Mathematical model-based study of Scottish herring and mackerel migration

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Abstract. The global sea temperature continues to rise and reaches a new high in 2019. This phenomenon will force the migration of Scottish herring and mackerel to higher latitudes and severely inhibit the development of small-scale Scottish fishing companies. This paper establishes a grey prediction model, a regression analysis prediction model and a fuzzy comprehensive evaluation model to explore the migration locations of herring and mackerel in the next 50 years, and to formulate appropriate business strategies for small-scale Scottish fishing companies. The model results show that in the next 50 years, herring and mackerel will migrate to Greenland and Norwegian waters, and will migrate out of the fishing range of small fishing companies from 2046 to 2053. Therefore, reducing labour costs is the most appropriate business strategy.

1. Introduction
The latest research published in Advances in Atmospheric Sciences shows that the global upper 2000-meter sea temperature in 2019 was 0.075 degrees Celsius higher than the average state from 1981 to 2010, the highest value in the history of modern ocean temperature observation records. During 1987-2019, the average ocean temperature rise rate was 450% of that during the period 1955-1986, and the increase in ocean temperature showed an accelerated trend [1]. Generally speaking, the suitable water temperature for herring and mackerel is 32~62.6°F, and the optimum sea temperature is 42.8°F. Herring and mackerel usually live at an altitude of about 80 meters, with similar habits and migration routes. Therefore, this article believes that herring and mackerel belong to the same species during the migration process.

2. Distribution projections for herring and mackerel

2.1. Experimental temperature data collection

2.1.1. Changes in experimental data. The original data of The Hadley Centre at the met office is an information grid of the world ocean [2]. Since this article only studies the sea temperature of the North Sea, the Norwegian Sea, and the Greenland Sea, it is necessary to segment the global raw data. This article cuts the ocean data according to the latitude and longitude of the three sea areas.
2.1.2. Regional mergers. The basic factors such as sea temperature and sea quality in the same sea area are the same. Therefore, sub-areas other than land must be combined. The principle of merging is to subtract the data of two adjacent columns, and the data image after the subtraction appears as a straight line to merge the regions. According to the difference result and the principle of merging, all sub-modules are finally merged into 6 areas.

Based on the average value of the temperature data at the center of each module, this paper predicts the future sea temperature of the Norwegian Sea, the Greenland Sea and the North Sea, as shown in Fig. 4.

2.2. Establishment of the grey prediction model

\[ Z^{(i)}(k) = 0.5 X^{(i)}(k) + 0.5 X^{(i)}(k-1), k = 2, \ldots, n. \]  

(1)
So \( Z(l) = (Z^{(1)}(2), \ldots, Z^{(1)}(n)) \).  

Then the grey differential equation model of GM (1; 1) is defined as:

\[ d(k) + aZ^{(1)}(k) = b, \]

\[ X^{(0)}(k) + aZ^{(1)}(k) = b. \]

Note: \( X^{(0)}(k) \) - the grey coefficient; \( Z^{(1)}(k) \) - the albino background value; \( a \) - development coefficient; \( b \) - the grey action.

By considering temperature changes, geographical factors and population factors, changing the development coefficient and whitening background value in the problem to estimate the parameter vector, substituting \( k = 2, \ldots, n \), get:

\[
\begin{align*}
X^{(0)}(2) + aZ^{(1)}(2) &= b \\
X^{(0)}(3) + aZ^{(1)}(3) &= b \\
& \vdots \\
X^{(0)}(n) + aZ^{(1)}(n) &= b
\end{align*}
\]

\[ Y = (x^{(0)}(2), x^{(0)}(n))^T, \quad u = (a, b)^T, \quad B = \begin{pmatrix} -Z^{(1)}(2) & 1 \\ \vdots & \vdots \\ -Z^{(1)}(n) & 1 \end{pmatrix} \]

Note: \( Y \) - the data variable; \( B \) - the data matrix; \( u \) - the parameter vector.

Then the matrix equation can represent the \( GM(1;1) \) model: \( Y = Bu \)

Calculations using the least-squares method: \( \hat{u} = (\hat{a}, \hat{b})^T = (B^T B)^{-1} B^T Y \).

