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Vertical Distribution of Giant Jellyfish, *Nomurai nemopilema* using acoustics and optics

Seonghun Kim[1], Kyounghoon Lee[2†], Won-Deuk Yoon[1], Hyungbeen Lee[1] and Yong-su Yang[1] ([1]Natl Fish. Res. & Dev. Inst., Korea; [2]Chonnam Natl. Univ., Korea)

1. Introduction

Since 1960, global warming, environmental pollution, marine construction, and over-exploitation of fishery resources have caused mass occurrences of jellyfish and have brought socio-economic problems around the world. The Yellow Sea is a semi-enclosed epicontinental marginal sea located between Korea Peninsula and North China Continent, separated from the West Pacific Ocean by the East China Sea in the south, and linked with Bohai Sea in the north.

Jellyfish has biological property of having asexual and sexual reproduction phases in a life cycle and can proliferate exponentially if the condition is appropriate for their reproduction.[1)] The East China Sea (ECS), Yellow Sea (YS) and Coatal area of Korea and Japan suffer every year since 2003 massive appearance of the giant jellyfish, *Nomepilema nomurai*. Although the origin of this giant jellyfish is still being debated, it is generally believed that the coastal area between the Changjiang Estuary and the Shandong Peninsula is one possible source.[2)] Kawahara et al.[3)] suspect an influence of Changjiang diluted water (CDW) on the distribution of *N. nomurai*. And indeed, Yoon et al. find a close relationship between the spatial distribution of *N. nomurai* and the CDW, and further surmise that the polyps of the giant jellyfish overwinter somewhere between the Changjiang Estuary and the Shandong Peninsula. They suggest that juveniles are transported to an area near the Changjiang Estuary and northern ECS during winter–spring.

The giant jellyfish in the Korean water also causes serious damages in fisheries, stings sea bathers resulting in loss of income for regional economy, and blocks up nuclear electric power station. As we developed and examined monitoring methodologies for jellyfish blooms in the Yellow Sea in order to compare a new methodology in jellyfish monitoring, so we verified its vertical distribution in the open sea when it moved and drifted to the YS.

2. Materials and Methods

The Visual Counting (VC) in all observations was carried out during daytime every 1 hour, which is about 10 nautical mile intervals. Jellyfish counting was done for a predetermined width of surface water, which is in general 5 to 10 m width, and knowing the speed of vessel, jellyfish abundance was evaluated. The speed of vessel was adjusted according to the abundance of *N. Nomurai* jellyfish for each stations (**Fig. 1**).

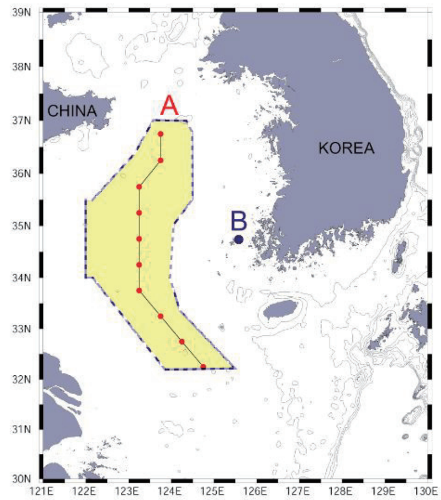

Fig. 1. Comparison among Visual Counting, Trawl Sampling and Acoustic methods (Koera-China Provisional Water Zone, A), and Visual Counting, Underwater Acoustic, Underwater Camera methods (B, Heuksan-Do site).

The Underwater Acoustic data (UA) can be quantified by echo-counting and echo-integration to estimate the biomass for a specific scatterer in the whole water column. Jellyfish's abundance can be adopted by echo integration using their frequency characteristics when it can be mixed with zooplankton stocks in sound scattering layer in order to estimate its abundance.[4,5)] But, such giant jellyfish as *N. nomurai* jellyfish is usually bigger than any others and is individually resolved scatterer. In addition, it has uncertainty in swimming tilt angle[6)] and can not be resolved with some individual fishes like a butterfish (*Psenopsis anomala*) nearly distributed. Therefore, echo counting method can be more appropriate than echo integration for giant jellyfish's density estimation.

