Underwater Visibility of Net Twines

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Introduction

It has been greatly concerned by researchers and fishermen how the visibility of twines inthe sea water correlate with the visual function of fishes and how it influences upon the behaviours of fishes and a large number of studies on these problems were carried out not only in the laboratory but also using the net under the practical operation. The measurements of visual range in these researches, however, were carried out using the human eye and so it is a question that these visual ranges have the same meaning to the fish eye. Physical factors, namely, net construction, diameters, colours, transparents, colour in the sea, turbidity and illumination of sea water, greatly influence upon the underwater visibility.

Yajima et al.[1),2)] dived using the aqua-lung and measured vertical and horizontal visual ranges of various dyed nets and discussed about the relationship between visual ranges and turbidity of sea water. And Inoue et al[3)] measured visual ranges of net twines illuminated by a horizontal beam in the tank water when the wavelength of light and the turbidity of water was changed variously and showed the relation between the visual range and turbidity. Similarly, Kajihara et al.[4)] measured the visual range of twines in the water by the same method with Inoue et al. using various twines of different materials, colours, and diameters and studied the relation between the visual ranges and the reflectance of twines.

The writer used the diffused flourescent light which illuminate to the tank water from the upper position and measured visual ranges of twines in the tank water having various brightness and turbidity, their theoretical analysis was discussed.

Apparatus and method used for the measurement of visual range

For the measurement of visual range of materials, an apparatus was used as shown in **Fig. 1**. L is a water tank, 500 cm in length, 40 cm in depth and 30 cm in width, made of wood and as inner side tank is painted by black enamel, the reflectance from it is negligibly reduced. A guiding shaft, K was fixed along the upper side of water tank. A moval metal rod, C was set on the shaft. To the end of this rod a black frame, N was attached which held twine samples vertically moved forward and backward along. In the case of backward and forward removals of the frame visual ranges r_1 and r_2 can be measured respectively.

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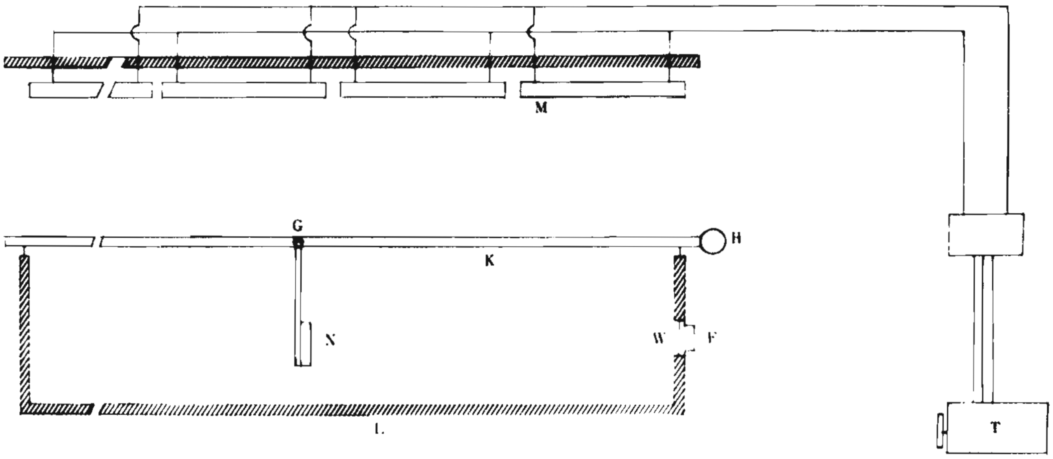

Fig. 1. Schematic diagram of the apparatus for measuring the visual range.

G: Metal rod
K: Guiding shaft
W: Window glass
M: Light source
H: Handle
L: Water tank
N: Frame suspending twine samples
T: Resicter box
F: Colour filter

The measurement of the visual range was done using a green-filter in front of the observer's eye. The characteristic curve of filter shows the transmitted wavelength between 488 mμ and 596 mμ the center of gravity being 535 mμ. And when the visual range is measured, it is preferable that the horizontal distribution of the diffused light from the light source is to be homogeneous. From the result of measurement of illuminance, the horizontal distribution of the diffused light at the water tank surface and 18 cm below the surface as shown in **Fig. 2** was almost homogeneous. The intensity of the water tank can be changed by the resister box, T. The turbidity of the tank water was increased by adding the colloidal solution of Indian Red.

