Problem Chosen	2020	Team Control Number
A	MCM/ICM Summary Sheet	2018561

Prediction of Fishing Position and Feasible Strategies

Summary

As the global temperature rises, the temperature of seawater also rises year by year, thus many creatures are leaving their former homes. Mackerel and herring in the North Atlantic are no exception. As the main fish species in Scottish fishery, located in the North Atlantic Fisheries, they also have to migrate to find shelter.

In order to predict the distribution of mackerel and herring near Scotland over the next 50 years, we establish a temperature-time model, we analyze the temperature of ocean observation points in the past 150 years, and regression equations to obtain the temperature changes of each point over time. The distribution of predicted sea surface temperature is obtained by smooth fitting using MATLAB software. On the basis of the above model, combining the temperature ranges suitable for the survival of two fish species, we establish a temperature-position model and use it to predict that the two species of fish are most likely to be distributed in Faroe Islands and Southwest Norway in 50 years.

Then, based on the models mentioned above, we analyze the impact of fish migration on small fishing companies. Referring to actual data, predictions are made on the time at which the company can continue to operate at its current location in different situations. Under optimistic, intermediate, and pessimistic conditions, we conclude that the company can run until year 2044 and 2029respectively.

Considering the distribution of fish schools after migration, we have separately analyzed two strategies: relocating some of the assets of the company to a location closer to the school of fish, and using a small proportion of small fishing boats with fishing vessels capable of operating without land-based support. After comprehensive calculation and analysis, we conclude that the latter strategy can effectively solve the issue. In addition, using refrigeration equipment to improve the freshness of fish can get greater benefits. We have also put forward opinions and suggestions on the potential issue of fishing vessels when entering other countries' territorial waters.

After solving the model, we conduct the sensitivity analysis. Result shows the strong robustness of our model. Variation of key parameters causes moderate changes to the computing result.

Keywords: Fitted regression; Fishing companies; Fish migration

North Atlantic Fisheries may not Exist in 30 Years

As we all know, in the past 100 years, the climate has warmed rapidly, and the temperature of seawater has risen as a result. Every day there is frustrating new evidence that climate change is adversely affecting life.

Fishermen friends, as fisheries move north continuously, looking for a temperature that is more suitable for them to survive, the North Atlantic Fisheries in Scotland, where we make money for generations may not exist due to the migration of many fisheries.

This is really a serious topic. This week, our team analyzed the trend of fish school changes over the next 50 years, and the situation is not optimistic. If nothing is done, we may all be unemployed in less than 30 years!

Since 2000, the average surface temperature of North Atlantic Fisheries has increased by nearly 1 degree Celsius, and the upward trend is becoming increasingly significant. It is worth mentioning that this sea is melting faster than almost anywhere else! Our research team are quite concerned about it.

In the future, where are the fish going and where are our livelihoods going?

Based on our big data simulation analysis and prediction, we speculated that about 25 years later, our fishermen in Scotland will no longer be able to enjoy fishing on the land belonging to our homeland and get rich income. Herring and Mackerel will go northward all the way across Shetland to Iceland, and they will even continue to reside in the northernmost Arctic Ocean, farther and farther from our Scotland.

For more than 100,000 years, the central Arctic Ocean has been completely covered by ice, so that the idea of fishing seems ridiculous. This was still the case until 20 years ago. However, because of human fossil fuel's endless emission and other effect, today, as much as 40% of the central Arctic Ocean is open water in summer. It is even possible to attract fishery ships soon, and by then, the Arctic fishing grounds may become the next North Atlantic Fisheries.

In order to cope with the possible crisis, our research team evaluated and analyzed various strategies, and among these, we have found the best feasible solution.

North Atlantic Fisheries may not Exist in 30 Years

Our Approach

First of all, we discussed the feasibility of relocation. As the school of fish moves northward, fishermen friends will need to pay more time and cost to reach the place where the school of fish gathers. Moving north to shorten the sailing distance seems to be a good choice, but it will face a certain relocation cost, when the relocation cost is higher than a limit, this strategy will not be able to obtain benefits in a short time.

