論文の内容の要旨

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論文題目　**Estimations of pelagic fish distribution and biomass in the East China Sea using hydroacoustic methods**

(音響調査による東シナ海の浮魚類の分布および資源量推定に関する研究)

I- General introduction

The East China Sea (ECS) represents one of the main spawning and nursery areas of small pelagic fishes in the waters off of the Japanese coasts. It also constitutes an important fisheries ground for commercially valuable pelagic fishes. The pelagic fish stocks have been evaluated using primarily virtual population analysis (VPA) method. Since 1996, acoustic methods have been introduced and the ECS pelagic ecosystem has been monitored annually using acoustic surveys. The deployment of fisheries acoustics has undergone hitherto improvement in terms of duration and coverage of surveys. However, the post-processing of acoustic data has been limited to the calculation of biomass indices. The present study comes as a leading work applying hydroacoustic methods to estimate abundance and biomass of commercial pelagic fish species in the ECS. It is prompted by the need to fulfill the Japanese government desire to improve management of fishery resources in the ESC.

Few years after its emergence, fisheries acoustics proved to be an advantageous tool that provides a better cost-effective use of survey time by eliminating the need to conduct independent coverage. The continuous acoustic sampling provides a high time- and space-resolution data set that traditional methods could hardly achieve. Notwithstanding the numerous advantages and the dramatic development in acoustic technologies, the Achilles heel of fisheries acoustic remains the identification and the classification of acoustic targets. This challenge is addressed in the second chapter which represents the backbone of this study.

II- Classification of fish schools based on evaluation of acoustic descriptor characteristics

Acoustic data were collected along 27 transects from 2002 to 2006 with a 38 kHz Simrad EK 505 scientific echosounder. Midwater trawling was conducted to collect biological information and to verify the species composition of acoustic backscatter.

The first step of the work aimed to classify echotraces and subsequently identify fish species acoustically monitored. Acoustic data were post-processed and five acoustic descriptors were extracted ((1) morphological: school length, height and height mean; (2) energetic: mean volume backscattering strength (*Sv*); (3) positional: mean school altitude (Depth).

Based on these features, two methods of supervised classification were applied, the discriminant function analysis (DFA) and the artificial neural network technique (ANN). Both methods showed encouraging and about equally highly correct classification rates (ANN 87.6%; DFA 85.1%). Despite the promising results, ANN technique required a large amount of data and time consuming training phase. Therefore, it is more recommended to be applied for automated identification during survey time. Both techniques revealed that positional and then morphological descriptors were most efficient in discriminating among fish schools. Fish catch composition from midwater trawling validated the fish group classification and assisted to identify fish species through representative examples of each grouping. Fish species were classified within three groups, the first (G1) consisted of three species occuring in the upper pelagic layer. The bulk of catch was made of Japanese anchovy, round herring and sardine. The second fish-group (G2) included five species taking place in midwater layers and represented mainly by jack mackerel, chub mackerel and shortfin scad Japanese scad. The last group comprised mesopelagic species (peasrlsides and lanterfishes) occurring in demersal layers.

III- Relationships between environmental factors and fish school properties

Good knowledge of the distribution patterns of fish schools is crucial for stock assessment and successful fisheries management. Focusing on the two fish-groups including pelagic species, the relationships between individual acoustic properties (abundance, density, length, height and depth) of fish schools and environmental parameters (temperature and salinity at different depths and bottom topography) were explored using generalized additive models (GAMs). The influence of environmental parameters on vertical distribution patterns was consistent between years. GAMs underlined the importance of temperature as the main gradient along which fish schools occur correspondingly to their preferences. The vertical profiles of temperature illustrated the water stratification in summer season. The temperature ranged from 26 to 29°C, but only 12 to 15°C at 200 m depth. Therefore, the thermocline played a major role in controlling the bathymetric distribution of G1-species and restricting their occurrence to the upper layer.

In case of G1-schools, temperature and salinity at the sea surface and at 30 m depth essentially controlled the school abundance and density. As for G2-schools, temperature and salinity at 100 m

depth and near the bottom had an exclusive effect on school depth, abundance, density and height. For both groups, bottom depth controlled mainly school density and depth. The correlations generated from GAMs were plotted as functional forms.

The results proved that GAMs are a powerful technique for defining and quantifying the intricate effects of environmental variables involved on the bathymetric distribution of pelagic fish species.

GAMs may be improved by accounting additional abiotic as well as biotic parameters should be taken in consideration to explore ecological preferences of target fishes for a better understanding of population's characteristics. Moreover, additional data sets throughout the whole year would be useful for further testing the stability and continuity of the suggested relationships during other seasons.

IV- Estimations of distribution and biomass

The spatial distribution of fish abundance using GIS mapping highlighted areas of high fish concentration occurring mainly in the northern part of the study area. G1-species were observed constantly in Tsushima straight and preferentially near the coasts off western Kyushu. On the other hand, G2-species showed lower values of density but were widely distributed within the surveyed area. The abundance expressed by the area of backscattering strength (*S*a) reached a maximum of 11 850 m^2 per nm^2.

In addition to the sea temperature, the hydrography of the surveyed area might have played a significant role in the fish spatial distribution. For example, Japanese anchovy and round herring are most likely drifted by the warm Tsushima current to northern areas.

According to the fish spatial distribution and the stationarity of the fish density, the surveyed area was divided into three blocks, in order to estimate the biomass within defined confidence limits. The partition of echo-integrals and catch data in the first chapter was essential to calculate the biomass for each species. The partitioned values obtained by this method represent the average fish density over one nautical mile chosen as an elementary distance sampling unit (EDSU). Based on literature, target-strength (TS) and length-weight relationships were determined. Then, the total biomass was estimated from the observed densities, together with error margins. The update of TS measurements should improve the reliability of biomass calculation.

The results obtained from acoustic surveys are compared with those of alternative methods, to indicate the accuracy that can be expected using acoustic method.

V- General conclusion

Throughout this work, the emphasis was on the most important application of acoustics in fisheries research which is the quantitative assessment of fish stocks. The study has expanded the results of the few previous attempts on using acoustic methods to estimate abundance and biomass of pelagic fish in the East China Sea. All steps of this method were run, starting from acoustic data process,

partition of echo-traces and subsequently identification of fish echoes assisted by catch trawl data. Afterward, fish school measurements were transformed into stock biomass.

The study represents a leading attempt dealing importantly with discrimination of co-occuring pelagic species into fish-groups based on acoustic school properties. The present research therefore introduced a directive approach relevant to the case of ecosystems with high fish diversity.

The study focused also on relationships between fish school characteristics and environmental factors. The sea temperature was the most significant; in particular, compared to horizontal distribution of sea surface temperature, the vertical stratification was more important in controlling fish distribution.

For foreseeable estimations of pelagic fish stocks, the analysis should include larger time-series data to better discriminate between fish species and consequently refine the stock estimates. This baseline study should be followed by the selection of reliable indices advantageous for the fine-tuning of VPA method. Then, acoustic surveys must be viewed as a necessary complement to, rather than a substitute for, conventional survey methods for a better management of pelagic fish stocks in the East China Sea.