STUDIES ON THE VISUAL RANGE OF NET TWINES IN WATER–II

Masahiro KAJIHARA*, Naoichi INOUE* and Susumojo SHINGGIH*

I. Introduction

The visual range of fishing net in the sea has been a subject of considerable interest among scientists and fishermen in recent years. On this subject, many studies were carried out both in the experimental tank and in the sea. Recently, Yoshimuta *et al.*[1] attempted to determine the horizontal visual range of coloured nets by plunging them in Tateyama Bay and they suggested that important factors for the visibility of coloured nets were not only the luminous reflectance of net twines and the threshold of their vision but other factors such as physical characteristics of the net, as well as the colour contrast between the surrounding water and the net in it.

In a previous report (Inoue *et al*)[2], the horizontal visual range of net twines illuminated by the parallel light beam was preliminarily studied to obtain mainly the relationship between the visual range and the turbidity. In succession to the previous experiments newly devised experiments were carried out and theoretical equations were derived to explain the relation between the visual ranges of net twines and their luminous reflectance in turbid water.

II. Method and Materials

Measurements of the visual range of the net twine in various turbid waters and in various coloured lights were carried out in a dark room by the same observer, using newly constructed water tank and its attached apparatus shown in Fig. 1. The tank is 300 cm in length, 30 cm in width and 40 cm in depth, the inner side of which is painted black. A light source (P) is a tungsten lamp of 5 volts and its current is always adjusted to 5 A during the measurements. The light beam which is collimated with lenses (L_1 L_2) passes through a window glass (W) and illuminates the twines which are pinned up to both sides of a movable frame (N). Using a handle (H), the frame is moved forward and then backward to the observer's eye (E) till the vision of the twine disappears and re-appears respectively. The mean value of these two kinds of distances between the frame and the observer's eye is defined as the visual range of the twine in this report. The turbidity in the tank water was altered by varying the quantity of dissolving white poster colour in

* *Division of Oceanography, Institute of North Pacific Fisheries, Faculty of Fisheries, Hokkaido University* (北海道大学水産学部北洋水産研究施設海洋部門)

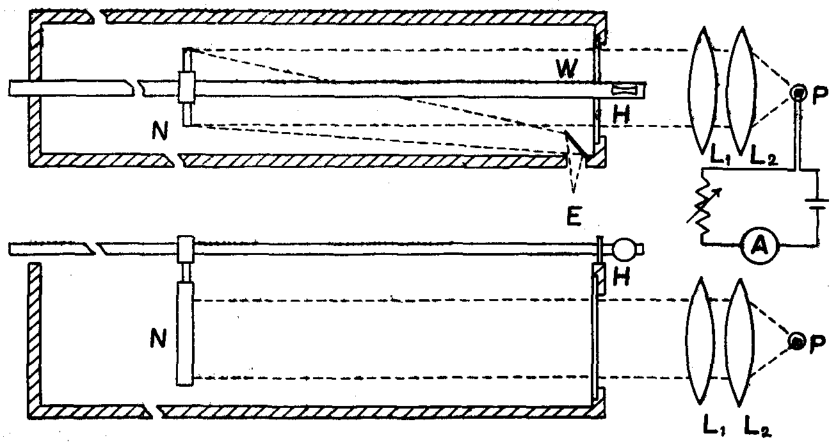

Fig. 1. Schematic diagram of the apparatus for measuring the visual range. (the upper figure is the plane figure and the lower the side view)
P; light soruce, L_1 L_2; lenses, H; handle, W; window glass, F; filter, N; net frame, M; mirror, E; position of the eye

