Irradiance Distribution in East Sea by Using Measured Optical Properties for Squid Jigging Vessels

JaeHyun Bae¹, SangWoo Kim¹, Taeyang Park², HyunWoo Cho², YoungDuk An¹, SangHyun Kim², HyunWoon Ra², YoungSil Cho², JaeSeok Koh², and MeeSuk Jung*¹

¹Fisheries Resources and Environment Division, East Sea Fisheries Research Institute, National Institute of Fisheries Science, 1194 Haean-ro, Yeongok-myeon, Gangreung-si, Gangwon-do, 25435, South Korea
²Department of Nano Optical Engineering, Korea Polytechnic University, 237, Sangidaehak-ro, Siheung-si, Gyeonggi-do, 15073, South Korea

(Received August 31, 2016 : revised September 20, 2016 : accepted September 30, 2016)

A fishing lamp is the instrument for attracting distributed fish to a certain place, and is the lighting system mainly used in fishery. In the inshore fishing, most fishing lamps are used for squid and hairtail jigging fishing, and the light source of the fishing lamps mainly used is metal halide with 1.5 KW in electric power consumption. We will analyze the irradiance distribution according to depth because squid is attracted towards light. To analyze irradiance distribution by such fishing lamps, data for seawater Type-II among the seawater types defined in 1976 are applied to East Sea. However, the Type-II data have limitations in analyzing precise seawater transmission characteristics, due to insufficient information on deep seawater. This paper analyzed the irradiance distribution of fishing lamps using the measurement of transmission characteristics in the seawater in East Sea up to 100 m underwater instead of Type-II data, which is not sufficient for transmission. A compensation factor was drawn between the actual measurement data and Type-II data through seawater transmission characteristics simulation.

Keywords : Fishing lamp, Irradiance distribution, East sea, Transmittance, Attenuation coefficient

OCIS codes : (010.4450) Oceanic optics; (010.5630) Radiometry; (220.2945) Illumination design

I. INTRODUCTION

Squids stay in deep seawater during the daytime, and come up to the water surface at night to eat small fish, and they have a habit of gathering well under light. Therefore, the fishing vessels used for inshore jigging fishing to catch squids mainly use metal halide lamps. Squids comprise about 92% among the main fish catch in the East Sea inshore fishing, and squids are major target fish. The number of fishing vessels using fishing lamps to catch squids is about 440, making up the most in the inshore fishing, and its average catch of fish is 40,000 tons.

Generally, 1.5 KW metal halide lamps are used for fishing lamps, and the maximum number of fishing lamps with maximum power standard regulated according to vessel tonnage is used. Since standardized information according to fishing lamp installation standard (maximum power standard) is insufficient, data collection and analysis according to fishing that uses fishing lamps are needed. The fact that the fishing lamp placement type and number of the lamps are different depending on fishing lamp installation standard should be recognized, because fishing characteristics are different by fishing vessel size. In this regard, this study made the light emitted from fishing lamps reflect the effect depending on fishing vessel’s appearance as in the real setting by carrying out fishing vessel modeling, based on the National Institute of Fisheries Science’s research.

For more precise and reliable data analysis, an accurate analysis on seawater needs to be backed up. Because the data of East Sea seawater for optical analysis are currently
limited, reliability is low in using the seawater of East Sea. To solve such a problem, this study collected optical characteristics data by actually measuring the optical intensity of seawater of East Sea. Based on the data, this study presented the compensator through comparison with existing data.

Through a fact-finding survey of the fishing vessels using fishing lamps at actual fishing sites, this study conducted the modeling of fishing lamps-using fishing vessels and metal halide lamps placement. Based on the actually measured data, this study embodied seawater, and analyzed irradiance distribution according to depth of seawater. With all these, this study aimed to draw irradiance distribution results quantitatively.

II. OPTICAL ANALYSIS OF SEAWATER OF EAST SEA

To precisely analyze irradiance distribution for fishing vessels, the exact optical properties, such as refractive index and transmittance, should be considered. To this purpose, this study analyzed the seawater types that have currently become the standard, and drew the seawater type, which is the most similar to East Sea through comparison with actually measured East Sea data.

2.1. Optical Properties of Seawater

Seawater is a sample having a mixture of water molecules and underwater floating matter. Refractive index and transmittance, which are optical properties to be considered for simulation, are decided by the temperature, salt concentration and pressure of seawater.