Another solution is to add fresh-keeping refrigeration equipment to enable fishing vessels to better maintain the freshness of fish when sailing over long distances and it can increase the value of fish after arriving at the port. Because the freshness of fish without refrigeration treatment decreases rapidly and the cost of the equipment is more appropriate, so after deriving from our model, this is a good method to overcome the possible crisis.

Although the acceleration of global warming is something we do not want to see, it really affects the economic life of people. The northward migration of fish schools in the Scotland fisheries area caused by the rising ocean temperature is quite serious. We recommend that friends in related areas prepare for the crisis in advance. Modify your business strategy or take other measures. We have full of confidence to cope with various possible changes brought about by the environment with our joint effort.

Contents

1 Introduction

1.1 Background

Over the past 100 years, it has become an indisputable fact that the climate has warmed, and the temperature of seawater has risen. Many animals have therefore left their homes on which they depended, looking for habitats that are more suitable for their survival.

The North Sea fishing ground in Scotland, where we live, may also be left because of the migration of many fisheries, all the way north, looking for a temperature that is more suitable for them to survive.

Herring and Mackerel, as two kinds of fish that live in the North Atlantic Fisheries all year round, may have to leave their previous home. So, will many related people who make a living from fishing, especially those small fishing companies, not make money? These issues deserve our deep consideration.

Global warming is something we do not want to see, but with the development of industrial level, we have to face such problems. People from all walks of life, including fishermen in Scotland and governors of the country, need to take steps to make some changes.

1.2 Restatement of the Problem

Affected by the greenhouse effect, the global climate is warming, and the ocean temperature is also increasing. As a result, herring and mackerel have gradually left their living environment and are looking north for a more suitable habitat. This has affected many fishing-dependent companies in the North Atlantic Fisheries.

So, we will investigate sea temperature changes over the next 50 years. Taking herring and mackerel as examples, we attempt to establish models and infer their migration paths and trajectories. The model will use this to give the best, worst case, and most likely point in time when the fish will not be caught by the company. Based on the above trajectory and analysis results, we will make appropriate decisions for the company, assess whether the company should make relocations, change its operating methods and whether to take other measures to make the company more profitable.

As the school of fish moves farther away, small fishing companies need to consider the cost of staying in place or moving near the school of fish.

Besides, for the territorial sea issues that may be involved in the model, appropriate considerations should be taken to reduce the impact.

1.3 Overview of Our Work

Changes in seawater temperature have changed the environment in which fish live, and fish need to find places more suitable for their survival. In order to determine the change of the location, we established a mathematical model to explore the relationship between temperature changes and location changes.

First, in order to achieve the purpose of predicting temperature changes, based on past data, we make multiple ways to regress data optimistically and pessimistically respectively.

In order to explore the relationship between temperature and habitat, we simulated based on the basic assumptions that fish swim towards the optimal temperature, and that fish are gathered in circles.

Second, to explore how the small fishing companies in Scotland are affected by changes of the living environment of fish, we have also established a model to explore the relationship between their earnings and the above changes. It is found that in the next two or three decades, the school of fish will be far enough away from the company, and the company will no longer be able to obtain good returns.

At last, in order to help the company so that they can survive over the next 50 years, we designed and comprehensively examined the impact of various solution models on the company, and finally gave the best solution.

2 Assumptions and Notations

2.1 Assumptions

To simplify our problems, we make the following basic assumptions.

- We assume the fish is at a constant depth, regardless of the effect of the depth of the water on the temperature.
- It is assumed that fish tends to gather near their suitable temperature.
- The effects of fish food and other factors are not considered, the optimal temperature for fish aggregation in the end is only related to temperature.
- The distribution form of fish gathering during migration is a circle.
- The water temperature changes continuously in space and time scales.

