The Change of Fishing Strategy with SST Rising

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Abstract: With the global warming, the sea surface temperature (SST) is rising, resulting in many adverse consequences. In this regard, we have done the following research: according to the relationship between SST and near earth temperature, the whole temperature change in the next 50 years is divided into three processes. 1. The difference of geometric position. The spatial discrete SST is obtained by multiple quadric surface interpolation fitting, and a geometric continuous function describing the temperature change is obtained. 2. The future SST is predicted by regression analysis, and the overall temperature increases with the increase of the year; 3. The annual cycle fluctuation with the seasonal rhythm. The influence of annual wave and half year wave on the annual temperature change is fitted by harmonic analysis. Finally, the regional changes of fish distribution and the sea surface temperature of the surrounding areas of Scotland in the next 50 years are predicted. The migration of two kinds of fish in Scottish waters was analyzed, and the catch of small trawlers joined by small Scottish fishing companies was compared. The survival status of fish can be divided into three levels: the most serious, medium and only for survival. Finally, based on the existing model, the existing material level and trade mode, some strategic suggestions are put forward.

1. Introduction

1.1 Background

Greenhouse gas emissions and global warming have a huge impact. Most of the energy generated by the greenhouse effect is absorbed by the ocean, especially the shallow water surface [1]. Therefore, "escape" behavior is very important for the survival of fish in some areas of the ocean.

The current habitat for herring and mackerel is near Scotland. At the same time, they are swarms of migratory fish, particularly sensitive to climate change and change. Herring is caught mainly in northern and western Scotland, while mackerel is caught more widely. In addition, herring and mackerel have high economic benefits. Therefore, the impact of global ocean temperature change on fish migration has important research value.

2. Notations

Table 1 Definition of Parameters in Interpolation Fitting of SST.

Parameter	Definition	Unit
$C_i^{t_i}$	The i^{th} representative sample obtained in the space of the study area based on the oceanographic survey conducted.	
R	Radius of the earth.	*km*
φ_i	The angle between the *x* axis and the position in spherical coordinates after longitude and latitude conversion.	*rad*

θ_i	The angle between the *z* axis and the position in spherical coordinates after longitude and latitude conversion.	*rad*
t_i	SST of the location of the sample	$^{\circ}C$
p_i	The coordinates of the position of the sample on the sphere surface	
Ω	Captured Scottish waters	

3. The Model of Ocean Temperature Changes

3.1 The retrieve of SST and verification

Because the SST data is not easy to measure directly, we get that there is a first-order linear correlation between monthly average SST and near earth temperature, the correlation coefficient is 0.98[3].

$$\rho(X,Y)=\frac{Cov(X,Y)}{\sqrt{D(X)D(Y)}} \quad (1)$$

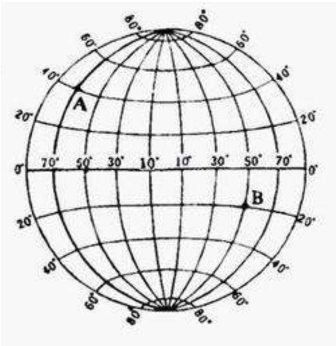
where X is monthly mean SST, and Y represents near-earth temperature.

When $|\rho(X,Y)|=1$, X is strongly linearly dependent on Y. In addition if X is strongly linearly dependent on Y, it can be converted to the form $Y=kX+b$.

3.2 The processing of SST

3.2.1 Interpolation Fitting of SST

We get the data of SST from NOAA, and simplify it with the method of multi quadric surface interpolation. We take 100 × 100 data grid in the direction of longitude and latitude in the SST data of Scotland.



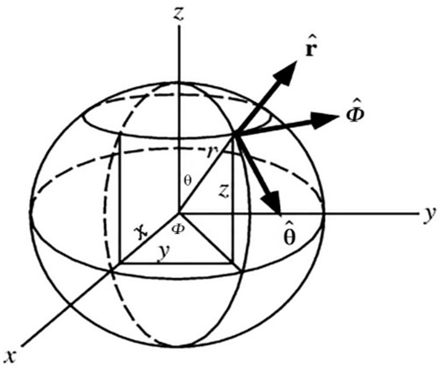


Figure1 The Latitude and Longitude of the Earth. Figure2 the Spherical Coordinate System.

To facilitate the following expression, we convert into the spherical coordinate system shown in Figure2.