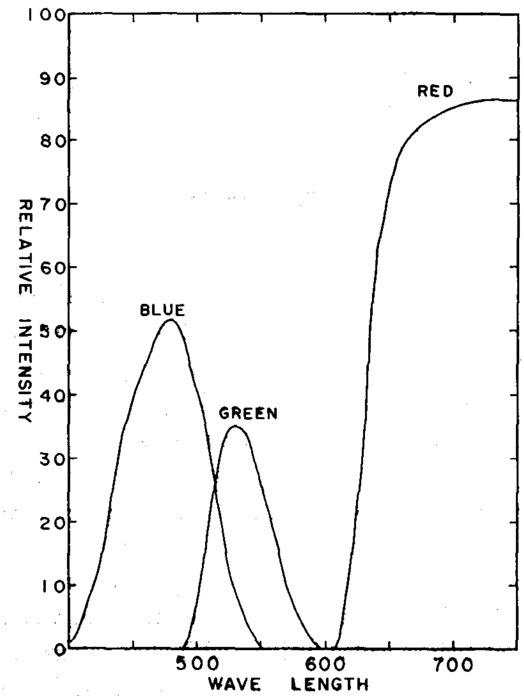

Fig. 2. Absorption characteristics of a blue, green and red filter

it and was measured by a water-tight selenium photocell under the same light condition which was used for measurements of the visual ranges. The absorption characteristics of these colour filters are shown in Fig. 2.

Materials used in these experiments are given in Table 1.

Table 1. Materials

Group	Materials	Diameter (mm)	Construction	Colour	Note
1	Amilan	0.73	210D: 3/12	Red	
	〃	〃	〃 〃	Green	
	〃	〃	〃 〃	Black	
	〃	〃	〃 〃	Blue	
	〃	〃	〃 〃	Yellow	
	〃	〃	〃 〃	Brown	
2	Nylon	〃		Transparent	Monofilament
	Amilan	0.71	210D; 3/15	Dark-Grey	Kokai-Colour
		〃	〃 〃	〃	Taiyo-Colour
3	Grilon	0.50	〃 3/6	White	
	〃	0.55	〃 3/9	〃	
	〃	0.65	〃 3/12	〃	
	〃	0.75	〃 3/18	〃	
	〃	0.85	〃 3/27	〃	
4	Paper	0.70		〃	
	〃	1.0		〃	
	〃	2.0		〃	
	〃	3.0		〃	
	〃	4.0		〃	
	〃	5.0		〃	

III. Result

Visual Range

For convenience' sake the sample twines are classified into four groups. The first one is composed of different coloured twines with the same diameter. Measured values of the visual range are plotted against the turbidity in Fig. 3. In any filter light, the visual ranges of yellow, blue, brown and green twines decrease in accordance with the increase of turbidity and each of these curves indicates almost the same slope. However, the slope of the experimental curves of the black and the red twine obtained in blue and green filter light, and of the black twine obtained in red filter light are quite different from those of other curves. For the experiments of the second group, the net twines which are generally used in salmon fisheries are utilized. As shown in Fig. 4, the visual ranges of coloured multifilament twines called Taiyo and Kokai colour show almost the same values but that of transparent monofilament twine is much smaller than those of the other two twines. Nevertheless, comparing with the results given in Fig. 3, the visual range of transparent monofilament twine is not always smaller than