2.2 Notations

Abbreviation	***Description***
O	The center point of the school of fish
r	Distance from the center of the school of fish (nautical miles)
d	Distance from shore to fishing point (nautical miles)
T	Temperature
SST	Sea surface temperature
t	Year
lon	Longitude
lat	Latitude
q	Yield of fish
v	Fish value (Euro)
w	Profit per catch (Euro)
c	Operating cost of the company (Euro)
m	Fuel money per nautical miles (Euro)
ac	Additional cost (Euro)

3 The Model

3.1 Time-Temperature Model (TT)

In this model, we predict the temperature by regression based on past temperature data and fit the data to obtain the temperature distribution in the spatial range around the Scottish fisheries within 50 years.

3.1.1 Construction and Solution

First, open the data set [1] with Panoply software. For, example, the figure below shows SST distribution worldwide in 1870.

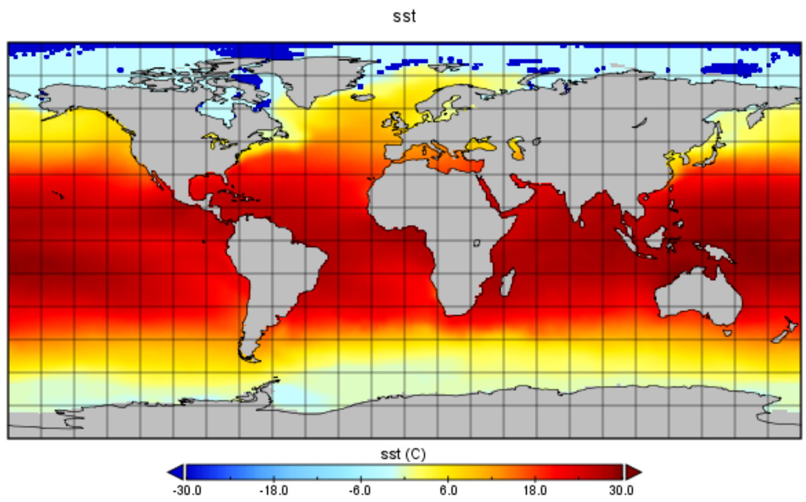

Figure 1 SST distribution in 1870

In order to simplify the model, several feature points are selected as the map below shown.

Considering the lower water temperature in the north, the stock of fish tends to migrate northward, thus more feature points are selected north of Scotland.

The coordinates of the point correspond to the actual latitude and longitude, as showed below, a minus sign in the coordinates indicates that the point is on the west side of the 0° meridian.

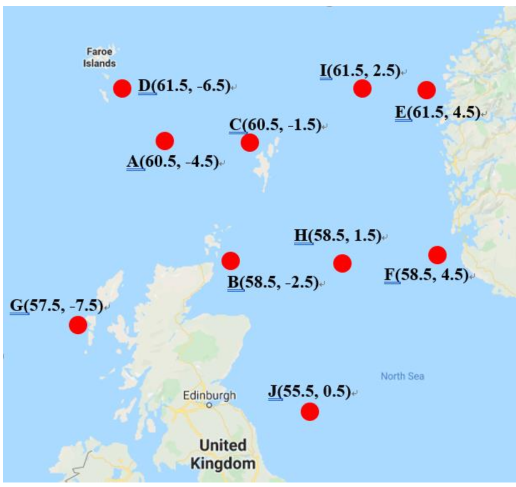

Figure 2 Positions of selected points

For the data at each point, we use MATLAB to analyze its annual average temperature change from 1870 to the present. The results are as follows:

