Title : The potential distribution of adult Antarctic krill in the Amundsen Sea

Lulu Liu and Jianlong Feng

Laboratory of Marine Environment and Numerical Simulation, College of Marine and Environmental Sciences, Tianjin University of Science and Technology, Tianjin,300000

1. Aim: This study aimed to obtain the potential distribution of adult Antarctic krill in order to provide useful information and reasonable reference for the policy on protecting potential krill habitats around the Amundsen Sea

2. Methods:

The presence data of the Antarctic krill is from KRILLBASE, which is an open access database of net-based juvenile and adult Antarctic krill (Atkinson et al., 2016). In total, we get 40 effective locations for Antarctic krill (Fig.1). Nearly all selected locations were concentrated in January, February, March, November, and December. These are too little data to get the temporal variation (There are only 8 points on monthly average), so we put these locations together to get the spatial distribution in this work. In order to avoid the spatial auto-correlation, which affects the accuracy of the model, we randomly removed a point with distance less than 0.1° between two points.

In this work, 8 physical and 9 ecological variable of the ocean were used to analyze the habitat preferences of Antarctic krill (Table 1). These variables are derived from the Global Ocean Reanalysis Simulation (GLORYS2v4) (http://marine.copernicus.eu/service-portfolio/) as monthly mean value of January, February, March, November, and December from 1993 to 2015 with a resolution of 0.25° × 0.25° . All the data used in this work was the first layer of the variables. The parameters used in the Maxent contained the average states of the variables (January, February, March, November, and December), their variability (maximum mean, minimum mean, and long-term change rate). The sea ice persistence index (ICE) was calculated as the proportion of the overall time during which the grid was covered by sea ice (the sea ice concentration larger than 60%). The index was calculated as ICE=M1/M, where M1 is the number of months which monthly sea ice concentration is less than 60%, and M is the number of months used in a year (in this work it is 5).The extent of all variables was clipped to match the study area, ranging from 80° W to 150° W and 55° S to 80° S. Furthermore, correlation analysis was performed on the attribute values of 17 variables, as too many variables would increase the complexity and random error of the model, which would reduce the accuracy of the results (Jiang, 2018; Zhang et al., 2019). The factors with Pearson's correlation coefficient larger than 0.7 was removed (Nachtsheim et al., 2017). In addition, the variables that contribute less than 0.01 to the Maxent model were removed (Nachstheim et al., 2017). Finally, 10 parameters, ICE (sea ice persistence index), PHYC (total phytoplankton), Fe_min (minimum dissolved iron), SPCO2_min (minimum surface CO2), U_max (maximum eastward velocity), Fe (dissolved iron), NPPV_min (minimum total primary production of phytoplankton), MLP_max (maximum density ocean mixed layer thickness), PO4_min (minimum phosphate), and V_max (maximum northward velocity) for the Antarctic krill were selected in this work.

In this work, the maximum entropy model (Maxent) was used to calculate the constraints and estimates the possible distribution of the Antarctic krill using the environmental variables and krill presence points. Maxent is quite prevalent in habitat modeling as only presence points was needed and works well with small sample sizes (Phillips and Dudik, 2008; Merow et al., 2013; Saupe et al., 2015). The program Maxent (version 3.4.1, https://biodiversityinformatics.amnh.org/open_source/maxent/, Phillips et al., 2006; Phillips and Dudík, 2008) was used in this work, 75% of the specie locations were selected to build the model, and the remaining 25% of the locations to test the model. Within the setting window, a bootstrap replicate run type was selected for 10 replicates with a random test percentage of 25% used. We used the bootstrap to sample the presence data for multiple runs. The cloglog was chosen as the output format, which gives a rough estimate of a probability of presence. The maximum test sensitivity plus specificity was selected as the threshold. Jackknife test was used to get the contribution rate and importance of variables. Model performance was assessed using receiver operating characteristic (ROC) curves using both the training and test data (Fielding and Bell, 1997; Nachtsheim et al., 2017). The area under the curve (AUC) can range between 0 and 1, the model can be judged as excellent if AUC is higher than 0.9 and good if AUC is between

0.8 and 0.9.