With regard to the transmittance of seawater, N. G. Jerlov’s Marine Optic (1964) presented the types of worldwide seawater by dividing them into I, IA, IB, II and III types as shown in Fig. 1 [1]. However, it included extensive oceans, and thus the seawater type of East Sea cannot be precisely known. Therefore, this study compared the actually measured data of East Sea with optical properties of the types of worldwide seawater.

The refractive index of seawater differs according to temperature, salt concentration and wavelength. The Index of Refraction of Seawater (1976) of R. W. Austin and Halikas presented refractive index depending on wavelength by temperature and salt concentration as shown in Fig. 2 [2]. The average water temperature in the fishing season (November) in East Sea measured by the Korea Hydrographic and Oceanographic Agency is 18°C, and salt concentration is 33‰ [3]. Therefore, this study applied the water temperature of East Sea in fishing season and refractive index data corresponding to salt concentration.

The transmission characteristics of seawater become different depending on wavelength, and N. G. Jerlov presented transmittance according to marine type as shown in Fig. 3. The attenuation characteristics of light according to wavelength were analyzed using the transmittances of the water surface.
and water with 10m depth as presented in Fig. 3, and the attenuation coefficient by wavelength was calculated using Eq. (1) (Beer-Lambert Law). Attenuation coefficient means a coefficient showing light reduction level, due to the absorption and scattering of light depending on seawater depth.

\[
I(\lambda) = I_0 \exp(-k(\lambda) \cdot z)
\]

\[
k(\lambda) = \ln \left( \frac{I_0(\lambda)}{I(\lambda)} \right) \cdot z
\]

where, \(I(\lambda)\) and \(I_0(\lambda)\) are the intensities of the transmitted and incident radiation for wavelength \(\lambda\) respectively, \(z\) is depth and \(k(\lambda)\) is the attenuation coefficient of wavelength \(\lambda\). Figure 4 shows the attenuation coefficient by wavelength in 10 m depth according to seawater types.

For the optical analysis of the seawater of East Sea as in the actual setting, this study actually measured spectral irradiance by depth. Profiler II (Satlantic LP, CANADA) was used as the measuring equipment. Profiler II is the equipment that can measure irradiance and radiance by depth, as well as marine temperature, salt concentration and pressure. The measured wavelength scope was 350–800 nm within the visible light region, and the depth was 0–121.95 m. Figure 6 shows the measured result. Transmittance was calculated based on the measured result, and Fig. 8 shows the result. Transmittance was calculated as shown in Fig. 7.

2.2. Comparison of Attenuation Coefficients

The attenuation coefficients on 10 m using the Beer-Lambert Law were calculated on the basis of measured data, and Table 1 shows the result. Figure 9 reveals the comparison result between the calculated attenuation coefficients from measured data and existing Marine Optic. As a result, we can see the optical properties of East Sea by Type-II are the most similar with measured results. With this, East Sea can be regarded as Type-II among various marine types.

The attenuation coefficient of Type-II, however, was the comparison between the transmittance values of water surface and 10 m depth of seawater, and the transmittance under 10 m depth of seawater was not presented. Therefore, attenuation coefficients in the other depths of seawater cannot be known. Precision may decrease in the case of simulation of East Sea with the Type-II presented in the Marine Optic using such attenuation coefficients. To enhance it, this study
### TABLE 1. Attenuation coefficient on 10m in actually measured data

| λ (nm) | 350 | 375 | 400 | 425 | 450 | 475 | 500 | 525 | 550 | 575 | 600 | 625 | 650 | 675 | 700 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Actually measured seawater | 0.24 | 0.23 | 0.17 | 0.13 | 0.10 | 0.08 | 0.07 | 0.08 | 0.08 | 0.10 | 0.25 | 0.33 | 0.37 | 0.47 | 0.65 |

### FIG. 9. Comparison between the calculated attenuation coefficients on 10 m.

FIG. 9. Comparison between the calculated attenuation coefficients on 10 m.

found a compensation factors through the simulation of Type-II seawater and measured seawater.

### III. FISHING VESSEL MODELING AND IRRADIANCE DISTRIBUTION ANALYSIS

For comparative analysis of the irradiance distribution between Type-II and measured seawater, this study conducted the modeling of fishing vessels using fishing lamps, and placed the fishing lamps based on the fact-finding survey and vessel information. This study embodied seawater that applied the transmittance and reflective index of Type-II seawater calculated above and those of measured seawater. In this way, irradiance distribution was analyzed.