Getting the predicted value:

\[ x^{(1)}(k+1) = (x^{(0)}(1) - \frac{\hat{b}}{a}) e^{-ak} + \frac{b}{a}, k = 1, 2, \ldots, n - 1. \]

\[ x^{(0)}(k + 1) = x^{(1)}(k + 1) - x^{(1)}(k), k = 1, 2, \ldots , n - 1. \]

This paper predicts the distribution of two fish schools based on the \( GM(1;1) \) model. Finally, the distribution positions of two schools of herring and mackerel are predicted as shown in Fig.5.

Fig 5. Distribution forecast of mackerel and herring.

2.3. Analysis of model results

According to the results of this study, in the next 50 years, the increase in sea temperature in the North Sea will force herring and mackerel to migrate to Norway and Greenland.
3. Forecast of the future fishing situation of Scottish small-scale fishing companies

According to the research results of this article, the increase in sea temperature can cause the migration of mackerel and herring to the waters of Norway and Greenland. Affected by temperature, herring and mackerel will move out of the fishing range of small-scale Scottish fisheries companies. It will have a direct impact on the amount of fish caught by fishing companies, and seriously inhibit the development of small-scale Scottish fisheries companies.

This article uses sea temperature and the location of Scottish herring and mackerel as variables to establish a regression analysis and prediction model to predict the best, worst and most likely fishing conditions faced by small-scale Scottish fishing companies. The best case refers to the longest time from now until the small fishery company cannot catch herring and mackerel, and the worst case refers to the shortest time from now until the small fishery company cannot catch. The most likely scenario is the time when Scottish herring and mackerel completely swim to a more suitable habitat, that is, the most likely time when small fishing companies cannot catch herring and mackerel.

According to relevant data [3], the following relationship exists between the location, time and temperature of Scottish herring and mackerel, as shown in Fig.6.

![Fig 6. Herring and mackerel relationship between location, time and temperature.](image)

### 3.1. Determines how closely the variables are related

It measures the closeness between variables by calculating correlation coefficients. The calculation is as follows.

\[
 pavedtext: r = \frac{\sum((X - \bar{X})(Y - \bar{Y}))}{n \delta_x \delta_y}, \\
 \delta_x = \sqrt{\frac{\sum(X - \bar{X})^2}{n}}, \delta_y = \sqrt{\frac{\sum(Y - \bar{Y})^2}{n}}.
\]

Note: \( r \) -correlation coefficient; \( X \)-time; \( \bar{X} \)-The average time; \( Y \)-Scottish herring and mackerel location; \( \bar{Y} \)-Average of scotch herring and mackerel positions; \( \delta_x \)-The standard deviation of the time series; \( \delta_y \)-The standard deviation of scotch herring and mackerel position series.

Correlation is divided into four levels: \(| r | < 0.3\) is irrelevant, when \(0.3 < | r | < 0.5\), it is low-level correlation; when \(0.5 < | r | < 0.8\), it is significant correlation; when \(| r | > 0.8\), it is highly relevant. By calculation, \(| r | = 0.979\), the fish school position is positively correlated with time.

### 3.2. Establishing a regression prediction model
By calculating that \( a = -113.37 \), \( b = 0.054 \). The regression prediction model is:

\[
Y = 0.054X - 113.37. \tag{14}
\]

Based on relevant literature, the fishing range of small fishing boats usually does not exceed 12 nautical miles. Converted to 0.2 latitude by the unit of measurement. Substituting \( Y = 0.2 \) into the prediction model, \( X = 2050.34 \).

3.3. Regression standard deviation test

The regression standard deviation can provide a test of the accuracy of the regression prediction model. Its calculation formula is:

\[
S = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n - k}} \tag{15}
\]

Note: \( S \) -Regression standard deviation; \( \hat{Y}_i \) -The predicted value of the Scotch herring and mackerel position in the \( t \) period; \( Y_i \) -The \( t \)-the value of Scottish herring and mackerel; \( n \) -the number of observation periods; \( K \) -Number of parameters in the regression equation.