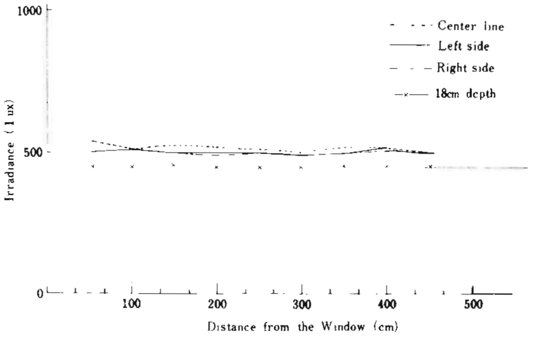

Fig. 2 Illuminance distribution at the water surface and 18 cm below the surface.

The attenuation coefficient of tank water was measured as follow. The tank water was iluminated by the collimated beam through the window glass and the green-filter, and tight selenium photocell putting at several points along the light path.

Apparatus and method for the measurement of the reflectance of samples

The reflectance of samples was measured by an integrating-sphere attached to the spectrophotometer as shown in **Fig. 3**. The method of measurement is as follows.

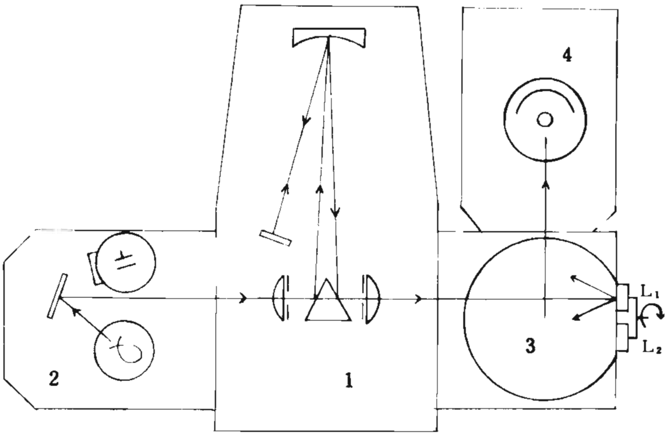

Fig. 3 Schematic diagram of the apparatus for measuring the reflectance of samples.

1. Spectrometer
2. Light Source
3. Integrating Sphere
4. Amplifier
A_1. Mercury Lamp
A_2. Tungsten Lamp
L_1. Perfect Diffuser
L_2. Samples

The perfect diffusing plate was used as a standard and put on the window side of the revolver of the intgerating-sphere and samples were on the other side. Monocromatic light whose wavelength was almost same with the mode of characteristic curve of a green-filter was projected to the surface of standard plate and then the photometer was adjusted so that its indication showed 100%. Next the knob of revolver was turned to 180° and the monocromatic light was projected to the samples, then indication of the photometer showed directly the reflectance of samples. The diameters and the reflectance of samples used in the experiment were shown in **Table 1**.

Table 1. Sample of net twines and values of reflectance of samples with the green filter

No.	Twine	Diameter	Construction		Wavelength (530 mμ)
1	Green	0.82mm	2200 D	Mono F.	0.051
2	Natural	0.87	2530 D	〃	0.077
3	〃	0.60	2530 D	〃	0.077
4	Grey	0.87	2530 D	〃	0.054
5	〃	0.60	2530 D	〃	0.054
6	Yellow Green	0.60	2530 D	〃	0.051
7	Blve Green	0.60	2530 D	〃	0.057
8	White	0.73	210 D/15F 3/12	Multi F.	0.870
9	Grey	0.73	210 D/15F 3/12	〃	0.123
10	Yellow	0.91	210 D/15F 3/15	〃	0.276
11	Black	0.85	210 D/15F 3/13.5	〃	0.020
12	〃	1.18	210 D/15F 3/30	〃	0.020
13	〃	1.68	210 D/15F 3/60	〃	0.020
14	〃	2.16	210 D/15F 3/80	〃	0.020

Result and Discussion

1) Visual range of samples

Examples of relationship between the visual range and attenuation coefficient are shown in **Fig. 4, 5 and 6**.