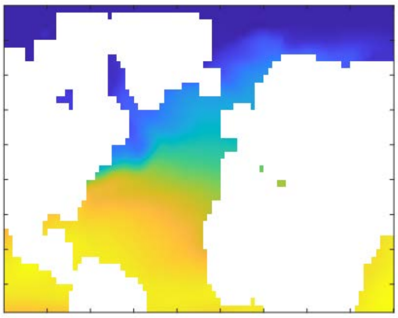


Figure 2 Part of the World Map.

Considering that the array is located in a spherical coordinate system, the properties of the array can be represented by positional parameters(R , φ_i , θ_i)and temperature parameter(t_i).

Multiple discrete array can form the data set H about temperature as

$$H = \{C_1^{t_1}, C_2^{t_2} \dots C_i^{t_i}\} \tag{2}$$

We construct the discrete data values as a continuous function of the position coordinates:

$$H(p) = H(\varphi, \theta, R) \tag{3}$$

In a particular location the function can be expressed as

$$H(p_i) = H(\varphi_i, \theta_i, R) = t_i \tag{4}$$

MQS is defined as the combination of the above conic surfaces, and the surface equation is

$$S(x, y) = \sum_{i=1}^{n} c_i \sqrt{(x - x_i)^2 + (y - y_i)^2} \tag{5}$$

Then we extend the definition to spherical coordinates and combine the Eq(4) to obtain:

$$H(p) = \sum_{i=1}^{m} a_i d_i \tag{6}$$

$$\begin{aligned} d_i &= R \arccos\left[\cos(90^\circ - \theta) \cdot \cos(90^\circ - \theta_i) \cdot \cos(\varphi - \varphi_i) + \sin(90^\circ - \theta) \cdot \sin(90^\circ - \theta_i)\right] \\ &= R \arccos[\sin\theta \sin\theta_i \cos(\varphi - \varphi_i) + \cos\theta \cos\theta_i] \end{aligned} \tag{7}$$

Combined with Eq(3), Eq(5) can also be expressed as

$$t_i = H(p_i) = \sum_{i=1}^{m} a_i d_{ij} \tag{8}$$

Next, we construct the row vectors A , T and the matrix D .

$$A = (a_1 \quad a_2 \quad \cdots \quad a_n), \quad T = (t_1 \quad t_2 \quad \cdots \quad t_n), \quad D = \begin{pmatrix} 0 & d_{12} & \cdots & d_{1n} \\ d_{21} & 0 & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & 0 \end{pmatrix}, T = A \cdot D \tag{9}$$

Then, we substituted in the existing sample data which is obtained by averaging the initial monthly data on an annual basis and used MATLAB to get the size of A vector every year. After we keep it for 50 times and take the average of all the A vectors $\overline{A}$ we get, finally we can construct function as

$$H(p) = \sum_{i=1}^{m} \overline{A} d_{ij} \tag{10}$$

Eventually in this way, we can get the continuous temperature trend model in space. And our fitting result is shown in Figure 4.

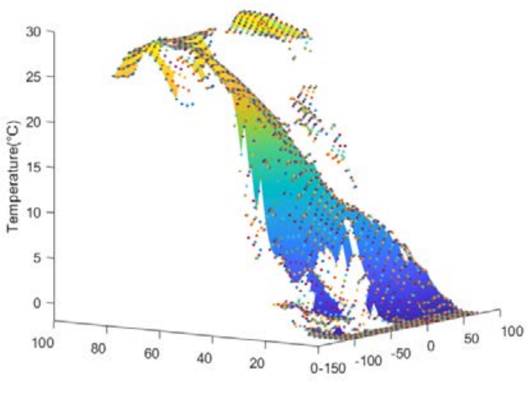


Figure3 The SST Interpolation Fitting Results.

3.2.2 Regression Analysis of SST

We can get the Root-mean-square Error (RMSE) of the original data and the control data.

Table 2 RMSE of the original SST and the control data.