#### 3.1 Seawater and Fishing Vessels Modeling

For modeling of the fishing vessels similar to actual fishing vessels, we have the fact-finding survey in Guryongpo in Pohang city, and Hupo in Uljin country. These are shown in Fig. 10.

This study selected three fishing vessels, 9.77 t, 40 t and 51 t fishing vessels, based on the fact-finding survey data and vessel information, and modeling was carried out using a 3D design program, Solidworks. The result is revealed in Figs. 11, 12 and 13. Actually, 54, 80 and 88 fishing lamps were placed on 9.77 t, 40 t and 51 t fishing vessels in line with stabilizer’s maximum power standard for fishing lamps according to fishing vessel’s size, and the locations were decided by referring to the fact-finding survey data and vessel information. A metal halide lamp having 1.5 KW in electric power consumption was used as the light source of a fishing lamp, and Fig. 14 shows the irradiance distribution and spectrum distribution. Light output was 718.42 W.

In this study, each seawater and fishing vessel was placed as shown in Fig. 15 in order to analyze the irradiance distribution of Type-II and measured seawater of East Sea. This study embodied seawater of which optical properties were considered using Lighttools [4], a design program of illumination optical system.

The seawater was set up in the dimensions of 2000m × 2000 m × 150 m, and the fishing vessels were located in the central surface of the seawater. The detectors to measure irradiance distribution were placed at 0 m (water surface), 50 m, 80 m and 100 m depths of seawater in consideration of 50 m ~ 100 m depth of seawater, where squids mainly inhabit. The detector size was set up as 50 m (200 m × 200 m), 80 m (300 m × 300 m) and 100 m (350 m × 350 m) by setting up in proportion with the depth of seawater.

This study compared and analyzed the irradiance distribution of Type-II and measured seawater, respectively, by placing the seawater and fishing vessels.

#### 3.2. Analysis of Irradiance Distribution of Type-II and Measured Seawater

In order to compare optical properties of each of these seawaters through simulation, this study conducted simulation
Irradiance Distribution in East Sea by Using Measured Optical Properties for … - JaeHyun Bae et al. 551

by applying each seawater to three fishing vessels. Average irradiance means the value dividing total intensity value irradiated to each detector by the size of detector. Average deviation means the value dividing standard deviation by average irradiance.

Irradiance distribution was demonstrated as log scale, and the maximum and minimum of histogram were set up equally as 40 W/m² and 1E-10 W/m², respectively, in order to compare irradiance distribution according to depth of seawater.

As for Type-II, this study carried out simulation on the seawater to which refractive index and transmittance presented in the existing data were applied and on the three fishing vessels. From Fig. 16, we can see that the irradiance distribution and shadow zone are different from the vessel’s shape and size, due to the placement of fishing lamps.

This study analyzed the irradiance distribution using measured seawater instead of the Type-II in the same conditions as shown Fig. 16 above. As a result of the analysis, the irradiance values up to 50 m depth of seawater were similar...
to each other, but a difference was shown from 80 m depth of seawater.

3.3. Comparison of Simulations according to Depth of Seawater by Each Seawater

In comparison with the irradiance of each seawater analyzed above, there were differences in the irradiance of Type-II seawater and actually measured seawater, and the differences are revealed in Figs. 18, 19 and 20. From the graphs, the same maximum irradiance value is shown for all the fishing vessels up to nearly 50 m depth of seawater, but the value started to become different at less than 50 m depth of seawater. Such a difference seems to occur, due to the lack of information of transmittances and attenuation coefficients in Marine Optic mentioned above.

To find out a factor that can compensate such a difference, this study analyzed the correlation of Type-II and measured seawater through the simulation. For such an analysis, we
additionally measured the irradiance at 10 m, 20 m, 30 m, 40 m, 60 m, 70 m and 90 m depths of seawater, and the result is shown in Table 2. This study regarded as the ratio of maximum irradiance by the two types of seawater with three fishing vessels according to the depth of seawater. As a result, the ratio of Type-II and measured seawater were similar in all the three fishing vessels. Through the average ratio, we extract compensation factors between Type-II and measured seawater.

