Application Research of Data Analysis and Mathematical Model Prediction in Marine Fishery

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Abstract. Fishery resources are the biological resources which are constantly updated and changed, Global ocean temperature affects the habitat quality of some marine organisms. When the temperature changes too much to continue to live, these organisms begin to migrate to more suitable places. If fishery companies can understand the migration regular of fish when the ocean temperature changes in advance, it will improve the efficiency of fishing. On the basis of previous project research, this paper studies the influence of sea water temperature change on the migration of herring and mackerel in the North Atlantic of Scotland, and establishes a prediction model of sea temperature. The model predicts the temperature of the Western Ocean in different latitudes near Scotland in the next 50 years, so as to predict the migration direction and migration frequency of the two kinds of fish. Through time series regression analysis, the shortest, longest and average time for the two kinds of fish to leave Scotland were analyzed and the migration direction and frequency of these two species were predicted, which can provide a reference for small-scale fishery companies in the coastal area of Scotland to solve the problem of declining fishing rate due to migration of herring and Mackerel. The conclusion and method of this study can also provide reference for other similar cases.

Keywords. Ocean warming; migration regular; prediction models; fishery.

1. Introduction
Global sea surface temperatures are rising at a rate of 0.03°C/yr [1] since satellites have been able to observe temperature changes. Changes in global ocean temperatures affect the living of Marine organisms to varying degrees, and when the temperature changes are too great for certain populations to thrive, they begin to migrate to other habitats.

Since the Ocean Heat Wave in the Northwest Atlantic in 2012, there have been a series of changes in the distribution of species in the Atlantic. The change of population distribution of Marine organisms not only has an impact on the ecological balance of the ocean itself, but also has a significant impact on the life of human beings, especially fishermen. For example, lobster-fishing in Maine earns about hundreds of millions of dollars a year before, but because of changes in ocean temperatures, lobsters have to migrate to colder Canadian waters, and lobster-fishing communities in coastal Maine have been severely affected [2, 3], the vast majority (about 84 percent) of U.S. fishermen are aware of the threat posed by warming waters [4].

Existing research [5] shows herring is one of the fish most affected by ocean warming, while herring is the important economic source of Scotland on the Atlantic fisheries. In addition, mackerel also makes an important contribution to it. Lessons from the Maine lobsters, it is not hard to see how...
studying future ocean temperature changes and predicting trends in Scottish herring and mackerel migration are crucial to the survival of fishing companies in Scotland, especially small ones.

We built a mathematical model to predict the most likely locations for herring and mackerel in the Atlantic in the next 50 years.

In addition, we need to analyze the changing temperature of the seawater to predict the best case, worst case, and most likely time when these fish will migrate too far for Scottish fishermen to harvest. We also need to judge whether it is essential to change the current operation mode of the Scottish fisheries based on the results of the forecast and analysis.

In this paper, we have done the following to try to protect the steady development of Scotland's fisheries.

• Select two species of fish, herring and mackerel, which have important economic contributions to Scottish fisheries, for the study and analysis of their living habits.
  • Consider both the Scottish fishing area and mackerel and herring migration distance at the same time, and then determine the scope of observation and analysis. Design a temperature prediction model based on the Atlantic, and select Scotland nearest fishing waters to model. And also respectively predict the temperatures of mackerel and herring activity areas in the next 50 years (2020-2070).
  • Analyze the effect factors of seasons and latitudes, calculate the change rate of sea water temperature, predict the best case and the worst case, and give the most likely elapsed time when Scotland small fishing companies will no longer be able to catch the two kinds of fish. We analyze the influence of time change and space change on seawater temperature.