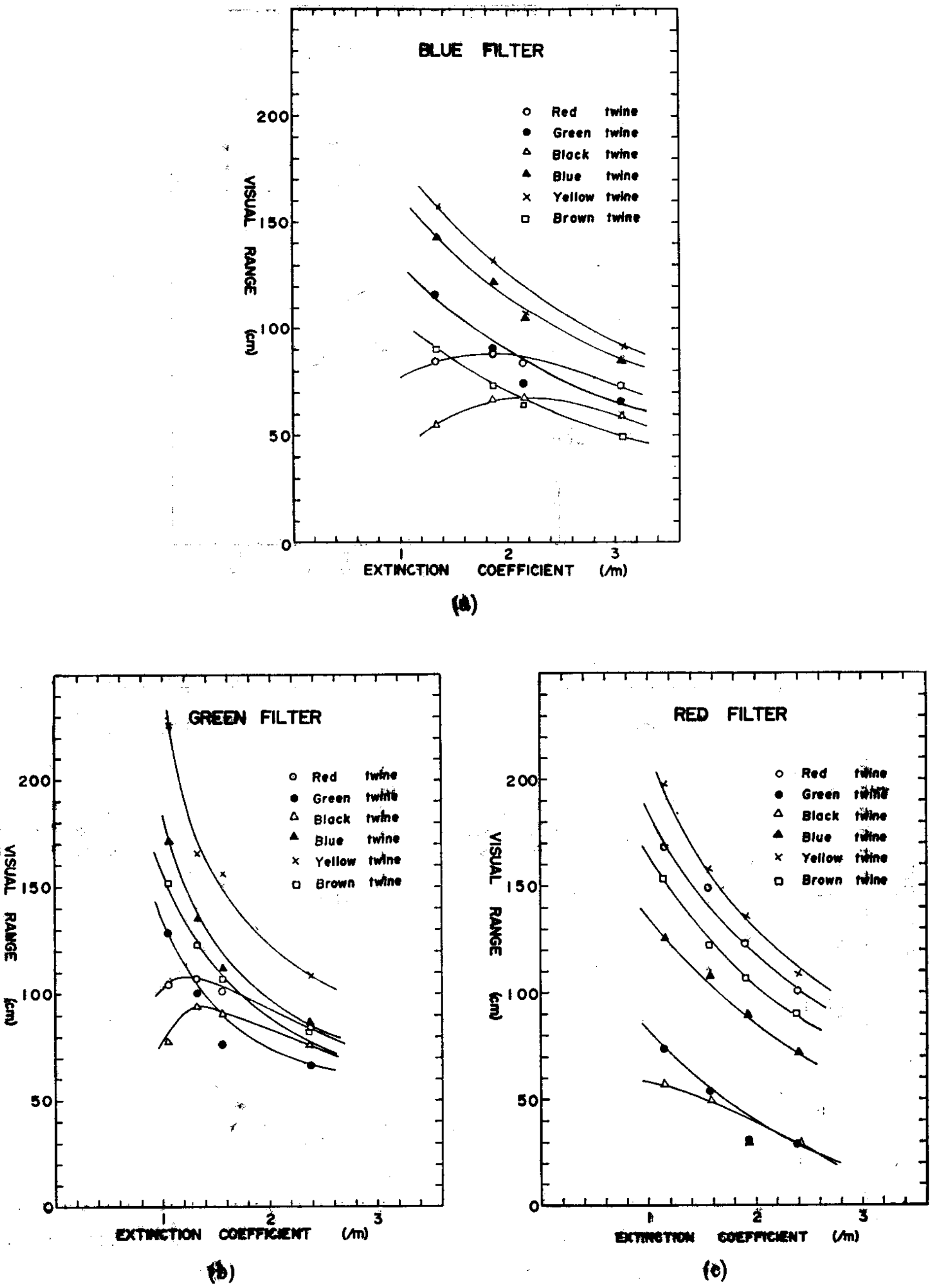

Fig. 3. Relation between the visual range of coloured net twines and the extinction coefficient of tank water