To generalize the compensation value, the average ratio of maximum irradiance was calculated in relation with the depth of seawater, and the compensation factor according to depth of seawater was expressed as a function through fitting. Figure 21 shows the result. Concerning the error value, due to fitting, standard deviation was 0.0569, and maximum error was 0.1242 at 30 m depth of seawater.

Consequently, this study found a compensation factors that can compensate the Type-II data to overcome its limited

---

### Water surface (0 m) Simulation

| Fishing vessels | 9.77t | 40t | 51t |
|-----------------|-------|-----|-----|
| Irradiance distribution | ![Image](image1) | ![Image](image2) | ![Image](image3) |
| Maximum Irradiance | 29.549 W/m² | 26.953 W/m² | 25.297 W/m² |
| Average Irradiance | 0.949 W/m² | 1.519 W/m² | 1.551 W/m² |

### 50 m Simulation

| Fishing vessels | 9.77t | 40t | 51t |
|-----------------|-------|-----|-----|
| Irradiance distribution | ![Image](image4) | ![Image](image5) | ![Image](image6) |
| Maximum Irradiance | 0.00310 W/m² | 0.00433 W/m² | 0.00446 W/m² |
| Average Irradiance | 4.347e-04 W/m² | 7.631e-04 W/m² | 8.064e-04 W/m² |

### 80 m Simulation

| Fishing vessels | 9.77t | 40t | 51t |
|-----------------|-------|-----|-----|
| Irradiance distribution | ![Image](image7) | ![Image](image8) | ![Image](image9) |
| Maximum Irradiance | 6.782e-05 W/m² | 1.047e-04 W/m² | 1.242e-04 W/m² |
| Average Irradiance | 7.814e-06 W/m² | 1.474e-05 W/m² | 1.599e-05 W/m² |

### 100 m Simulation

| Fishing vessels | 9.77t | 40t | 51t |
|-----------------|-------|-----|-----|
| Irradiance distribution | ![Image](image10) | ![Image](image11) | ![Image](image12) |
| Maximum Irradiance | 8.739e-06 W/m² | 1.475e-05 W/m² | 1.874e-05 W/m² |
| Average Irradiance | 9.585e-07 W/m² | 1.887e-06 W/m² | 2.068e-06 W/m² |

FIG. 17. Irradiance distribution of actually measured seawater depending on depth.
optical properties. In order to do that we measured the irradiance in seawater of East Sea and have simulation of irradiance distribution between Type-II and measured seawater. Table 4 shows the compensation factors.
TABLE 2. Maximum irradiance and ratio depending on depth to type of fishing vessels about Type-II seawater and actually measured seawater

| Depth (m) | Type-II seawater | Actually measured seawater | Ratio between seawater |
|-----------|------------------|---------------------------|------------------------|
| 0         | 29.571           | 29.549                    | 0.99926                |
| 10        | 1.605            | 1.3435                    | 0.83707                |
| 20        | 0.229            | 0.209                     | 0.91266                |
| 30        | 0.045            | 0.061                     | 1.35556                |
| 40        | 0.0109           | 0.0126                    | 1.15596                |
| 50        | 0.00294          | 0.00310                   | 1.05442                |
| 60        | 8.611e-4         | 7.862e-4                  | 0.91302                |
| 70        | 2.697e-4         | 2.092e-4                  | 0.77568                |
| 80        | 8.836e-5         | 6.782e-5                  | 0.76754                |
| 90        | 3.076e-5         | 2.637e-5                  | 0.85728                |
| 100       | 1.093e-5         | 8.739e-6                  | 0.79954                |

| Depth (m) | Maximum irradiance depending on depth about 40 ton fishing vessel | Ratio between seawater |
|-----------|------------------------------------------------------------------|------------------------|
| 0         | 26.952                                                          | 1.00004                |
| 10        | 1.789                                                           | 0.82281                |
| 20        | 0.288                                                           | 0.89931                |
| 30        | 0.0607                                                          | 1.32290                |
| 40        | 0.0150                                                          | 1.15333                |
| 50        | 0.00433                                                         | 1.03926                |
| 60        | 3.906e-4                                                       | 0.92913                |
| 70        | 1.310e-4                                                       | 0.80133                |
| 80        | 4.237e-4                                                       | 0.81450                |
| 90        | 4.711e-5                                                       | 0.89938                |
| 100       | 1.836e-5                                                       | 0.80773                |