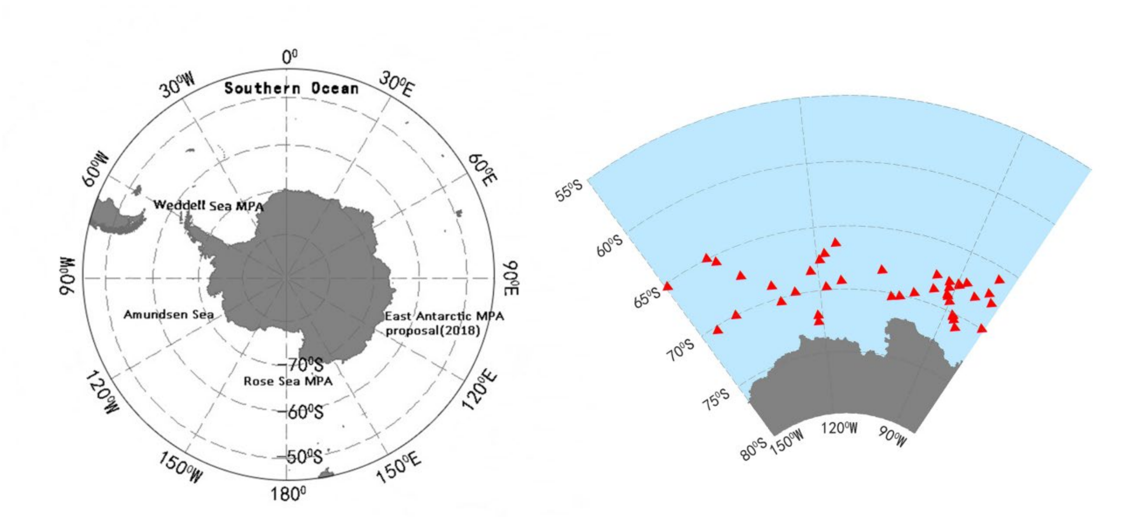

Fig.1 Locations of the Southern Ocean, Weddell Sea MPA, Rose Sea MPA, and Amundsen Sea (left), locations of the Antarctic krill in the Amundsen Sea (right)

Table 1 Physical and ecological variables from the GLORYS2v4

Physical	Ecological
Temperature,TEM	Total Chlorophyll ,CHL
Salinity,SAL	Nitrate ,NO3
Eastward velocity,U	Phosphate ,PO4
Northward velocity,V	Dissolved silicate ,SI
Sea surface height,SSH	Dissolved oxygen ,O2
Density ocean mixed layer thickness,MLP	Total primary production of phyto ,NPPV
Sea floor potential temperature,BOT	Dissolved Iron ,Fe
Sea ice,ICE	Surface CO2 ,SPCO2
	Total phytoplankton ,PHYC

3. Result: In this work, Maxent performed well in terms of generating species distribution models for Antarctic krill in the Amundsen Sea (Fig.2), with the AUC values equal to 0.91 (0.92 for training data and 0.90 for test data). Results show that the high suitable habitat for Antarctic krill located between 65° S and 72° S, which account for 8.1% of the total area of the Amundsen Sea. The moderate suitability habitat

mostly located at the border area of the high suitable habitat and there was also a small area in the central west of Amundsen Sea, and account for 6.7% of the total area. The low suitability habitat account for 11.2% of the total area, and mostly located at south of 65° S. The unsuitable habitat occupied the largest percentage in area (74.0% of the total area), which located around the coastline (south of 73° S) and between 55° S and 63S.

Based on percent contribution, ICE, PHYC, and Fe_min were the top three parameters used in the prediction of the Maxent model that affected the distribution of Antarctic krill in the Amundsen Sea. The ICE was the greatest contributor (57.2%) to the model, the contributions of PHYC was larger than 10% (12.4%) and the contributions of Fe_min was smaller than 10% (7.6%).The contributions of other variables were less than 5% to the model.