2. Data Analysis and Mathematical Model Design

2.1. General Assumptions
In order to establish the mathematical model scientifically, the following assumptions and conventions are proposed based on the actual situation:

• There are many types of herring and mackerel, and the herring and mackerel that appear in this paper refer to the mackerel and herring living in Atlantic.
• Herring lives 10 meters below water, and its suitable temperature is $10^0\text{C} \text{ to } 12^0\text{C}$. Mackerel lives 90 meters below the water, and its suitable temperature is $8^0\text{C} \text{ to } 10^0\text{C}$.
• Scotland's current main fishing area is around latitude $56^\circ \text{ N}$ and longitude $10^\circ \text{ W}$.
• The fishing company used in the research is located at latitude $57^\circ \text{ N}$ and $7^\circ \text{ W}$. It only has ordinary fishing boats, and the range of boats activity is within latitude $56^\circ \text{ N}$ to $58^\circ \text{ N}$, and longitude $11^\circ \text{ W}$ to $13^\circ \text{ W}$. British fishing areas are $50^\circ \text{ N}$ to $60^\circ \text{ N}$, and longitude $12^\circ \text{ W}$ to $3^\circ \text{ E}$.
• The number of fish caught is positively propositional to the number of fish living in an area.
• Under the influence of all external factors, the number of fish follows logistic model change.
• The temperature is directly proportional to both the growth rate of fish $r$ and maximum capacity of population before it hits the optimal temperature, and inversely proportional after.

2.2. Ocean Temperature Model
We explore the time series distribution of the Atlantic plate in the ocean observations from 2000 to 2009 of Argo2020. At the same time, considering that the geographical position of the UK is about latitude $52^\circ \text{ N}$ to $58^\circ \text{ N}$, and longitude $7^\circ \text{ W}$ to $2^\circ \text{ E}$, and the need to reserve space for fish migration, we choose to explore the ocean plate from latitude $50^\circ \text{ N}$ to $70^\circ \text{ N}$, and longitude $20^\circ \text{ W}$ to $5^\circ \text{ E}$. According to the longitude and latitude division, we use Kmeans [6] (Set the parameter to 5) to divide the selected region in the western hemisphere into five parts. As shown in figure 1.

According to the classification principle, all these five divisions need to be modeled for observation. However, in order to simplify the model and minimize extra costs, we choose the fishing area closest to Scotland (i.e., the area in blue, and approximately located at latitude $63^\circ \text{ N}$ to $70^\circ \text{ N}$ and longitude $10^\circ \text{ W}$ to $20^\circ \text{ W}$) for modeling. Call the blue part area 1.
For the part of the ocean in the eastern hemisphere, we set up two observation points in the same way as shown in figure 2, and still choose the fishing area closest to Scotland to set up the observation model (i.e., the red area in the figure below, roughly located at latitude 60° N to 70° N and 1° E to 5° E). Call the red part area 2.

Since herring lives 10 meters underwater and mackerel lives 90 meters underwater, we analyze them separately. We take the area 10 meters underwater as an example to establish the temporal and spatial distribution model of ocean temperature. The rest of the places can be modeled in the same way.

2.3. The Temporal Distribution of Seawater Temperature
We collected sea temperature data at different depths in these two areas from 2010 to 2019 [7, 8] and analyzed seasonal changes in temperature of where mackerel and herring live in area 1 and area 2.

It can be seen from figure 3 that the seawater temperature exhibits a clear cyclical change over time, so we use Addition model what plus the influence of the seasons on the data to perform seasonal analysis on it, the seasonal factor is shown in table 1.

Table 1. Seasonal factor (10 meters underwater).

| Season | Seasonal factor |
|--------|----------------|
| Spring | -1.4540705     |
| Summer | -1.5575872     |
| Fall   | 2.0313670      |
| Winter | 0.9802906      |
In addition, in order to more clearly reflect the effect of seasonal factors on sea temperature, we have also made images after removing seasonal factors, and found that it has a roughly linear increase, as shown in figure 4.

Using linear regression analysis, we get the equation of water temperature change over time at 10 meters as in equation (1).

\[ y = 22.818 + 0.012x \]  

where \( y \) is temperature and \( x \) is several quarters since the first quarter of 2010.

Use the calculation result of this function and add the seasonal factor \( q \) to get the final forecast result \( y_p \) as in equation (2).

\[ y_p = 22.818 + 0.012x + q \]  

We use this function to test the sea temperature from 2010 to 2019. As can be seen from figure 5, the prediction function fits the actual value well.

We use this model to predict the temperature of the water area 10m depth in the next 50 years (2020-2070), and get the results as shown in figure 6.