As shown in the above formula, the smaller the value, the smaller the average error between the actual value (current observation value) and the predicted value. The prediction accuracy will be higher. Simultaneously, to compare the accuracy of different models, it is often necessary to calculate the coefficient of dispersion or standard deviation: \( V = S / Y \times 100\% \), and generally hope that \( V \) does not exceed 15%. The standard deviation is estimated that \( V = 9.67\% < 15\% \).

According to the normal distribution theory, if the confidence level is 95%, then \( t = 2 \) (after querying, the true value of \( t \) is 1.96). In the actual forecast, for the convenience of calculation, suppose the value of \( t \) is 2. The upper limit of the interval is 2053, and the lower limit is 2046. That is to say, the upper and lower confidence intervals for the migration of herring and mackerel out of the fishing range of small fishery companies are \([2046, 2053]\). 

3.4. Analysis of model results

The worst case faced by small Scottish fisheries companies is the migration of herring and mackerel out of their catch in 2053. The best scenario is to move out of its fishing range in 2046, and the most likely scenario is to move out of its fishing range in 2050.

4. Evaluation of the management strategy of the small-scale fishing company in Scotland

As the sea temperature rises in the next 50 years, herring and mackerel will migrate to Greenland and Norwegian waters, which will seriously inhibit the development of small Scottish fishing companies. In order to ensure that small fishery companies continue to operate while reducing economic losses, fishery companies need to adjust their business strategies. The article establishes a fuzzy comprehensive evaluation model to develop the best management strategy for small fishery companies.

4.1. Evaluation process

After determining the affiliation of the evaluation factors, the expert questionnaire method was used to score and evaluate 10 groups. Select the most representative group to evaluate the business strategy of the small fishing company to determine the best business strategy.

First, determine the affiliation of each evaluation factor. Secondly, the fuzzy decision theory is used to sort the indexes of each evaluation factor. Finally, the fishery management strategy is divided
into five levels. Let the comment set = \{Very critical, a little critical, quite satisfactory, a little indifferent, it doesn’t matter at all\}. Set the level vector \( C = (5,4,3,2,1) \) in the comment set. This process is to evaluate whether small-scale fishing companies need to change their business strategies. In addition, it needs to be evaluated again to get a suitable business strategy. Calculate the membership degree vector of each evaluated item level. Combine the vector with the weight and perform normalization processing to obtain the membership degree matrix of the comprehensive evaluation layer, and so on, to obtain the complete evaluation result.

Factor set: \( U_i = \{\text{decreasing fishery resources, decreasing range of fishable waters, increasing labor costs, decreasing fish production, increasing policy efforts}\} \).

Commentary Episode: \( V_i = \{\text{very critical, somewhat critical, moderate, somewhat indifferent, totally okay}\} \).

Weights: \( W = \{0.26, 0.20, 0.23, 0.20, 0.11\} \) \( \quad \) (16)

\[
B = \begin{bmatrix}
3 & 1 & 0 & 0 & 0 \\
2 & 2 & 0 & 0 & 0 \\
1 & 2 & 0 & 1 & 0 \\
0 & 1 & 3 & 0 & 0 \\
0 & 0 & 2 & 1 & 1
\end{bmatrix}
\] \( \quad \) (17)

\[
R = \begin{bmatrix}
0.7500 & 0.2500 & 0 & 0 & 0 \\
0.5000 & 0.5000 & 0 & 0 & 0 \\
0.2500 & 0.5000 & 0 & 0.2500 & 0 \\
0 & 0.2500 & 0.7500 & 0 & 0 \\
0 & 0 & 0.5000 & 0.2500 & 0.2500
\end{bmatrix}
\] \( \quad \) (18)

\[
B = A \times R = \left[ \begin{array}{c}
0.3525 \\
0.3300 \\
0.2050 \\
0.0850 \\
0.0275
\end{array} \right]
\] \( \quad \) (19)

Taking the comment with the largest value as the comprehensive evaluation result, it can be seen that its business mode must be changed. \( U_i = \{\text{Reduced fishery resources, reduced catchable area, higher labour costs, reduced fish production, more robust policies}\} \).