RMSE	Original 40 data	Control 10 data
1st order polynomial fitting	9.4475	14.2500
6th order polynomial fitting	6.6377	2.4130
1 order Fourier fitting	7.8167	8.4170

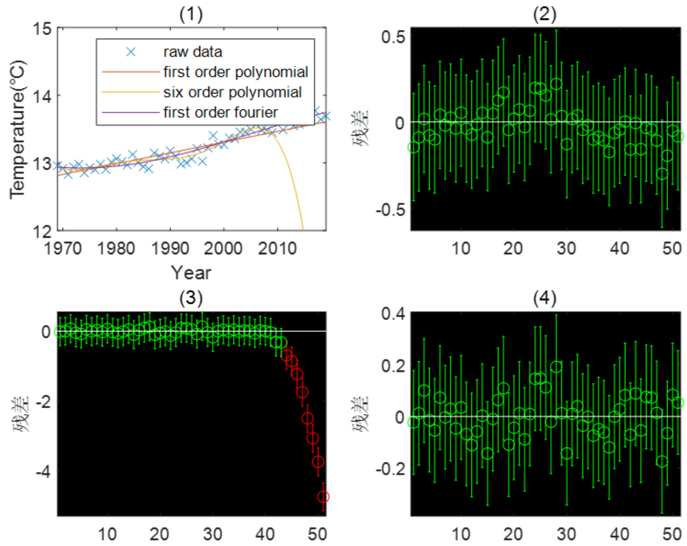


Figure 4 Fitting curve and residual of the first 40 data

After Method 1, we can get an obvious straight line. Through Method 2, the predicted value will show a large data drop phenomenon. As for Method 3, the variation error between the fitting value and the predicted value is small, so it can be used as the method to formally predict the temperature change trend in the next 50 years. Subsequently, we performed a formal data regression fitting.

$$T = 2144 - 296.3\cos(0.01018x) - 798\sin(0.01018x) \quad (11)$$

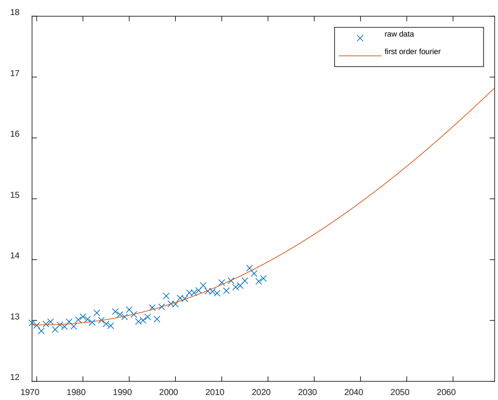


Figure5 Fit temperature curve

3.2.3 Harmonic Analysis of SST

In order to further analyze the annual variation of SST, it is more appropriate to select the data for Harmonic Analysis. Its Fourier series expansion is

$$T = A_0 + \sum_{n=1}^{\infty} A_n \cos(n\omega_t - \alpha_n) \tag{12}$$

The Harmonic Equation is

$$T = A_0 + A_1 \cos(\omega_t - \alpha_1) + A_2 \cos(2\omega_t - \alpha_2) = A_0 + T_1 + T_2 \tag{13}$$

If $D = \alpha_1 - (\alpha_2/2 + 180^\circ)$, the meaning of D is[3]:

•When $D = 0$, the maximum values of annual and semi-annual periodic component appear at the same time.

•When $D > 0$, the semi-annual periodic component was ahead of the annual periodic component, and the annual maximum value of SST was ahead of time, while the minimum value was behind time, indicating that the heating time was shorter and the heating rate was higher than the cooling rate.

•When $D < 0$, the semi-annual periodic component lags behind the annual periodic component.

D is negative and closer to -90°. Therefore, the warming period of Scottish waters is longer and the cooling period is shorter.

$$T = 1321 + 208.5351\cos(0.515x + 115.5132^\circ) + 30.3451\sin(1.03x + 119.7332^\circ) \tag{14}$$

In Table 3, the value is -0.0135 it can be considered that satisfactory fitting results can be obtained if n only takes 1 and 2 terms in Harmonic Analysis.

Table 3 Harmonic Analysis Parameters.

A0	A1	$\alpha_1(^\circ C)$	A2	$\alpha_2(^\circ C)$	A2/A1	D	R (%)
1321	208.5351	115.5132	30.3451	119.7332	0.1455	-124.3534	-0.0135

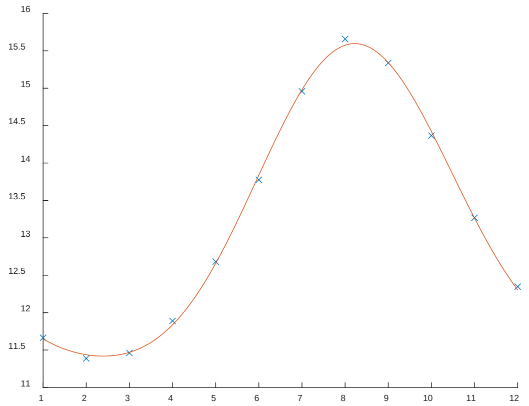


Figure 6 Harmonic Analysis Rendering.