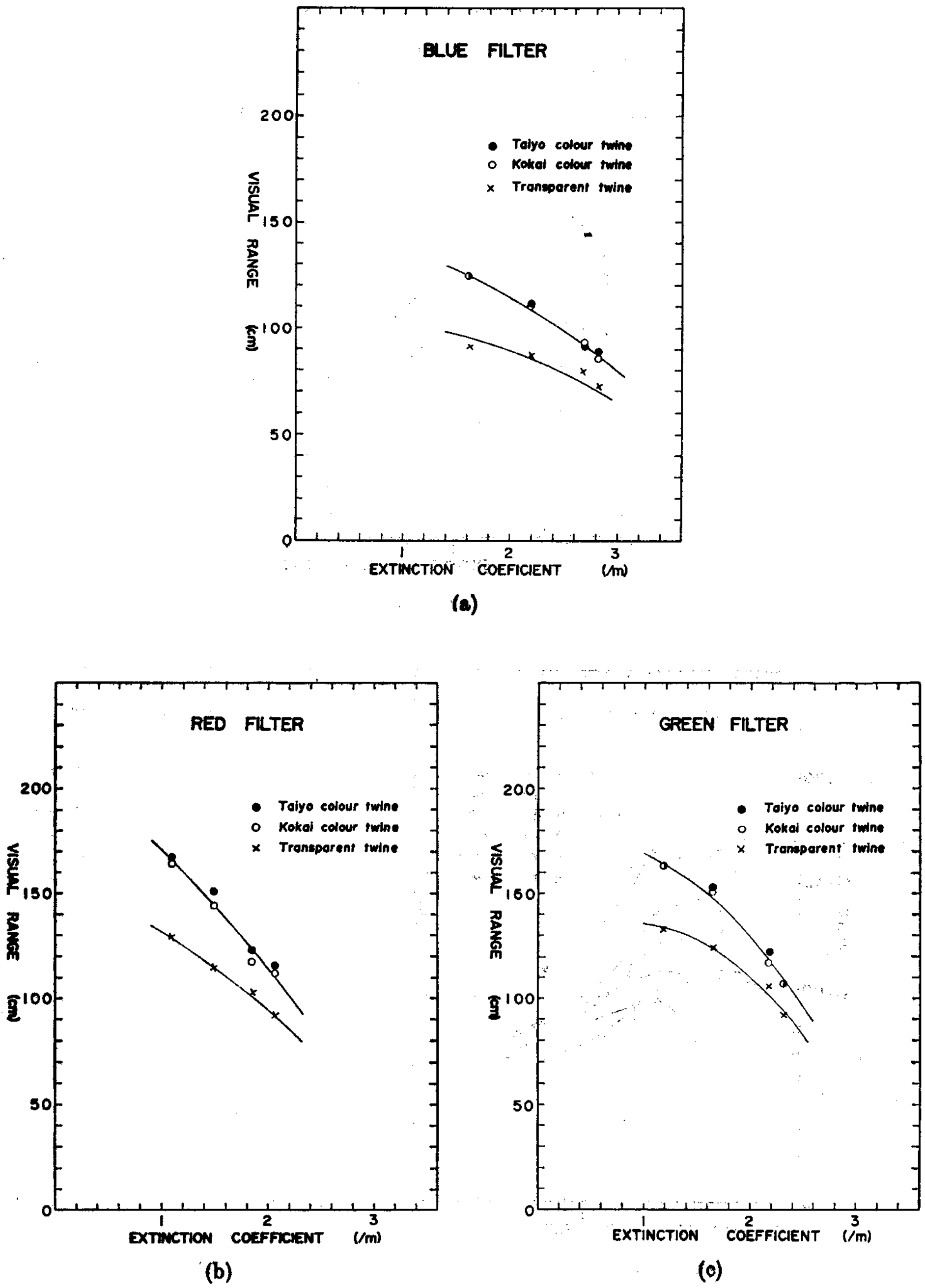

Fig. 4. Relation between the visual range of net twines used in salmon fisheries and the extinction coefficient of tank water

those of the first group twines. But if less turbid water such as ocean water is used for the experiment the visual range of transparent twine will be smaller than those of the first group twines judging from the tendency of the curves as shown in Fig. 3 and Fig. 4. An example of the results obtained from the third group to study the relation between the visual range and the diameter of twine is shown in Fig. 5. In any turbid water their visual ranges increase with the increase of their diameter. The description of the results of the fourth group should be deferred to a later paragraph for the reason that these samples are not twines but are white paper stripes. They are used to study the relation between the visual range and the width of paper stripes as for the third group.