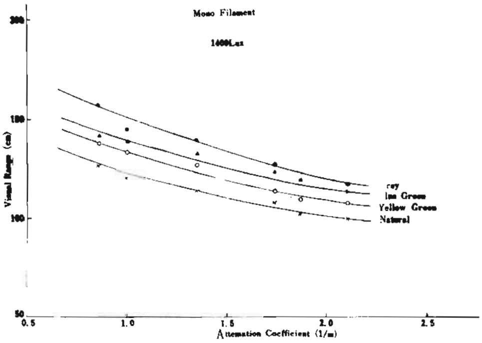

Fig. 4. Relation between visual range of net twines and attenuation coefficient.

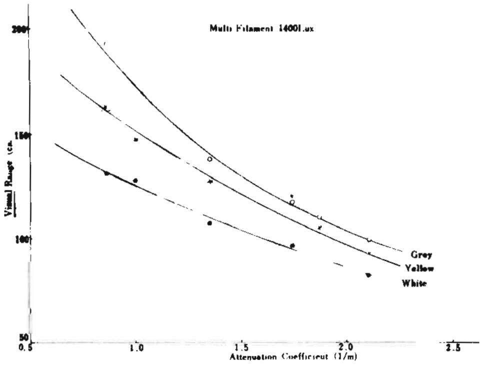

Fig. 5. Relation between visual range of net twines and attenuation coeffcient.

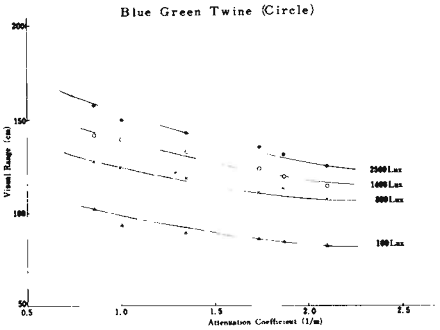

Fig. 6. Relation between visual range of blue green twine and attenuation coefficient.

The visual range decreased with increase of attenuation coefficient and with the decrease of illuminance.

2) Working formula of the visual range

The visibility of the object is dependent on the luminance, Bo of the water space in the solid angle which the object subtend to the eye and on the background luminance, Bh. The contrast, C is defined by the equation,

$$C=\left|\frac{Bo-Bh}{Bh}\right| \tag{1}$$

where Bo and Bh can be formulated in accordance with W. E. K. Middleton [5] as follows.

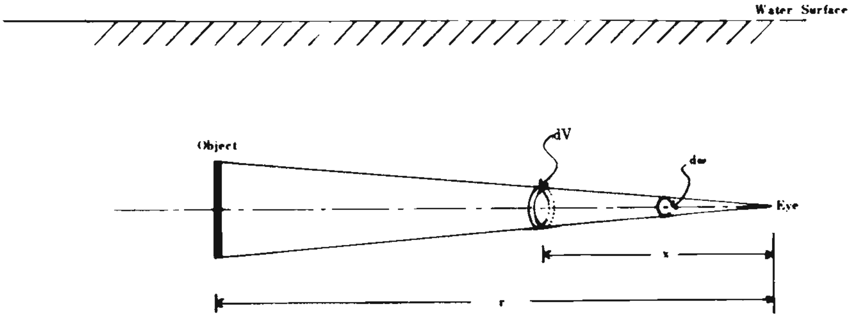

Fig. 7. Schematic diagram for estimating the brightness contrast.

Consider an volume element,

$$dV=d\omega\cdot x^{2}\cdot dx \tag{2}$$

of the cone of water (Fig. 7) the base of which is a portion of object and the apex of which is at the observer's eye. The volume element, dV is assumed to be iluminated to the same extent and in the same way no matter what the value of x. The intensity of the volume element in the direction of eye will be

$$dI = dV \cdot A \cdot b \tag{3}$$

where b is the scattering coefficient and A is a constant proportionally to be determined from the boundary conditions.