3.2.4 The forecast of SST in waters off Scotland

Through the above models, we have been able to obtain the accurate SST changes to months within the range of Ω in the next 50 years. Due to specific SST change status diagram is more, thus, we just show some pictures.

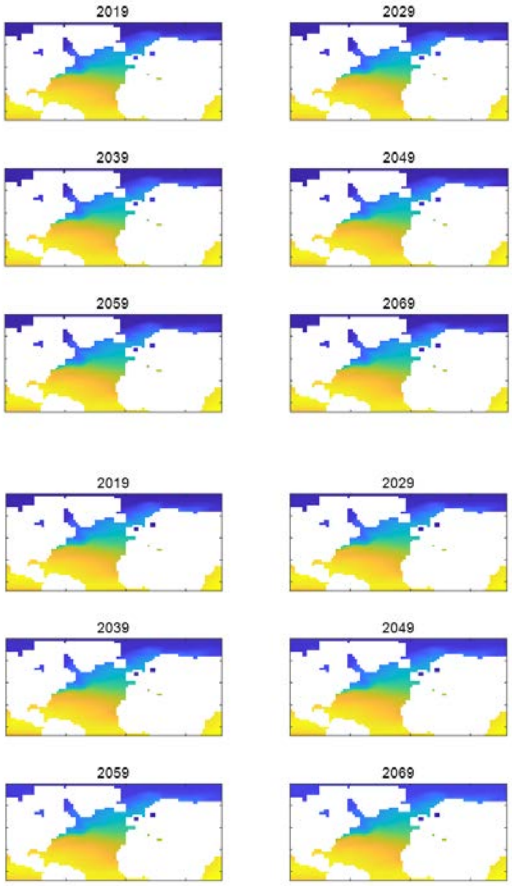


Figure 7 Water temperature distribution in February and August.

We can see a clear trend of rising temperatures in the seas around Scotland. The average annual temperature has risen from 14℃ today to 17℃ in 50 years, a rise of around 3℃.

3.3 Prediction

3.3.1 Prediction of fish distribution in waters off Scotland

Due to the fish is more[7], thus, we just show Scottish sea fish distribution respectively of years of 2019, 2029, 2039, 2049, 2059, 2069 in February and August.

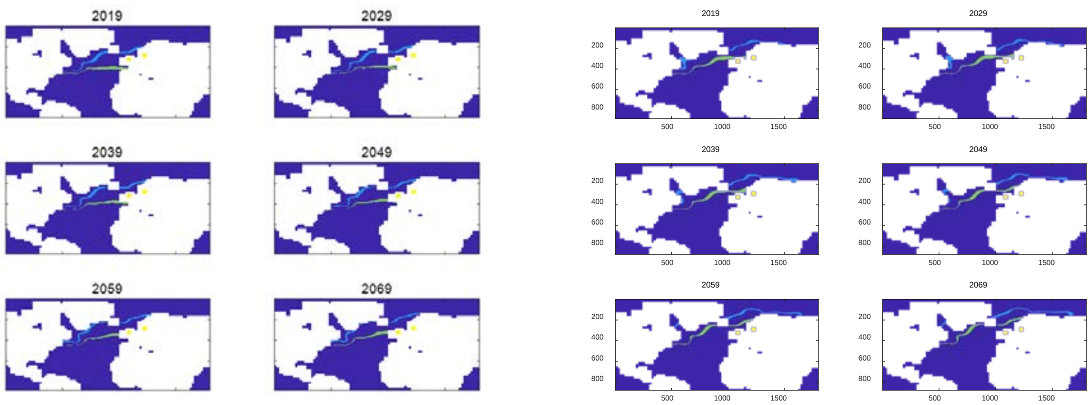


Figure 8 Fish Distribution Map in February and August.

It can be seen that mackerel is still more likely to be around Scottish waters in 50 years' time, while herring is more likely to be around Greenland in 50 years' time.

3.3.2 Prediction of fishing conditions

We divided the shoal into three types according to the living habits of herring and mackerel.