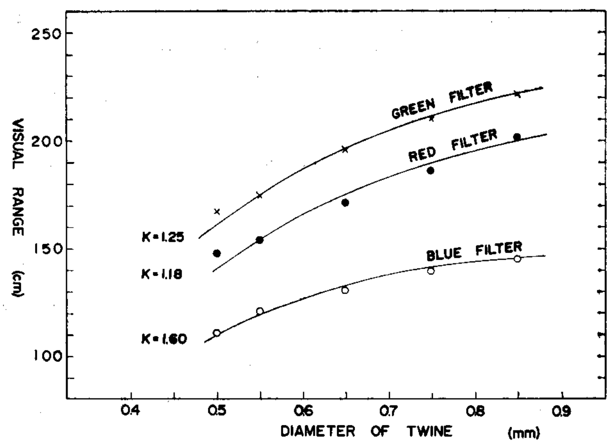

Fig. 5. Relation between the visual range and the diameter of twines

Luminous reflectance

Luminous reflectances of the twines were measured by using a scattering meter with specially designed adapters mounted in it, the schematic diagram of which is shown in Fig. 6. The light beam from a light source (P) is collimated and made monochromatic through lenses (L) and a filter (F). It passes through a parallel

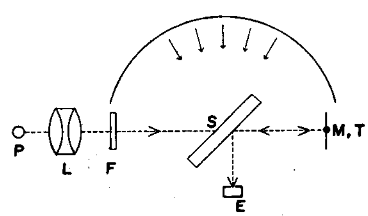

Fig. 6. Schematic diagram of the apparatus for measuring luminous reflectance of the twine

P; light source, L: lense, F; filter, S; splitter, M; mirror, T; twine, E; phototube plane splitter (S) mounted at the center of the scattering meter and reaches the twine (T) or the mirror (M) which is used to measure the intensity of the incident light illuminating the twine. A small part of the light beam which is reflected at the mirror or scattered on the surface of the twine comes into the phototube (E) through reflection on the surface of the splitter. The luminous reflectance R_{180} to be measured in this experiment corresponds to the ratio of the backward luminance of the twine B_T to the incident luminance of the light beam B_M, that is, $R_{180}=B_T/B_M$. Let ω be the solid angle subtended by the twine at the phototube, then B_T will be P_T/ω, where P_T is the illuminance produced by B_T on the surface of the phototube. The solid angle ω is equal to S/r^2, where S is the illuminated area of the twine normal to the beam of incidence and r is the distance EST. The reading of the galvanometer in the circuit of a phototube current produced by the light beam reflected from the mirror and that from the twine are E_M and E_T respectively. Here, E_M is reduced to have the same projective area as that of the twine. Let P_M and P_T be the illuminance produced on the phototube by the mirror and the twine, then P_M and P_T are estimated as follows,

$$P_M = \frac{E_M - E_0}{a}, \qquad P_T = \frac{E_T - E_0}{a} \tag{1}$$

where a is a constant which is the ratio of the phototube current to the illuminance of the light received by the phototube, and E_0 is the reading of the phototube current caused by the scattered light inside the wall which is produced by the reflection at the opposite surface of the splitter. The beam of incidence being parallel, its luminance B_M is equal to the illuminance P_M. Accordingly, the backward luminous reflectance can be expressed as follows,

$$R_{180} = \frac{E_T - E_0}{E_M - E_0} \cdot \frac{r^2}{S} \tag{2}$$

In the experiment, the twines were suspended in the cell which was filled with water. The results are given in Table 2.

Table 2. Measured values of backward luminous reflectance

colour of twine \ filter light	Blue	Green	Red
Red	0.0084	0.0097	0.025
Green	0.0099	0.0098	0.0083
Black	0.0084	0.0090	0.0083
Blue	0.021	0.015	0.017
Yellow	0.025	0.027	0.026
Brown	0.084	0.013	0.025

∴ White paper : 0.21 (no filter)

