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Fish Migration Model Based on Time Series

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Abstract: The rising ocean temperature forces marine organisms to migrate north to colder waters in search of more appropriate areas. As two important fish in the Scottish fishing, the potential migration of mackerel and herring will damage local fishery to some extent. For small fishing companies that lack refrigeration in boats, the relocation of stocks may be too far beyond the reach, so the decrease of fishing opportunities can be fatal. Therefore, as consultants, we need to predict the future fish migration and make recommendations for the business mode of small fishing companies and fishermen. We divide the area around and south of Scotland by latitude and longitude. Then we use global sea surface temperature (SST) data to calculate the average temperature of each region in fishing season over the past 11 years. We establish time serious into the basic SST Model, extract the trend of the SST in different regions with the change of years and draw the fitting curve and prediction curve. Based on this, we made effective prediction of the migration location in 50 years.

1. Introduction

Each creature has its suitable environment. Animals choose the most suitable place to maximize the adaptation so that to promote the survival and reproduction. When the temperature changes beyond the acceptable range of species, they will look for other habitats that are more suitable for them, which is known as migration. For example, the lobster population of Maine is moving north for colder waters. When fish migrate for their survival because of the change in sea surface temperature, they also disrupt the operation of fishing companies.

Small fishing companies in Scotland use boats without refrigeration to catch fresh fish and then ship them to ports. As important trades in Scottish fishery, herring and mackerel may change their habitats as sea surface temperatures rise, far more beyond the fishing scope. This can result in great economic losses for those companies.

2. Sea Surface Temperature Model (SST Model)

2.1 The Design of SST Model

In the first model, we need to establish the relationship between sea surface temperature in the north Atlantic and the year. The key is to find a certain rule based on the existing data of sea surface temperature and then predict the situation 50 years later according to the trend. Based on latitude and longitude, we divide the waters around Scotland into the following four regions.

Region 1: From 50 to 55 degrees north latitude and from 0 to 5 degrees west longitude
Region 2: From 55 to 60 degrees north latitude and from 0 to 5 degrees west longitude
Region 3: From 55 to 60 degrees north latitude and from 5 to10degrees west longitude
Region 4: From 60 to 65 degrees north latitude and from 0 to 5 degrees west longitude

For these four regions, we will establish time series X_t respectively, where X_t represents sea surface temperature and we can decompose it into: $X_t=m_t+s_t+Y_t$.

The common fishing season for mackerel and herring is near August. In order to simplify the model appropriately and maintain the continuity and integrity of the original data, we select the average sea surface temperature in July, August and September of each year for 11 years from 2009 to 2020.Each region is a series of small areas. For each of the 33 months, we average the sea surface temperature data of the small areas that make up the same area as the SST data for the corresponding ocean during the fishing season.

Taking Region 1 as an example, the periodicity data used for fitting covers 11 years in total, with 3 data per year.

Assuming that the periodic data is X_{ij}(i=1,2,...,12; j=7,8,9)

Step 1: Extract cycling item

· Figure out the mean of year i : $\bar{X}_i = \frac{\sum_{i=1}^{n} X_{ij}}{3} (j = 7,8,9)$

· Zero-mean for each month : $st_{ij} = X_{ij} - \bar{X}_i (i = 1,2,\cdots,n;\ j = 7,8,9)$

· Figure out the cycling item : $S_j = \frac{\sum_{i=1}^{n} sti_j}{n} (j = 7,8,9)$

Step 2: Gain the data removing the season term

$Z = \bar{Y} = (Y_{1,7}, Y_{1,8}, Y_{1,9}, Y_{2,7}, Y_{2,8}, Y_{2,9}, \cdots, Y_{n,7}, Y_{n,8}, Y_{n,9}) = (Z_7, Z_8, \cdots, Z_{9n})$

Step 3: Regression fitting

Step 4: Prediction

2.2 The Result of SST Model

With the help of MATLAB, we establish the time series models for the four sea areas respectively. After eliminating the periodic term regression fitting, we obtain the fitting curve of sea surface temperature of the four sea areas from 2009 to 2020 and the prediction curve of sea surface temperature in the future. After 2048, the sea surface temperatures in July, August and September will stabilize to a certain extent, as shown in Table 1.

