (cd/m^2) and variation coefficient ν for different materials varying in thickness, respectively. The mean luminance of nylon monofilament ranged from 0.3 to $0.4 \text{ cd}/\text{m}^2$, approximately one-third that of zinc-plated wire. The luminance variation coefficient of nylon monofilament was small: 0.02 to 0.04. The mean luminance of nylon monofilament L (cd/m^2) increased almost linearly with its thickness D (mm). The relationship between L and D showed the following equation formula (correlation coefficient, $r=0.98$), $L=0.132D+0.095$. It is considered that both mean luminances in No. 150 and No. 200 nylon monofilament are rather fluctuant: the cross section of the nylon monofilament becomes larger when the

Fig. 3. Hookline luminance distributions in clear water of 0.1 m^{-1} .

Symbols ○, □ and ● represent the nylon monofilament, zinc-plated wire and red-colored wire snoods respectively.

thickness increases resulting in that the luminances in the center part and both sides to appear fluctuating.

The mean luminance of zinc-plated wire (3+9) ranged from 1.3 to $1.6 \text{ cd}/\text{m}^2$, larger than any other. In this case, the relationship between L and D was uncertain. The luminance variation coefficient of zinc-plated wire (3+9) ranged from 0.22 to 0.27. The luminance variation coef-

Table 2. Mean luminance (L , cd/m^{-2}), standard deviation (σ , cd/m^{-2}) and variation coefficient (v) of unused materials

Experimental	lines	L (cd/m^2)	σ (cd/m^2)	v
Nylon monofilament fiber	No. 80	0.287	0.008	0.027
	No. 100	0.298	0.007	0.025
	No. 120	0.306	0.012	0.038
	No. 150	0.425	0.007	0.016
	No. 200	0.378	0.011	0.030
Zinc-plated wire snood (3+9)	No. 28	1.464	0.367	0.251
	No. 29	1.462	0.391	0.267
	No. 30	1.584	0.396	0.250
	No. 31	1.332	0.291	0.219
Zinc-plated wire snood (3×3)	No. 28	1.757	0.733	0.417
	No. 29	1.348	0.587	0.435
Red-colored wire snood	No. 30	1.496	0.289	0.192
Blue-colored wire snood	No. 30	0.528	0.091	0.173

ficients of zinc-plated wire (3×3) were larger than those of zinc-plated wire (3+9). It is thought that there is an uneven condition in the cross section of the wire (3×3) since there is a construction of 9 wires and a twist as shown in the cross section diagram Fig. 1.

The mean luminance of red-colored wire was nearly the same as that of zinc-plated wire, but the mean luminance of blue-colored wire was smaller than that of zinc-plated wire. The luminance variation coefficients of both colored wires were the smallest of all wires. This is understood to have been caused by painting, which makes all parts of unevenness of the surface of colored wires smooth.

It is a remarkable feature, in these circumstances, that the luminance variation coefficient of nylon monofilament is considerably smaller than that of zinc-plated wire. It is reported that catch rate decreases as the variation coefficient increases in squid jigging fishing.⁸⁾ Viewed in this light, a small variation coefficient most likely has some relationship with an increase in tuna catch rate due to similar visual sense characteristics. It is also considered that colored wires with a small variation coefficient can cause positive effects in increasing tuna catch rate.

Spectral Luminance

The degree of decrease in light in seawater is larger than that in air and differs considerably in wavelength accordingly.⁹⁾ Spectral irradiance

distribution varies by sea areas.^{10,11)} Furthermore, color vision is absent in tuna,⁴⁾ but visual sensitivity varies with wavelength. Therefore, it is thought that the spectral luminance reaching the tuna eye from the snood varies remarkably with the optical characteristics of snood, fishing ground and tuna eye.

Firstly, Fig. 4 shows the spectral luminance reflectances $R(\lambda n)$ of nylon monofilament No. 80, zinc-plated wire (3+9) No. 30, red-colored wire No. 30 and blue-colored wire No. 30 for different wavelengths λn respectively. They were calculated using the formula (1). The spectral luminance reflectances $R(\lambda n)$ of nylon monofilament and zinc-plated wire (3+9) were approximately 0.02 and 0.12 respectively, varying very little with different wavelengths. That being the case, the inherent contrast of the snood material could be computed with the $R(\lambda n)$ value and the luminance reflectance from the water background assumed to be 0.02.¹²⁾ The inherent contrast of nylon monofilament was quite smaller than that of zinc-plated wire (3+9) making nylon monofilament difficult to see for tunas.