IV. Discussion

In the previous report[2], the following theoretical equation concerning the visual range of the twine in the horizontal parallel light beam was presented,

$$\varepsilon = e^{-2kr}\left|\frac{2\,k\,R}{\pi\,\beta_{180}} - 1\right| \tag{3}$$

where ε is the threshold of brightness-contrast of the human eye, k the extinction coefficient of tank water, r the visual range, β_{180} the volume scattering function of the direction of 180° and R the luminous reflectance of the twine, which was preliminarily assumed as a perfect diffuser. However, the twine cannot be considered as a perfect diffuser in fact, the equation should be changed as follows,

$$\varepsilon = e^{-2kr}\left|\frac{2\,k\,R_{180}}{\beta_{180}} - 1\right| \tag{4}$$

where R_{180} is the backward luminous reflectance of the twine which agrees with the value defined in equation (2). The value β_{180} is not constant but variable according to the nature of water. From the night observations over the sea by Chesterman and Stiles[3] it appears that the volume scattering function $\beta(\phi)$ is simply permissible to write as $\beta(\phi)=(k/4\pi)f(\phi)$, where $f(\phi)$ is the relative scattering function. But this relation was not found in the measurements of the volume scattering function of the sea water by both Tyler[4] and Jerlov[5]. However, the volume scattering function $\beta(\phi)$ may be considered to be a function of the extinction coefficient k and the relative scattering function $f(\phi)$. Thus we assume approximately

$$\beta\,(\phi) = C \cdot k \tag{5}$$

where C includes the relative scattering function and should be also affected by some other factors such as the nature and size distribution of suspended material. We may now write in place of equation (4).

$$\varepsilon = e^{-2kr}\left|\frac{2\,R_{180}}{C} - 1\right| \tag{6}$$

On the other hand, the threshold of brightness-contrast is well known to be affected by the background brightness and the visual angle of the object, and then the following experimental equation is assumed in accordance with the previous report[2],

$$\varepsilon = \frac{\varepsilon_0}{1 - A\,e^{-\lambda\theta}} \tag{7}$$

where A and λ are constant, θ is the visual angle of twines (or paper stripes) subtended to the observer's eye and ε_0 is the threshold of the large visual angle

($>1°$) which is generally considered to be 0.02[6]. These three unknown values C, A and λ in equations (6), (7) are estimated from the results of the third and fourth groups mentioned above by trial and error method. That is $C=0.010$, $A=1.6$ and $\lambda=1.3\times10^3$. Fig. 7 shows the relation between the threshold and the visual angle, in which white and black spots are data obtained by the experiment of the third and fourth groups respectively and full line is from equation (7). Then following two equations (8) and (9) derived from the equation (6) suggesting that there are several limits in the visual range for R.

$$R_{180} = \frac{C}{2}\left(1 + \frac{\varepsilon}{e^{-2kr}}\right) \tag{8}$$

$$R_{180} = \frac{C}{2}\left(1 - \frac{\varepsilon}{e^{-2kr}}\right) \tag{9}$$

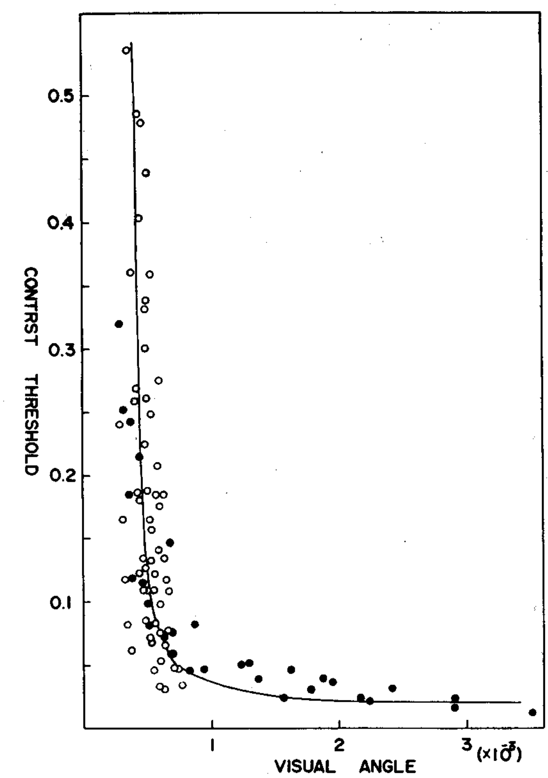

Fig. 7. Relation between the threshold of brightness-contrast and the visual angle. (white points are data in the case of white paper stripes of the fourth group and black points are those of grilon twines of the thrid group)