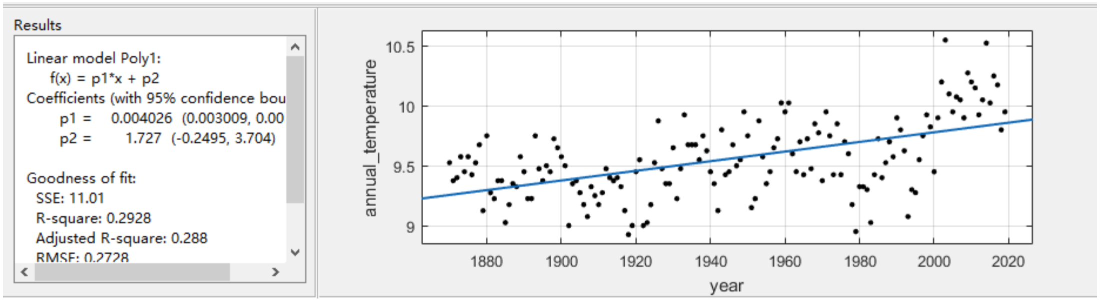

Figure 3 Normal estimation of sea surface temperature

Due to seasonal migration of fish, fish are not co-located in the same year. We look at temperature changes in the same month each year. Select January, April, July, and October as the characteristic months, and regress the temperature to analyze the temperature change from 1870 to the present, and get the temperature-longitude-latitude equation model

And predict the temperature within 50 years at each point.

Using MATLAB software, the temperature situation at each point now and 50 years later, using Thin-Plate Spline interpolation, to fit a smooth surface to estimate the temperature distribution of the entire sea area, as shown in the figure below (The temperature is deeper in the dark colors in the picture).

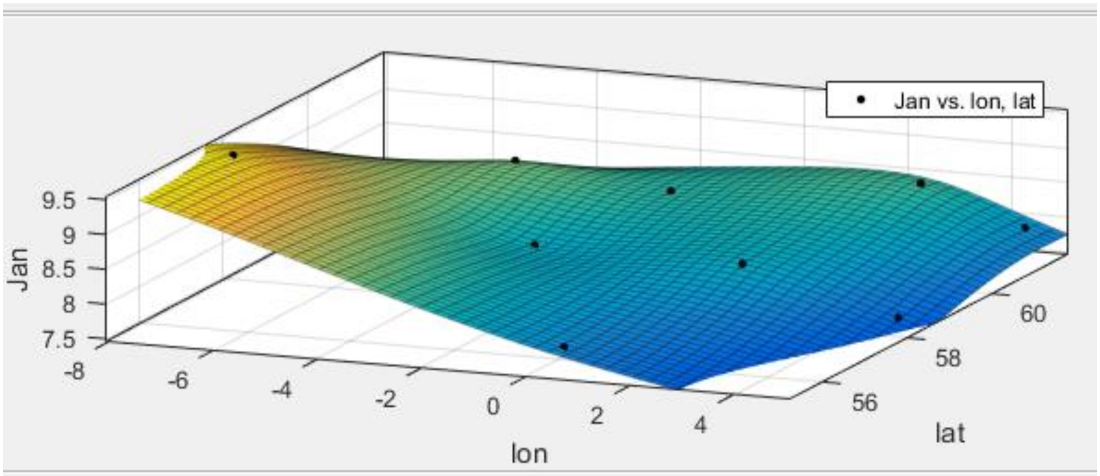

Figure 4 Temperature fitting surface

In order to establish the relationship between temperature and geographic location, an isotherm map was made and superimposed on the map to visually see the distribution of sea surface temperature in the North Atlantic Fisheries.