A Towed Underwater Camera (TUC) was used to monitor the jellyfish's individual distributed from surface to vessel bottom (around 10 m depth) due to shadow zone of acoustic monitoring area. It was attached on the towed sledge and towed at stable depth position by controlling the research vessel's speed. In this case, the up-ward video monitoring was collected in staying 3 knots of vessel speed, and

†E-mail: ricky1106@naver.com

analyzed to estimate the density of jellyfish distributed up to 10m depth. For quantitative analysis of the density of the giant jellyfish, the 3 methods were simultaneously applied in jellyfish monitoring and compared (**Fig. 2**).

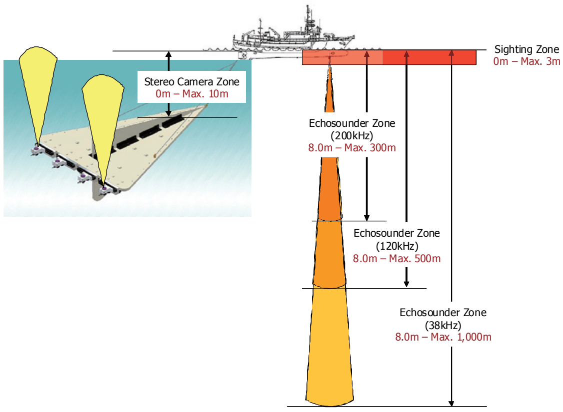

Fig. 2. Jellyfish monitoring scheme to compare with visual counting, trawl sampling and acoustic methods as well as a towed underwater camera system.

3. Result and Discussion

In order to compare with those by the TUC and the UA in 3 dimensional water column, even though the detection range error can be happened according to turbidity, VC is able to count the range up to 3m below so that the detected depth of VC will be estimated by 2.5m depth. By the result, the maximum density of jellyfish which distributed in the surface area was 10.06 (inds./1000m^3), and the averaged value was 1.03 (inds./1000m^3). The standard deviation of density estimation can be higher in continuous VC method, this cause will be higher in intensive density of jellyfish's patch.

The results of UA survey was shown in the maximum density of jellyfish, which distributed in the depth from 10–40m depth, was 0.31 (inds./ 1000m^3), and the average was 0.05 (inds./1000m^3).

Based on the distribution density of visual counting which is widely utilized in the estimation of distribution density of jellyfish, Results indicated that the density of jellyfish was shown to be 74.8% (101 inds.) and 85.2% (115 inds.) by the towed underwater camera and the underwater acoustic, compared to 135 individual jellyfish investigated by the visual counting survey in the first time. In addition, the number of jellyfish was greatly decreased in the second time; 23.2% (16 inds.) and 34.8% (24 inds.) by the towed underwater camera and the underwater acoustics, respectively. Summarizing results of first and second surveys, the correlation of densities by the visual counting and the towed underwater camera was shown to be low (R=0.54). Furthermore, the correlation of densities by the visual counting and the underwater acoustic was estimated to be much lower (R=0.3). Also, the relationship between TUC and UA has comparatively low correlation (R = 0.51).

For underwater acoustics, the maximum distributed density of *N. Nomurai* jellyfish was estimated in 74.0 (103 inds./m) at St. 249, and the averaged density was estimated in 41.0 (103 inds./m). Then, underwater acoustic method can be verified that the jellyfish was intensively and vertically distributed as around 93% in the range from surface to 40m depth, this result also showed that the jellyfish individuals were mainly distributed in surface and pelagic areas and moved by current field (**Fig. 3**).

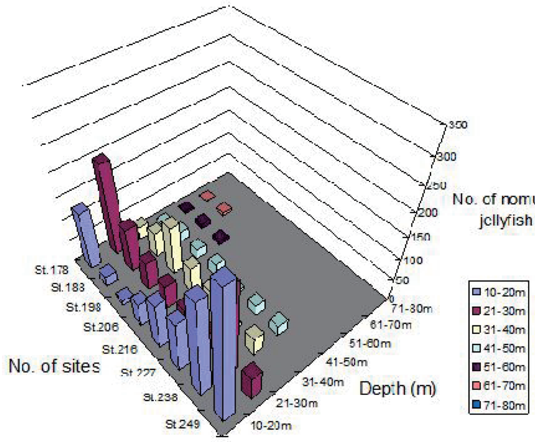

Fig. 3. Vertical distribution of *N. Nomurai* jellyfish using underwater acoustics.

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†E-mail: ricky1106@naver.com