Table 4 Levels of Environmental Tolerance

Environmental tolerance level	Level.1	Level.2	Level.3
Mackerel	$12\sim13^{\circ}C$	$10\sim14.5^{\circ}C$	$4.5\sim16.5^{\circ}C$
Herring	$9\sim11^{\circ}C$	$6\sim13^{\circ}C$	$1\sim18^{\circ}C$

We have drawn the distribution of mackerel and herring under three environmental tolerance level and the fishing ranges of the small Scottish fishing companies' offshore trawlers. Since there are many pictures of specific fish distribution and fishing range, we only show pictures of specific moments.

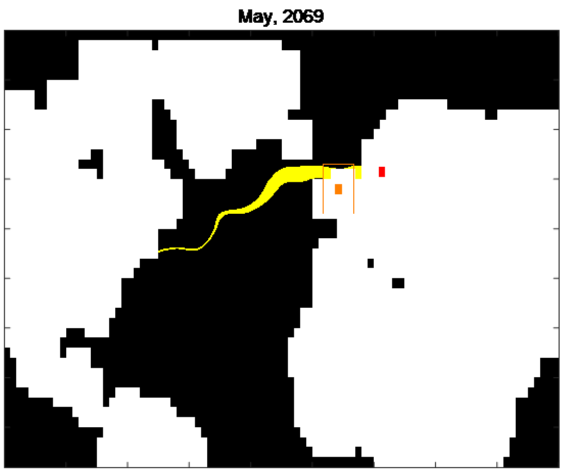


Figure9 Under Severe Conditions

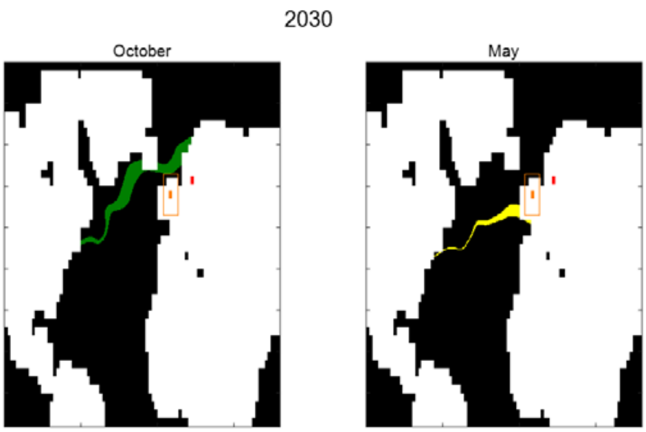


Figure10 Under Severe Conditions

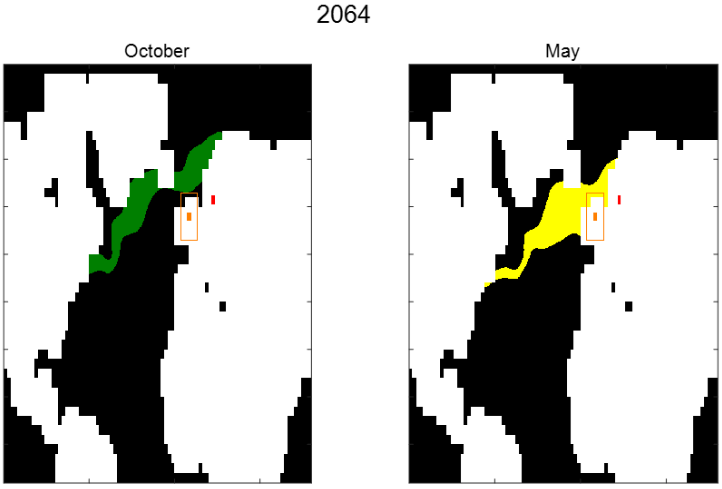


Figure11 Under Moderate Conditions

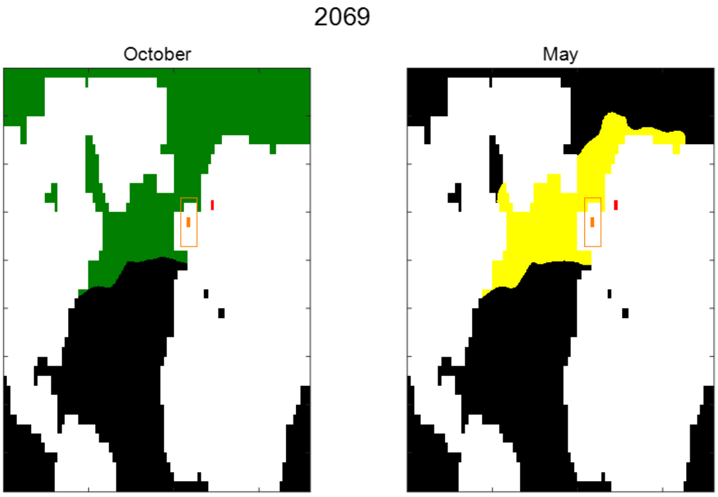


Figure12 In a Wide Range of Conditions

Even under the most severe conditions, mackerel can still be caught after 50 years. For herring, under the most severe conditions, there would be no herring around Scotland after 2030, while it would not be completely fished until 2064.

4. Extending of The Model & Sensitivity Analysis

The comparison formula for sensitivity is shown below.

$$\Delta Q = \frac{F_1 - F_0}{F_0} = \frac{\sum^{\Omega}\left[H_1(\varphi,\theta,R) - H_0(\varphi,\theta,R)\right]}{\frac{\sum^{\Omega} H_0(\varphi,\theta,R)}{n}} = \frac{\sum_{\varphi=-180^\circ}^{180^\circ}\sum_{\theta=-90^\circ}^{90^\circ}\left[H_1(\varphi,\theta,R) - H_0(\varphi,\theta,R)\right]}{\frac{\sum_{\varphi=-180^\circ}^{180^\circ}\sum_{\theta=-90^\circ}^{90^\circ}\left[H_0(\varphi,\theta,R)\right]}{n}} \tag{20}$$

Where F_1 is the size of the data after the change.

In the end, we get the final data changes for the three situations.