The illuminance at the eye due to this light scattered from dV is

$$dH = dI \cdot x^{-2} \cdot e^{-Kx} \tag{4}$$

The luminance at the eye to the volume element is

$$dB = dH \cdot d\omega^{-1} \tag{5}$$

where $d\omega$ is a solid angle which dV subtends at the eye.

From equations (2), (3), (4) and (5),

$$dB = A \cdot b \cdot e^{-Kx} \cdot dx \tag{6}$$

Now, integrating the equation (6) from $x=0$ to $x=r$,

$$Br = \int_{x=0}^{x=r} dB = \int_{x=0}^{x=r} A \cdot b \cdot e^{-Kx}\, dx = A \cdot b \cdot K^{-1}(1 - e^{-Kr}) \tag{7}$$

where r is a visual range of the object and Br is a total luminance of the water in the cone of a solid angle, $d\omega$. Similarly, integrating the equation (6) from $x=0$ to $x=r$ which is the length the water tank, the luminance of the background, B_L is

$$B_L = A \cdot b \cdot K^{-1} \cdot (1 - e^{-KL}) \tag{8}$$

The luminance produced by the object at the observer's eye will be

$$B_T = R \cdot Br \cdot e^{-Kr} \tag{9}$$

The radiant emittance, Bo produced by the point P of the object in the direction of observer's eye is

$$Bo = Br + B_T \tag{10}$$

where r is defined as the visual range of water, contrast is equal to the thresholds of brightness contrast, ε. Namely,

$$C = \left| \frac{Bo - Bh}{Bh} \right| = \varepsilon \tag{11}$$

$$\varepsilon = \left| \frac{Br + B_T - B_L}{B_L} \right| = \left| \frac{R \cdot e^{-Kr} \cdot (1 - e^{-Kr}) + e^{-KL} - e^{-Kr}}{1 - e^{-KL}} \right| \tag{12}$$

Now, if it is assumed that the black twine is perfect black, the reflectance is zero. The equation (12) is

$$\mathcal{E} = \left| \frac{e^{-KL} - e^{-Kr}}{1 - e^{-KL}} \right| \tag{13}$$

And, substituting the obtained values of r and k from the experimental results into the equation (13), then the relation between $\mathcal{E}$ and θ is illustrated as shown in **Fig. 8**. R is the visual range and k is the attenuation coefficient.

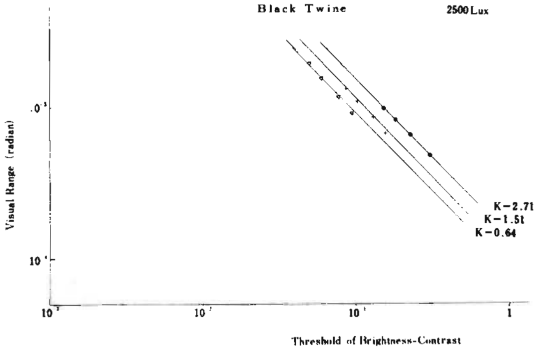

Fig. 8 Relation between visual angle and thresholds of brightness-contrast.

From Blackwell's[6] experimental result, the thresholds of brightness contrast is the function of visual angle in the region of small it. Namely,

$$\log \mathcal{E} = D \cdot \log \theta + \log E \tag{14}$$

where D and E are constants.

But as the value of E changed by the illumination in water, E seemed to take the different values by the illuminance measured on the water surface and the attenuation coefficient. And the values of D were shown in **Table 2** were obtained with the method of least square. Though the values of D changed fairly by the illuminance, the mean value, D=0.77 was taken as the first approximation.

Table 2 Values of D

H (lux)	2500	1400	800	400	100
D	−0.90	−0.67	−0.60	−0.73	−0.93

Consequently, the equation (14)

$$\log \mathcal{E} = -0.77 \cdot \log \theta + \log E \tag{15}$$

Using the equation (15), log E was computed in each various illuminance and turbidity in black twine. It was shown in **Table 3**.

