学位論文内容の要旨

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学 位 論 文 題 目

Predicting potential fishing zones of Japanese flying squid (*Todarodes pacificus*)

using data from 4D-VAR assimilation system

（4D-VAR データ同化システムを用いたスルメイカの潜在的漁場予測）

Introduction

Japanese flying squid (*Todarodes pacificus*) plays a key role in marine ecosystem linking oceanic micronekton and large top predators, and is an important target of Japanese fisheries. The coastal waters of southwestern Hokkaido are one of the main fishing grounds of this species. The high sensitivity of Japanese flying squid to ambient environment can result very different fishing catches caused by marine environmental changes. Understanding of the marine environmental effects on squid catches, however, is still poor mostly due to the lack of information on fisheries data, meanwhile, environmental data collected by boats and weather stations does not catch variability across variable scales. To reduce this gap, based on the assumption that squid were caught in areas where fishing vessels were located, distribution of fishing positions detected from nighttime visible images (DMSP/OLS and VIIRS/DNB) were applied as a useful source of information to observe squid occurrences. And the environmental variables provided by 4D-VAR assimilation system can be used as reliable daily information of oceanographic features. This dissertation aims to 1) validate the performance of the species distribution model using squid occurrence data collected independently by research boat, 2) investigate the effect of oceanographic factors on Japanese flying squid distributions, to predict more precisely and 3) develop applicable daily predictions for the development of local squid fisheries.

Materials and methods

The study area spanned 40.7°N – 42.7°N and 139°E – 142.7°E, covering the coastal waters of southwestern Hokkaido, Japan. Considering the distinctive oceanographic features in different ocean current system, the area was sub-divided into three sub-regions for fitting 4D-VAR based model: Japan Sea region, Tsugaru region and Pacific region. Environmental data were derived from satellite (SST, Chlorophyll-a concentration, Kd(490)) and 4D-VAR assimilation system (u, v, w,

temperature, salinity and EKE). For the 4D-VAR dataset, environmental variable at each depth that give high correlation coefficient with squid occurrences was used. Fishing locations were obtained from nighttime visible images (DMSP/OLS). 70% of dataset were randomly extracted and used for model building and the remaining 30% were used for validation. The potential fishing zone of Japanese flying squid were predicted with a range of statistical models (GLM, GBM, GAM, CTA, ANN, SRE, FDA, MARS and MAXENT) using the "Biomod2" library in the R statistical software. One satellite based model was fitted for the whole region, and three sub-regions were fitted with different model using 4D-VAR based variables. Bathymetry was considered as influential variables in both satellite-based model and 4D-VAR based model. Predictions were validated based on true skill statistic (TSS) and area under the receiver operating characteristic curve (AUC). To divide the areas into good potential fishing zones (predicted presence area) or not (predicted absence area), the statistical criteria MaxKappa was implemented to optimize the threshold. The new-generation nighttime visible sensor (VIIRS/DNB) was applied to validate the model, daily fishing vessels' locations were overlapped with corresponding daily potential fishing zone maps to extract prediction values. The ratios of the numbers of fishing located at predicted presence area to the total numbers of actual fishing presence were calculated.

Experimental fishing operations were deployed to validate the real performance of model applications. The selections of fishing locations were based on daily potential fishing zone predictions. Catches of the prediction-based operations were compared with other routine operations. Real squid fishing vessels' locations were recorded using radar on board.

The selected model was applied to use daily environmental data to simulate the predictions between 2008 and 2011. The monthly averaged simulation results were used to show the pattern of squid distributions. Average values of all daily predictions between 2008 and 2011 were calculated, the water feature under high prediction zones were applied to interpret reasons of squid assemblages. The correlation coefficients used for variables selections were investigated and associated with the oceanographic features of waters. Environmental differences between presence and absence of squid assemblage were compared in each sub-region. And the relationships given by model were also elucidated in this study.

During fishing season (From June until December) between 2012 and 2014, a series of 183 cloud free single-pass images of DMSP/OLS and 197 cloud free single-pass images of VIIRS/DNB were obtained. To reduce redundancy and keep the temporal intervals of data, random samplings were employed to select one daily image from every ten days for fitting models, then 46 images of DMSP/OLS and 55 images of VIIRS/DNB were used to build models. Independent validation dataset was derived by randomly selecting data from the rest of the nighttime visible images, a total of 30 DMSP/OLS images and 30 VIIRS/DNB images were retained as the validation dataset. Both DMSP/OLS data and VIIRS/DNB data were resampled into same spatial resolution with 4D-VAR dataset of 1/54° x 1/72°. Then two series of models (DMSP/OLS based and VIIRS/DNB based)

were established based on the same model using the same configuration as Chapter 2. The predictive performances of these two models were tested, and how the use of new-launched satellite images can improve the predictions was further discussed. Cloud-free nighttime visible images collected on the same date from DMSP/OLS and VIIRS/DNB were compared to present the superiority of using VIIRS/DNB data in locating squid fishing vessels.

Results and Discussion

4D-VAR based models showed a better performance in predicting potential fishing zones of Japanese flying squid. The application of data from 4D-VAR system ensured the full coverage of data without weather restriction, moreover, data from 4D-VAR system can provide reliable future predictions. Boosted regression trees (GBM) were proved to be the most appropriate model for every sub-region comparing with other habitat models. Validations based on nighttime visible data and field surveys showed that the spatial-temporal distribution of Japanese flying squid could be well predicted using 4D-VAR and bathymetry dataset, and the use of prediction maps effectively reduced failure rate of fishing operations by T/S Ushio-Maru. Three days forward potential fishing zones (PFZ) prediction system were established and maps have been freely shared to local fishermen since 2013 through daily email services and Web-GIS system.

The potential fishing zones predicted by the model appeared in coastal regions with relatively high eddy occurrences and sub-surface coastal upwellings that might be related to availability of food for squid. Seasonal distribution patterns of squids were well presented in prediction maps, and this could provide useful information for understanding squid migration. For most of regions and months, lower daily water temperature was observed at 50 m depth of the area where squid was present than the area where squid was absent. This implied the important of water temperature for squid distributions in short term (daily).

VIIRS/DNB data gives higher spatial resolution so reduces the chance of misidentification of fishing vessels. In addition, considering overpass time (VIIRS/DNB, 01:30 LT vs DMSP/OLS, 19:30 LT), the VIIRS/DNB can provide more reliable information of position of fishing vessels using lights during the short summer nights. Predictions based on the VIIRS/DNB images showed better performance than the DMSP/OLS images as well. Although prior habitat models in early chapters produced modest potential fishing zones prediction, more accurate models and more effective applications could be expected to achieve the sustainability in local fisheries along with the continuous technology progress and data improvement.