For the Antarctic krill in the Amundsen Sea, the ICE, PHYC, and Fe_min were the main factors affecting the habitat suitability, with the contribution about 77.2% in total. Average of ICE, PHYC, and Fe_min in January, February, March, November, and December from 1993 to 2015 were calculated and shown in Fig.3. Results show that the ICE increased as latitude increased in the Amundsen Sea. The mean value of high and moderate suitable habitat sare about 0.31 and 0.32, respectively. Results also show that the ICE might be the main restrictive factor in the northern part of the central region, where the PHYC and Fe_min were within the optimum range.The PHYC was largest along the coastline, especially in the Pine Island Bay (with values larger than 3.23). In general, the PHYC in the east part was higher than that in the west part. It showed that the high and moderate suitable habitat had relative higher PHYC than the outer part of the Amundsen Sea, the mean value of high and moderate suitable habitat are about 2.68 $mmol/m^3$ and 2.30 $mmol/m^3$, respectively. Results also show that in the northern part of the central region, where belonged to unsuitable habitat, the PHYC value was also larger than 2.48 $mmol/m^3$ and smaller than 2.77 $mmol/m^3$. It seemed that at these areas the food supply was not the restrictive factors for the adult Antarctic krill. The Fe_min was largest along the coastline, and results show that the high and moderate suitable habitat had relative higher Fe_min than the outer part of the Amundsen Sea, the mean value of high and moderate suitable habitat are about 7.4×10-5 and 7.5×10-5 $mmol/m^3$, respectively.