| Depth (m) | Maximum irradiance depending on depth about 51 ton fishing vessel | Ratio between seawater |
|-----------|------------------------------------------------------------------|------------------------|
| 0         | 25.211                                                          | 1.00341                |
| 10        | 1.645                                                           | 0.84620                |
| 20        | 0.273                                                           | 0.91575                |
| 30        | 0.0589                                                          | 1.32767                |
| 40        | 0.0149                                                          | 1.18121                |
| 50        | 0.00433                                                         | 1.07159                |
| 60        | 4.365e-4                                                       | 0.93130                |
| 70        | 1.569e-4                                                       | 0.82108                |
| 80        | 5.890e-5                                                       | 0.80752                |
| 90        | 2.296e-5                                                       | 0.86061                |
| 100       | 1.888e-5                                                       | 0.82230                |

TABLE 3. Average and standard deviation of maximum irradiance ratio depending on depth

| Depth (m) | Average Ratio between seawater | Standard deviation |
|-----------|--------------------------------|--------------------|
| 0         | 1.00000                         | 0.002208           |
| 10        | 0.83536                         | 0.01179            |
| 20        | 0.90924                         | 0.008741           |
| 30        | 1.33538                         | 0.017638           |
| 40        | 1.16350                         | 0.015391           |
| 50        | 1.05509                         | 0.016177           |
| 60        | 0.92448                         | 0.009883           |
| 70        | 0.79936                         | 0.022764           |
| 80        | 0.79652                         | 0.025339           |
| 90        | 0.87243                         | 0.023406           |
| 100       | 0.80986                         | 0.011526           |

**FIG. 21. Polynomial and graph through Fitting.**

Figure 22 shows the ratio of irradiance between Type-II literature and measured data. From the results, these ratios have a difference after 50 m depth. So, the compensation factor should be considered for the research of irradiance of sea water in deep regions.

**IV. CONCLUSION**

Since optical properties of seawater of East Sea are not currently formulated, it depends on Type-II seawater data of existing literature. In this regard, this study actually measured the light transmittance of the seawater of East Sea, and compared and analyzed with the optical properties on the seawater of existing literature which has insufficient information. Based on the fact-finding survey data and actually measured data of irradiance in seawater, the irradiance distribution was analyzed through simulation from the modeling on fishing vessels and seawater. As a result, this study confirmed that there were differences of the irradiance distribution between the Type-II and measured seawater as the depth
of seawater increased because existing literature has insufficient data according to depth. Such a difference occurred due to the lack of information on Type-II seawater. This study found the compensation factors to compensate the differences on the Type-II and measured seawater through simulation. By using such a compensation factors the irradiance distribution on the seawater of East Sea can be precisely analyzed with the Type-II data without measurement.

ACKNOWLEDGMENT

This work was supported by a grant from the National Institute of Fisheries Science (R201642).

REFERENCES

1. N. G. Jerlov, Marine Optics, (Elsevier, New York, NY, USA, 1976).
2. R. W. Austin and G. Halikas, “The index of refraction of seawater,” SIO Ref. No. 76-1 (Scripps Institution of Oceanography, California, USA, 1976).
3. Korea hydrographic and oceanographic administration, (Korea ocean observing and forecasting system Statistical data Ulleungdo Water temperature and Salt concentration, 2013).
4. SYNOPSYS, Inc., “Lighttools version 8.1,” http://optics.synopsys.com/lighttools/.
5. S. J Choi and H. Arakawa, “Relationship between the catch of squid, Todarodes pacificus, STEENSTRUP, according to the jigging depth of hooks and Underwater illumination in squid jigging boat,” J. Korean Fish. Soc. 34, 624-631 (2001).
6. M. S. Jung, K. D. Lee, J. S. Ko, and J. H. Bae, “Irradiance Distribution Analysis of a Squid Jigging Vessel Using an LED Plus Metal Halide Fishing Lamp Combination Under Optimized Conditions,” Korean J. Opt. Photon. 25, 315-325 (2014).
7. S. J. Choi, “Characteristics of Spectral Irradiance Based on the Distance from the Light Source and Operating Method for Fishing Lamps with a Combined Light Source,” Kor. J. Fish. Aquat. Sci. 42(6), 711-720 (2009).
8. SATLANTIC, Inc., “Operation Manual for the Profiler II,” http://www.satlantic.com.