2.4. The Spatial Distribution Model

We collect temperature data for this marine area from 2005 to 2012 from the National Oceanic and Atmospheric Administration [9, 10] and explore the change of sea temperature with latitude, as shown in figures 7 and 8.

Taking area 1 as an example, we explore the sea water temperature with variation of latitudes at depth of 90 meters and 10 meters.

It can be seen that water temperature is related to latitude and depth. The higher the latitude, the deeper the depth, and the lower the water temperature as shown in figure 9.

After considering the influence factors of time and space, we performed regression analysis and finally obtained the equation for predicting seawater temperature as shown in table 2, where \( y_a \) is the actual temperature, \( y_p \) is the predicted temperature and \( x \) is the latitude.

We take five years as a phase and divide the next 50 years into 10 phases. Based on the suitable temperature for herring is 100°C to 120°C, the suitable temperature for mackerel is 80°C to 100°C, we make the following predictions for the herring quantity in fishing areas (latitude 56° N) as shown in figure 10.

And the predictions for herring migration over the next 50 years, based on the ocean temperature models, are as follows (figures 11 and 12). Here only the distribution of herring populations in the first and tenth phases is given, see the Appendix for the remaining phases.
Figure 6. Temperature changes over the next 50 years (2020-2070).

Figure 7. Average temperature in different seasons at 10m depth.

Figure 8. Average temperature in different seasons at 90m depth.

Figure 9. Temperature variations at different latitudes of 10 meters and 90 meters.

Table 2. Prediction equation.

| Season | Water depth (m) | Prediction equation \( y_a = y_p - (a + bx) \) |
|--------|----------------|-----------------------------------------------|
| Spring | 10             | \( a = -0.5371 \) \( b = 30.4870 \)           |
|        | 90             | \( a = -0.5371 \) \( b = 30.4870 \)           |
| Summer | 10             | \( a = -0.5611 \) \( b = 32.0399 \)           |
|        | 90             | \( a = -0.5588 \) \( b = 31.5895 \)           |
| Fall   | 10             | \( a = -0.5424 \) \( b = 30.5872 \)           |
|        | 90             | \( a = -0.5158 \) \( b = 29.6651 \)           |
| Winter | 10             | \( a = -0.5850 \) \( b = 33.0482 \)           |
|        | 90             | \( a = -0.5076 \) \( b = 29.1908 \)           |

Similarly, we show the change of mackerel population in the fishing area of Scotland and the migration over the next 50 years as shown in figures 13-15.

From the above analysis, we can see that herring and mackerel will migrate north over the next 50 years, and the number of both caught in the fishing areas of Scotland are decreasing year by year.

At the same time, we analyzed the change of the total amount of the two kinds of fish with time in three different situations, as shown in figures 16-18. The three situations are: the best situation that is human beings take protective measures and delay global warming; the general situation that is natural development; the worst situation that is environmental pollution and global warming.
Figure 10. Variation of herring quantity at 56 ° N.

Figure 11. The first phase (10m).

Figure 12. The tenth phase (10m).

Figure 13. Variation of mackerel quantity at 56 ° N.

Figure 14. The first phase (90m).

Figure 15. The tenth phase (90m).

Figure 16. Best case.

Figure 17. Worst case.
3. Conclusion

We analyzed and predicted the migration direction and frequency of herring and mackerel in the waters of the North Atlantic near Scotland. With the increase of global ocean temperature and the migration of fish, the fishery economy of Scotland's coastal areas is under serious threat. A model is established to predict the temperature change of the North Atlantic Ocean. The conclusion was as follows:

- The water temperature is related to latitude and depth. The higher the latitude, the deeper the water depth and the lower the water temperature.
- In the next 50 years, herring and mackerel will move north, and the number of these two kinds of fish in Scottish fishing areas is decreasing year by year.
- In the next 15 years, the herring and mackerel in the study area will migrate to other waters more suitable for habitat due to the change of sea water temperature.

The research method of this paper can predict the migration direction and migration frequency of fish, it can also put forward solutions to the problems that small-scale fishery companies in coastal areas may face.

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