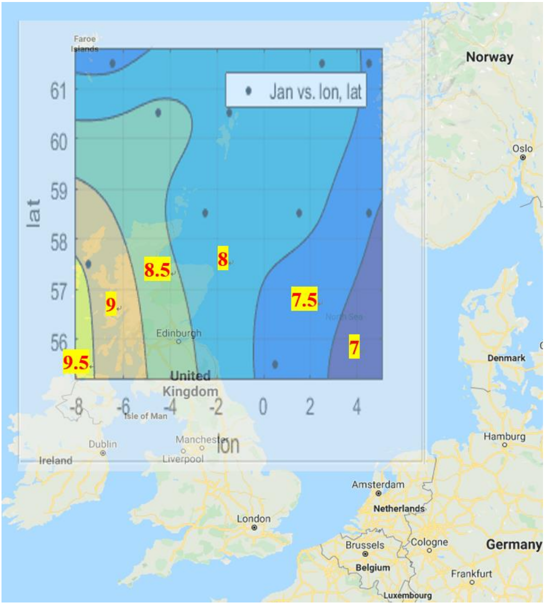

Figure 5 2070 Jan T distribution

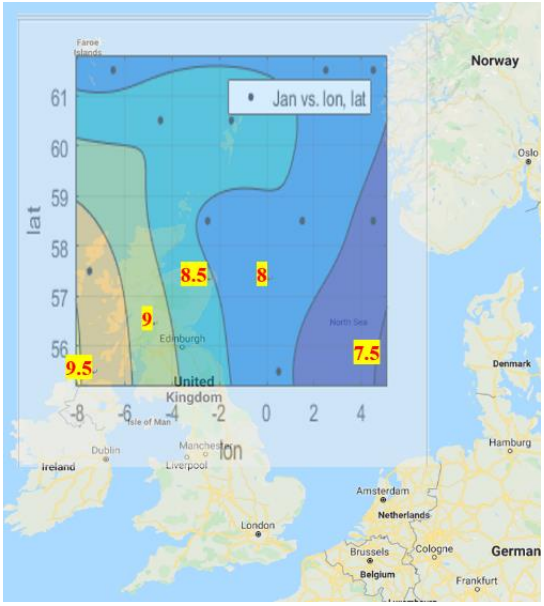

Figure 6 2020 Jan T distribution

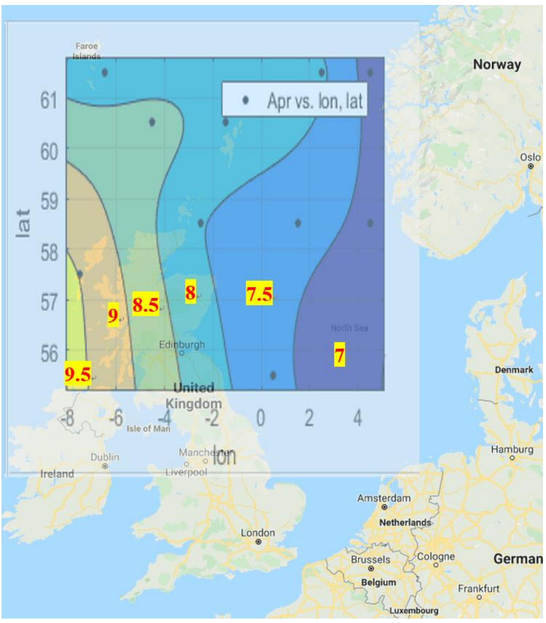

Figure 7 2070 Apr T distribution

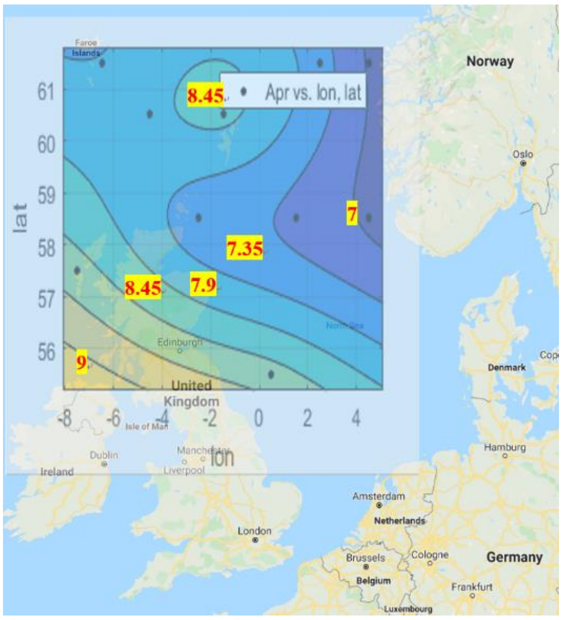

Figure 8 2020 Apr T distribution

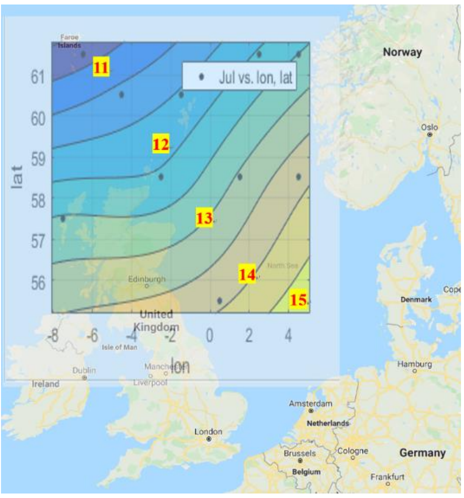

Figure 9 2070 Jul T distribution