Measure Set: \( V_2 = \{\text{Partial transfer of fishing company assets to mobile areas of two fish stocks; transfer of all fishing company assets to migratory locations of two fish stocks; use of small fishing vessels in pursuit; changes in catching species; reduction in workforce}\} \). The strategy with the largest value is taken as the comprehensive evaluation result, and the fifth option is selected.

4.2. Analysis of model results
According to the fuzzy comprehensive evaluation model, small-scale fishing companies must change their existing operating methods. Secondly, taking the business strategy with the largest value as the comprehensive evaluation result shows that choosing to reduce the labour force is the most appropriate business strategy.

5. Summary and recommendations
5.1. Summary
As the metabolism speeds up, the fish's demand for oxygen increases and the sea temperature rises. This phenomenon has caused global fish populations to migrate north to find more suitable habitats [4]. The model prediction results show that as the temperature rises, herring and mackerel will swim into the Greenland Sea and the Norwegian Sea in the next 50 years. The migration of herring and mackerel will seriously inhibit the development of small Scottish fishing companies. According to the regression analysis and forecasting model, the worst situation faced by small-scale Scottish fishing
companies in the future is that herring and mackerel will move out of the fishing range of the fishing company in 2046, and the best case is to move out of the fishing company’s fishing range in 2053. The most likely scenario is to move out of the fishing range of the fishing company in 2050.

The migration of Scottish mackerel and herring will have a direct impact on Scotland’s fisheries resources and labour costs. Residents who rely on fishing for their livelihoods will lose their source of income and severely inhibit the development of small-scale fishing companies in Scotland. At the same time, according to the data collected in this article, the co-fishing zone will have a serious impact on fishermen and fishery companies. This negative impact will mainly be reflected in the increase in the number of fishing, the decrease in the number of fishing boats and the restriction of fishing output. In addition, due to differences in the language and culture of the residents of the common fishing area, it will also cause problems such as increased fishing costs.

5.2. Some recommendations
Based on these issues, this article comprehensively considers multiple factors to establish a fuzzy comprehensive evaluation model. Through model analysis, some optimization schemes are obtained to improve the future business prospects of fishery companies.

(1) Change business methods. Through the establishment of a fuzzy comprehensive evaluation model, this paper concludes: small fishery enterprises need to change their management methods, reduce manual fishing, and increase advanced equipment.

(2) The government must increase law enforcement. The Scottish government should strengthen the Scottish fisheries legislation to make it easier or faster for managers to respond to challenges. Scotland’s existing management system and permit arrangements are operationally obsolete. For example, fishing gear conflict/damage and unlicensed fishing. Improving the fishing conditions in Scotland requires new legislation to strengthen the management of Scottish coastal waters. It can not only promote better fishing activities, but also maximize the benefits.

6. Conclusion
In the next 50 years, due to the increase in sea temperature, herring and mackerel will migrate to Norway and Greenland. In addition, herring and mackerel will migrate out of the fishing range of the Scottish Small Fisheries Company between 2046 and 2053. If a fishing company wants to reduce losses, it should change its business strategy and reduce its labor force.

References
[1] Jansen T, Campbell A, Kelly C, Hatijn H, Payne MR. (2012) Migration and Fisheries of North East Atlantic Mackerel (Scomber scombrus) in Autumn and Winter. J. Sci. PLoS ONE, 12: 51-57.
[2] Trenkel VM, Huse G, MacKenzie B, Alvarez P, Arizzabalaga H, et al. (2012) Comparative ecology of widely-distributed pelagic fish species in the North Atlantic: implications for modelling climate and fisheries impacts. J. Sci. Prog Oceanogr, 66: 911-945.
[3] Graham CT, Harrod C. (2009) Implications of climate change for the fishes of the British Isles. J. Sci. Fish Biol, 74: 1143-1205.
[4] Reid DG, Walsh M, Turrel WR. (2001) Hydrography and mackerel distribution on the shelf edge west of the Norwegian deeps. J. Sci. Fish Res, 50: 141-150.