Table 3. Values of log E of black twine which computed form equation (15)

log E (10^{-4}) k : attenuation coefficient

Lux \ k	0.64	1.05	1.27	1.51	1.95	2.71
2500	3.10	2.21	2.20	2.21	2.53	1.25
1400	3.55	2.31	2.68	2.38	3.17	1.98
800	4.29	4.10	3.26	3.08	3.17	1.98
400	5.56	5.50	3.92	3.58	4.16	2.63
100	7.75	7.32	5.42	5.38	4.70	4.24

As the relation between K and E, and between H and E were considered to be lenear correlation, the following experimental formula (16) was assumed. Namely,

$$\begin{aligned} \log E &= \alpha \log K + \log X \\ \log E &= \beta \log H + \log Y \end{aligned} \qquad (16)$$

From the lenear correlation of the equation (16), log X and log Y were obtained. As E was a function of K and H shown in equation (16), the equation (17) should be satisfied with the about two-equations which must exist simultaneously.

Therefore,

$$\log E = -0.205 \log K - 0.41 \log H + \frac{\log X + \log Y}{2} \qquad (17)$$

Using the equation (17), log E is shown in **Table 4** was computed from each various turbidity and illuminance which was the experiment.

Table 4. Values of log E computed from equation (17) which based on black twine

log E (10^{-4})

Lux \ k	0.86	1.00	1.35	1.74	1.87	2.10
2500	2.91	2.73	2.56	2.16	2.09	1.99
1400	3.20	3.19	2.81	2.53	2.45	2.34
800	4.01	3.76	3.30	2.97	2.88	2.75
400	4.88	4.59	4.02	3.62	3.50	3.35
100	7.19	6.74	5.92	5.33	5.16	4.92

Basing on the above mentioned results, the thresholds of brightness contrast were computed from each various turbidity and illuminance which used in the experiment. Basing on the above mentioned results, the thresholds of brightness contrast were computed from the equation (15) and (17). Substituting values of ε into the equation (12), reflectance of samples was obtained. The results of the computed values and the experimental ones were shown in **Table 5**.

Table 5. Computeel values of luminous reflectance. The numbers in the brackets are the experimental values.

Twine	Luminous Reflectance
Green (E)	0.822 (0.0220)
Natural (E)	0.994 (0.0300)
〃 (C)	0.640 (0.0213)
Grey (E)	0.255 (0.0237)
〃 (C)	0.284 (0.0210)
Yellow Green (G)	0.535 (0.0223)
Blve Green (G)	0.377 (0.0293)
White	0.705 (0.0907)
Grey	0.408 (0.0213)
Yellow	0.665 (0.1470)

According to Table 5, it was apparent that the computed values and the experimental ones were wrong. As the result, it was a question that the method for the measurement of the reflectance by using an integrating-sphere had the same measuring to samples projected that the tranparent twines must consider not only the reflectance but also the tranparency. In regard to this problem, more fundamental research need to investigate.

Acknowledgment

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網糸の水中視程について

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水中での物体の見え具合いは物理的要因と視覚生理との総合作用の結果として決まるものであるが、今回はその第一歩として人間の目を用いて網糸の見え方、即ち網糸の視程の研究を行なった。

実験は水面の上から散乱光を照射した時の水平視程を測定すると共に、水中視程に大きな影響を与える物理的諸要因、即ち物体の色、反射率、透過率及び濁り、照射光度等をかえて視程測定を行ない、Koschmieder, Middleton の大気中の視程の理論式を実験条件に合う様に書きかえ、実測値を解析し、物理的要因とコントラストの識閾という生理的要因とに分けて視程に対する影響を調べた。

その結果、黒糸では視角の小さい範囲では視角が減少すればコントラストの識閾は直線的に増加し、その直線の傾斜は水槽水の濁り、表面照度によってそれぞれ変化する事がわかった。この様な関係はBlackwellの大気中における実験でも確かめられている。