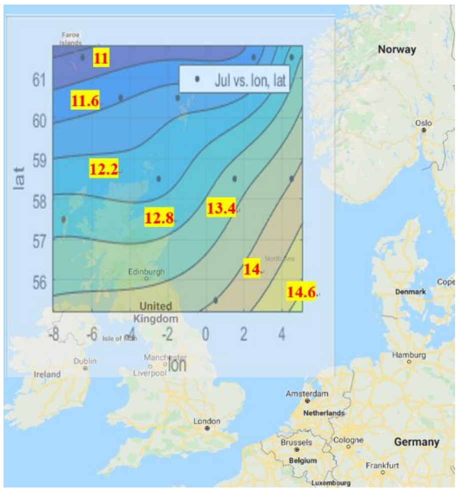

Figure 10 2020 Jul T distribution

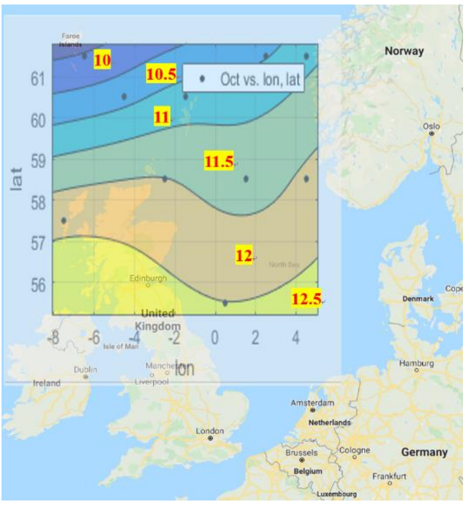

Figure 11 2070 Oct T distribution

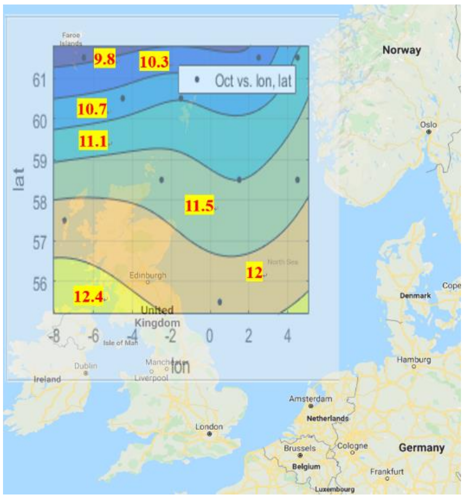

Figure 12 2020 Oct T distribution

Comparing the results between 2020 and 2070, we can get that Sea surface temperature rose overall in 50 years, and the isotherm moved northeast. The average rise per point is about 0.5 °C.