Table 5 Sensitivity Shift Rate Table (%)

Year	2019	2029	2039	2049	2059	2069
Time defect	-1.4007	-3.5112	-6.7057	-10.8677	-15.7106	-20.8427
Location defect	-6.6432	-8.4076	-11.2183	-14.9843	-19.4378	-24.1979
Data floating	47.0794	45.5056	43.7993	42.0162	40.2054	38.4081

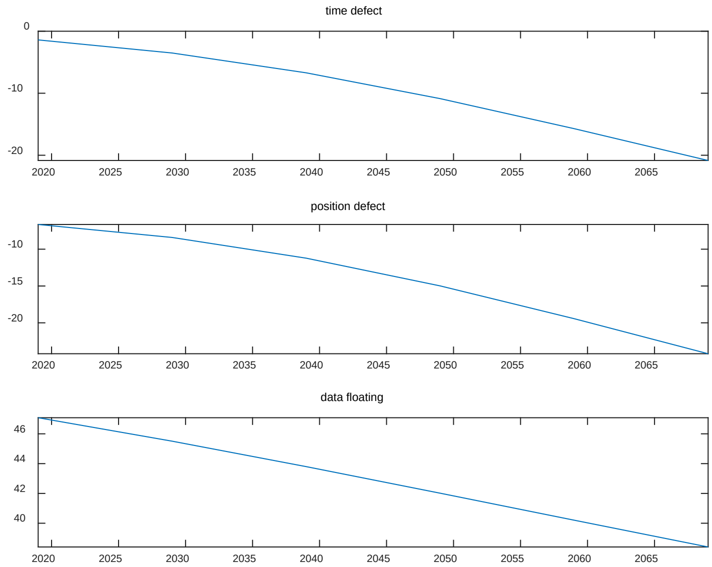


Figure 11 Cheap Rate Image of Each Three Case

From the results that in the case of time defect, the model deviation is the least. While, in the case of wrong data, the deviation of the model is the largest. As the forecast time increases, the deviation rate will increase.

5. Conclusion

Global warming will affect all kinds of organisms, among which the habitat and migratory range of fish will change in the future seriously affecting the business of fishermen. The trend of SST and the living habits of shoals can reasonably predict the location of shoals in the future. In this way, fishermen can be helped to make a reasonable response in time.

We recommend that small fishing companies in Scotland move some or all of their assets from the current ports in Scotland to the Norwegian coast. Because in the next 50 years, a lot of herring will move to Norwegian coast. Companies could lease large vessels around 2030 and buy large vessels in 2064. In good conditions, the original boats can still be used to ensure normal fishing. As for 2064, even under normal conditions, herring will leave Scottish waters. We recommend that small fishing companies in Scotland move some of their assets to Norway as early as possible to form multinational companies. This is less risky than moving assets after the transition.

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