The former is in the case of the brightness of the twine which is greater than that of background and the latter is in the case of the reverse condition. Fig. 8 shows the curves computed from equations (7), (8) and (9), the diameter of the twine being assumed to be 0.73 mm. If the visual range r is presumed to be zero, ε becomes obviously ε_0 from the equation (7), and then the backward luminous reflectance has two limiting values 0.0051, 0.0049 as shown in Fig. 8. Namely, in the region where values of R_{180} are between them, the twine cannot be seen at any distance. Also an interesting tendency can be seen in Fig. 8, that is, the slope of curves decreases rapidly and converges to a limiting value 2.0 m with the increase of R_{180} in the case of the twine which is brighter than the background. This limit is determined by the diameter of the twine. The experimental points in Fig. 8 are obtained by interpolation on curves shown in Fig. 3, in the case of k=1.0. The relationship among these points and theoretical curves reveal a relatively good fit.

As it is mentioned above, the visual range of net twines under any turbid conditions in water will be calculated from equations (7), (8) and (9), when the diameter and the luminous reflectance of twines are known. It should be noticed,

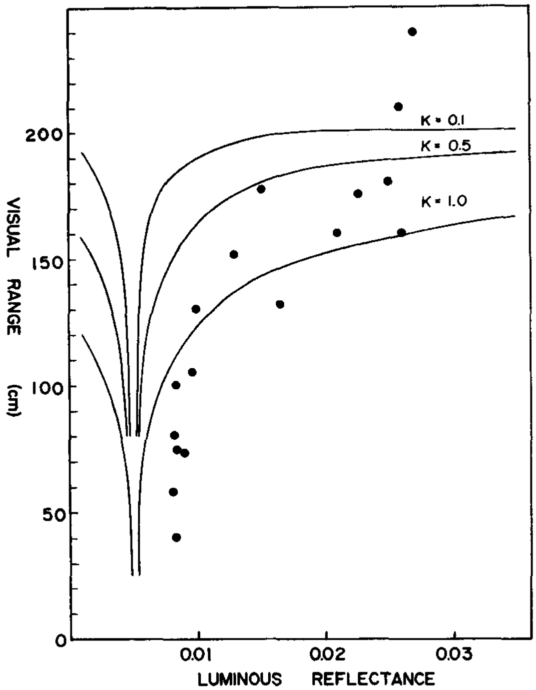

Fig. 8. Visual range as a function of luminous reflectance in cases of several extinction coefficients (the curves are from equations (7), (8), (9) and experimental points (k=1.0) are obtained from Fig. 3 by interpolation)

however, that these results are obtained in the case of horizontal parallel light beams, so it might be dangerous to apply them to the fishery technique just as they are.

References

1) Yoshimuta, C. et al. (1963). (in Japanese), Maximum horizontal distance allowing coloured nets visible. *Bull. Tokai. Reg. Fish. Lab.*, **37**, 37–40.
2) Inoue, N. et al. (1958). (in Japanese), Studies on the visual range of net twines in water-I. *Bull. Jap. Soc. Sci. Fish.*, **24** (6 & 7), 501–506.
3) Chesterman, W.D. & S.W. Stiles: (1948). The visibility of targets in a naval search-light beam. In symposium on searchlights, *London, Illum. Eng. Soc.* 75–102.
4) Tyler, J.E. (1961). Sun-altitude effect on the distribution of underwater light. *Limnol. Oceanogr.* **6**(1).
5) Jerlov, N.G. (1963). Optical oceanography. *Oceanogr. Mar. Biol. Rev.* **1**. 89–114.
6) Middleton, W.E.K. (1952). *Vision through the atmosphere.*