Respectively, it is predicted that the area will migrate to the northeast of Norway, the northwestern Faroe Islands, and Iceland within 50 years. Therefore, the areas where the two fish are most likely to live are probably in the areas below.

Figure 13 Most likely locations of two fish species

3.2 Temperature-Location Model (TL)

3.2.1 Local Assumption

- Fish schools are more likely to appear at more suitable temperatures.
- At the optimum temperature, the schools of fish gather densely in a circular area
- At present (i.e. 2020), the temperature around Scottish fishing grounds is relatively suitable for two species of fish.
- Fish migrate seasonally and periodically.

3.2.2 Construction and Solution

There is a difference in the optimal temperature of life between Herring and Mackerel. Herring is in deeper water, about 7°C, and Mackerel is also in deeper water, about 5°C.

The water temperature model in Model 1 is the value at shallow water. From deep water to shallow water, it may still be regarded as the optimal temperature difference that is still 2°C.

The optimal temperature difference between the two makes the route different during the migration process. The direction of travel during the migration of the two is considered to be along the gradient of the temperature change, that is, the direction of the perpendicular of the isotherm.

As the temperature rises, the school of fish will migrate to the lower surrounding waters.

We use yield-barycenter method to study the change of the position of the fishing ground, so as to reflect the spatial change of the fish school.

Standardize the obtained production statistics and use the following formula to calculate the center of gravity of the catch.

$$X = \frac{\sum_1^n Ci * Xi}{\sum_1^n Ci}$$

$$Y = \frac{\sum_1^n Ci * Yi}{\sum_1^n Ci}$$

In the formula: X and Y represent the longitude and latitude of the barycenter of the production, Xi is the longitude of the center point of the i^{th} day, Yi is the latitude of the center point of the i^{th} day, and Ci is the output of the i^{th} day. [2]

According to the yield-barycenter method, the Scottish fishing grounds are roughly distributed around 40°N and 70°W.

Using the obtained historical data, a schematic diagram of the positions of the two fishes in the last year is drawn in bottom-left figure.

Using model one, the possible fish school locations in January, April, July, and October in 50 years are predicted, and the predicted migratory routes of the two fish are drawn in bottom-left figure.

Figure 14 Current migratory route

Figure 15 Predicted migratory route

It can be found that the fishery will move west and north. In summer, autumn reaches farthest north near the Faroe Islands.

- For the optimistic situation, that is, when the temperature rises slowly, the school of fish migration is not large.

- For the pessimistic situation, the school of fish moved away from the North Sea and moved towards Iceland.

Both two extreme situations above may occur, but the probability is small. Taking an observation point as an example, the temperature-probability image at a time point is shown in the figure. It can be considered that the temperature T follows a normal distribution, $T \sim N(\mu, \sigma^2)$.

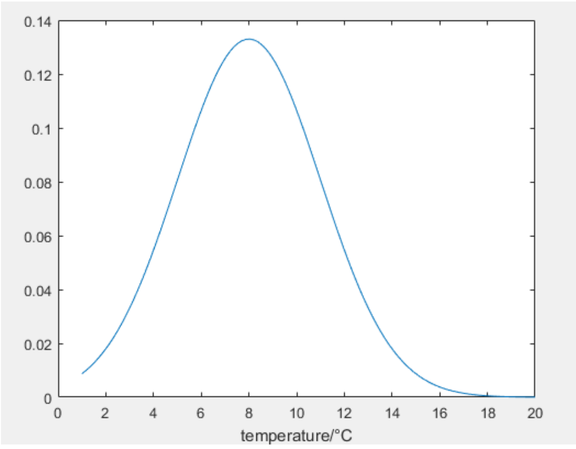

Figure 16 Normal probability plot of temperature

All possible temperature-time functions of the observation point over a period of time constitute a random process:

$$\xi(\mathrm{t}) = \{\xi_1(t), \xi_2(t), \dots, \xi_n(t)\}$$

$$\xi(t_i) = \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{(ti-\mu i)^2}{-2\sigma^2}}$$

At any time, it can be considered that the temperature at this point is within a range of *(μ-σ,μ+σ)* with great probability. For temperature variables. For T_i at various points on the sea, there is $T_i \sim N(\mu, \sigma^2)$, which obeys the same statistical law.