Table 1: The Stable Temperature of Each Region

Location	Stable temperature(℃)
Region 1	30.59637
Region 2	21.84657
Region 3	20.13814
Region 4	18.50794

The optimum temperature for both fish species is 18℃ and the survival temperature is 20℃. According to the data, after 50 years, i.e. in 2070, only the sea surface temperature of Region 4 will

be below 20℃, and even close to the optimum temperature. And Region 4 itself indeed has the distribution of mackerel and herring. It indicates that in addition to temperature, Region 4 possesses other conditions that fish basically need. Fish migrate in groups to defend against predators and we ignore particular climates, thus assuming that no mass die-offs will occur during the migration. So the most likely habitat for both species 50 years later is Region 4. It covers from 60 to 65 degrees north latitude and from 0 to 5 degrees west longitude.

The companies' original location is in the north Atlantic that is exactly in Region 3. The fishing range is limited by the lack of refrigeration. Therefore, if companies continue to operate in the current location, fish will move further than small fishing companies can catch. To estimate when this would happen, we analyze it based on the environment temperature of two fish.

· The best case

Fish leave the sea only when sea surface temperature exceeds survival temperature 20℃. That is, we need to find the minimum year for the surface temperature of Region 3 to surpass 20℃. According to the prediction of Region 3, the best-case scenario is that companies will be unable to catch fish in 2049.

· The worst case

Fish leave the sea as long as the surface temperature is above the optimal temperature 18℃. The prediction of Region 3 shows that fish stocks will outstrip fishing range by 2041.

3. Conclusion

According to the SST Model, mackerel and herring will migrate to Region 4 within a few years, causing economic losses to the Scottish companies located in Region 3 with limited technology. In this case, small fishing companies should change their operating mode. There are two options in the following:

· Option 1: Transfer some or all of the assets from current location in Region 3 to Region 4, where fish will go.

· Option 2: Replace existing small fishing vessels and purchase a certain proportion of vessels with refrigeration.

Both schemes can increase the catch significantly to increase revenues in spite of the cost. For more specific assessment, we list the cost and benefit factors associated with the two options.

Table 2: Factors of Costs and Benefits

Option 1: Transfer assets		Option 2: Replacing the vessels	
Costs	Benefits	Costs	Benefits
the cost of transferring assets c_1	the benefit gaining from increased fish b_1	net cost of buying new fishing vessels c_2	the benefit gaining from increased fish b_2

We will calculate the costs and benefits by quantifying each of these factors. Since the specific data is limited, we adopt approximate methods to obtain the specific values of each component.

3.1 Cost

· We approximate the cost of setting up a small company [1] as the cost of transferring the company, i.e. c1 = £ 10970

· We regard the net cost as the difference between the cost of buying a new boat and the cost of

selling the old boat, and then c2 = £ 98726.43 can be calculated.

3.2 Net Profit of Each Option

Synthesize the potential costs and benefits, we compare the two options.

Table 3: Comparison of the Two Options

	Option 1	Option 2
Cost	£ 10,970	£ 98,726.43
Benefits	£ 521,179.26	£ 3,001,234.65
Net Profit	£ 510,209.26	£ 2,902,508.22

Limited by data sources, we cannot give very accurate results. Through the above analysis and comparison, however, Option 2 can bring more profits. It means that the fishing companies should change to use small fishing boats to help to catch fish. But at the same time, we also consider that as small companies, if they cannot pay the cost of Option 2 at one time and are concerned about risks, they can also choose Option 1 as transition. Anyway, the potential migration of fish stocks urges small fishing companies to make changes instead of sticking to the status quo.

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