The $R(\lambda n)$ value of red-colored wire was about 0.02, rather small up to the wavelength of 550 nm; but was about 0.37 at 640 nm. The $R(\lambda n)$ value of blue-colored wire was 0.17 at its maximum value at the wavelength of 465 nm. From the aforementioned items, it is understood that the $R(\lambda n)$ values of colored wires vary with different

Fig. 4. Spectral distribution of luminance reflectance (R). Symbols ○, □, ●, and ▲ represent the nylon monofilament, zinc-plated wire, red-colored wire and blue-colored wire snoods respectively.

wavelengths.

Secondly, how the $R(\lambda n)$ value of the material varies with different fishing grounds and wavelengths must be discussed. The optical classification of ocean water based on spectral transmittance of downward irradiance was reported by Jerlov.¹⁰⁾ Here the northern part of Indian Ocean was taken as an example where the experimental operations of tuna longline fishing have been carried out in recent years.¹⁾ According to Jerlov's optical classification, the aforementioned sea area is assumed to be Ocean Type $IA^{10)}$ in which the spectral distribution of downward irradiance decreases with an increase in depth and varies with different wavelengths. The distribution for the horizontal component decreases to approximately 80% of the downward light,¹⁰⁾ but it is almost the same relatively. Therefore, the spectral luminance reflectance $RT(\lambda n)$ from snood at a tuna swimming layer in the northern part of Indian

Ocean is obtained as a product of the $R(\lambda n)$ and of the spectral irradiance $T(\lambda n)^{10)}$ according to wavelength. Fig. 5 shows the $RT(\lambda n)$ made a trial calculation by varying wavelengths at a tuna swimming layer to be 100 m deep. The $RT(\lambda n)$ peaked at around 470 nm for every snood material, and the zero value is over 550 nm. The largest $RT(\lambda n)$ is that of blue-colored wire, and the next largest is that of zinc-plated wire ($3 \div 9$). The $RT(\lambda n)$ of nylon monofilament and red-colored wire were extremely smaller in comparison with those of the two materials previously mentioned. In comparison between Fig. 4 and Fig. 5, it is found that the $RT(\lambda n)$ have greatly declined in red-colored wire, and the former spectral characteristics have also disappeared. Under these circumstances it is understood that the $RT(\lambda n)$ of snood material is greatly influenced by water type.

To take into consideration the spectral sensi-

Fig. 5. Spectral distribution of luminance reflectance (RT) at the layer of 100 m deep in the northern part of Indian Ocean.

Fig. 6. Relative luminance (RTL) reaching yellowfin tuna for different wavelengths at the layer of 100 m deep in the northern part of Indian Ocean. Same symbols as fig. 3 used.

tivity of fish eye, the relative luminance $RTL(\lambda n)$ for yellowfin tuna *Thunnus albacares* was calculated. The $RTL(\lambda n)$ was obtained as a product of the $RT(\lambda n)$ and the yellowfin tuna spectral sensitivity $L(\lambda n)$, the peak of which was at 490 nm of wavelength.⁴⁾ Fig. 6 shows the $RTL(\lambda n)$ calculated for the respective materials at the depth of 100 m in the northern part of Indian Ocean. In this figure it is considered that the value of integration along the spectral distribution curve in a range of visible spectrums from 400 nm to 700 nm is equivalent to the volume of stimulation strength to a yellowfin tuna eye. When the volume of stimulation strength from nylon monofilament is defined as a 1.0, the volumes from blue-colored wire, zinc-plated wire (3+9) and red-colored wire are 8.6, 6.0 and 0.7 respectively. The volumes of stimulation strength from nylon monofilament and red-colored wire are smaller, but those from blue-colored wire and zinc-plated wire (3+7) are larger. Namely, as shown in Table 2 the luminance of red-colored wire is almost the same as that of zinc-plated wire (3+9); but the volume of stimulation strength to a yellowfin tuna eye becomes small. Under these circumstances, the nylon monofilament and red-colored wire are less visible than the other two snood materials. Furthermore, it is well known that when fish come close to fishing gear they have no other sense except the visual sense to detect its presence.³⁾

Therefore, it seems that the catch rate of yellowfin tunas is different in the case of using blue-colored and red-colored wire snoods which have the largest and smallest volumes of stimulation strength. Merely for test purposes, the volume for the demand of two different colored wire snoods in relation to the fluctuation in tuna catch rate was investigated. Consequently, it became evident that red-colored wire snood holds 90% of the colored wire snoods which are being used

at the present time, although both colored wire snoods were developed to prevent a naked wire snood from corroding. Thus, the better catch rate for red-colored wire snood could be attributed in part to the invisibility of this material.

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