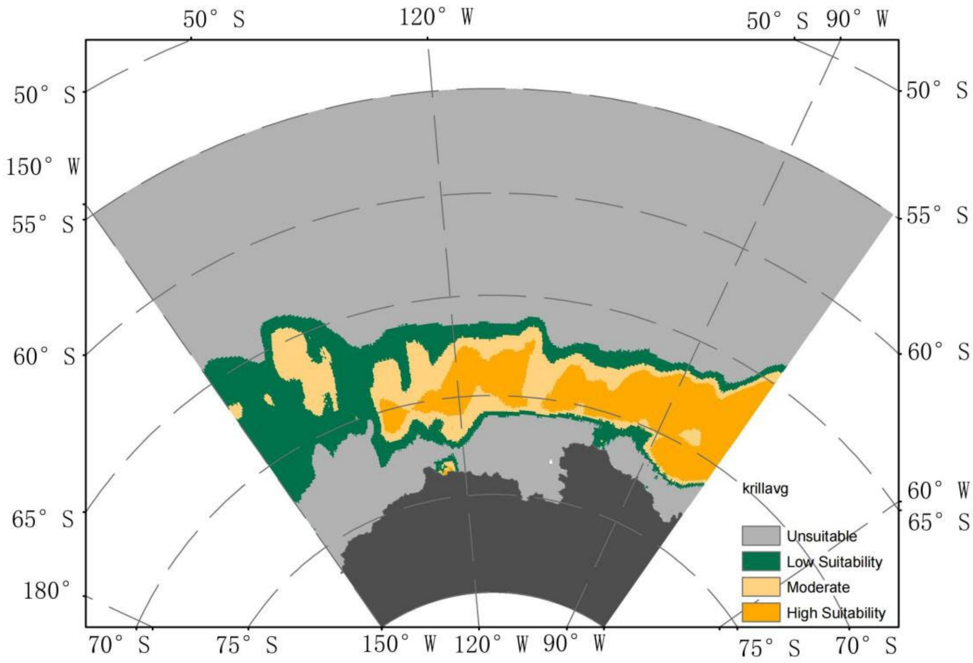

Fig.2 Habitat suitability maps for Antarctic krill in the Amundsen Sea

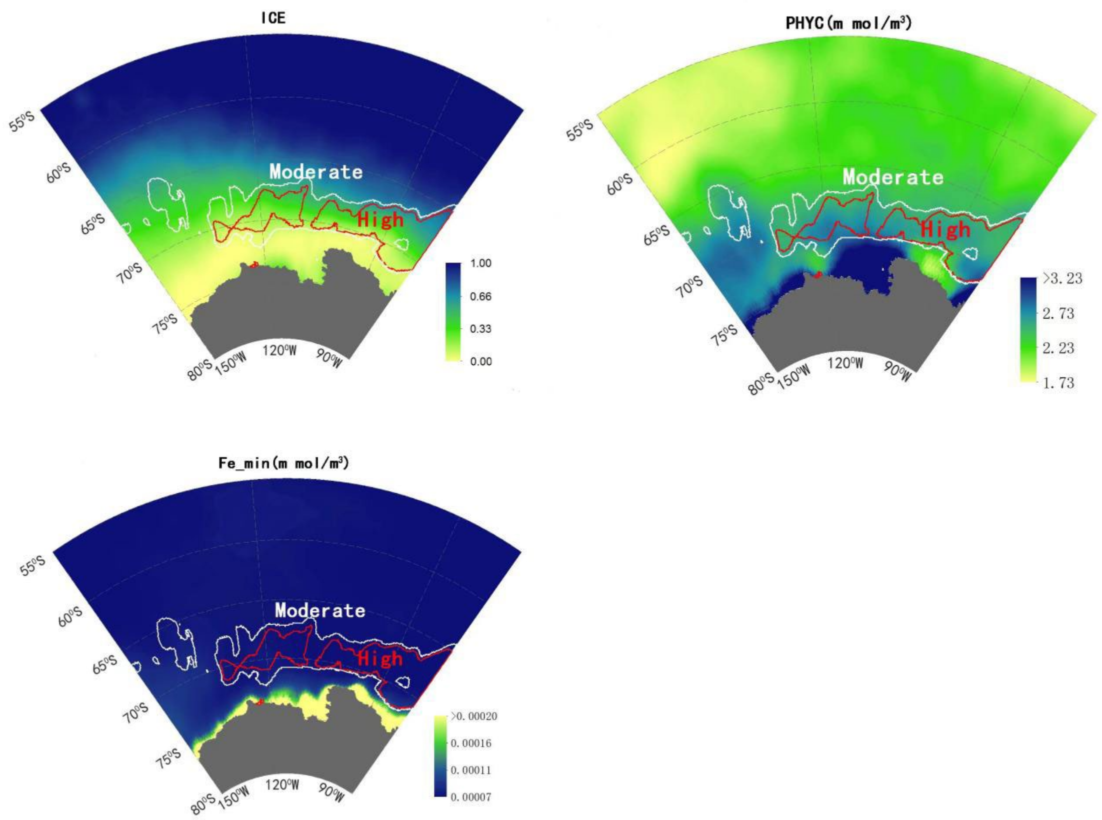

Fig.3 Average of 3 selected variables in January, February, March, November, and December from 1993 to 2015 and the border of moderate (white line) and high (red line) suitable habitat

4.Discussion: In this work, the presence data (40 points) of the Antarctic krill is from KRILLBASE, in which the data concentrated in January, February, March, November, and December. During these months, the adult krill swarms feed on phytoplankton in surface waters (Flores et al., 2012b). The results still agreed with what we know about the abundance and distribution of adult Antarctic krill, and the effects of environment conditions on distributions (Berglund, 1985; Atkinson et al., 2008; Krafft et al., 2010). However, the overwintering strategy of adult Antarctic krill was not taken into account. In addition, these are too little data to get the monthly variation (There are only 8 points on average). During the dark season,adult krill usually migrates to deeper water levels below 200 m or concentrates under the sea ice (Siegel, 2005; Taki et al., 2005; Flores et al., 2012b). We did not get observations during the dark season. This current method is not able to provide the habitat suitability maps of the adult Antarctic krill in the dark season. Therefore, differences may exist in the distributional behaviors and habitat preferences of Antarctic krill as the season progressed. In addition, there may be underestimate as it is difficult to get presence data in the shelf area when there is ice cover. Despite these, our results still have reference significance for the policy of the protecting potential krill habitats around the Amundsen Sea for the CCAMLR.

5. Conclusion: Using the Maxent model and sets of environmental variables, the suitable habitat distribution and how the environmental variables affect the abundance and distribution of adult Antarctic krill were carried out in this work. High suitable habitat for Antarctic krill mostly located between 65° S and 73° S in the Amundsen Sea. The high and moderate suitable habitat accounted for 14.8% of the total area. The ICE, PHYC, and Fe_min were the three largest contributors to the model, contributed 77.2% in total. Adult Antarctic krill preferred habitats with ICE of 0.42–0.93, PHYC of 2.48–2.77 mmol/m^3, and Fe_min of (7.10×10-5)–(9.45×10-5) mmol/m^3.

6 Perspectives in future: Future improvements and more extensivestudies may be carried out when more data is available in the Amundsen Sea.