It can be considered that the probability of the entire temperature change at the peak position of the normal distribution within 50 years is the largest, about 8 degrees Celsius. The linear prediction result of temperature in Model 1 falls within this interval, so it can be considered that the fish migration will be affected by the linear increase of temperature.

Therefore, for the most likely case, the temperature changes moderately, and the school of fish is still in the coastal area of Scotland in spring and winter, but it will be active in the Faroe Islands and further north in the summer and autumn.

3.3 Predictive Analysis of Impact on Fishing Company Behavior

If the water temperature changed rapidly, the school of fish moved to a place far away from the original Scottish fishing grounds very early. The yield of fish caught on the fishing grounds was too small to support small fishing companies.

The model will find out where the fish are moving, and the fishing company will not be able to reap the benefits.

Based on the best and worst predictions of the location and water temperature changes, combined with models one and two, we will give the approximate time of the prediction, so that we can continue to make decisions about whether to change the business model.

3.3.1 Construction and Solution

First, two water temperature prediction models were determined, and two fitting methods were used to predict the sea surface temperature.

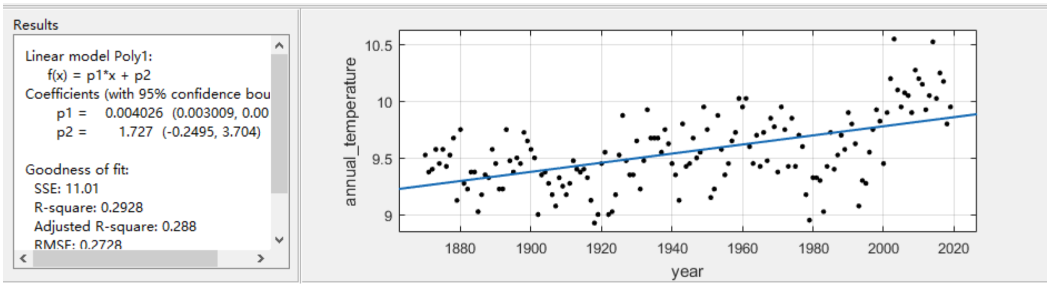

Figure 17 Normal estimation of sea surface temperature

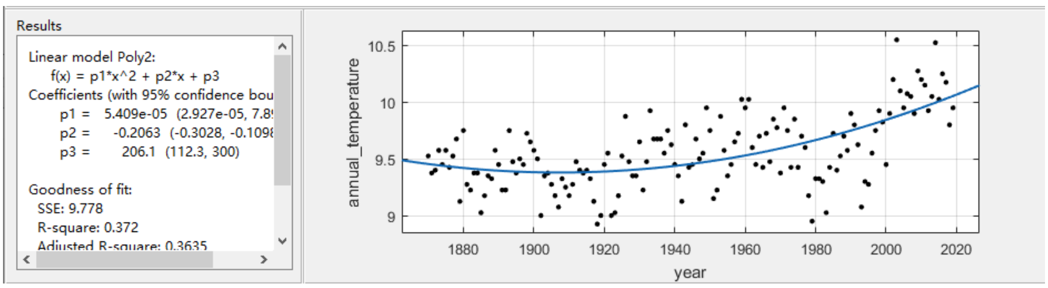

Figure 18 Pessimistic estimation of sea surface temperature

From the distribution of points, we can see that the temperature has risen significantly in the past two decades. The possible reason is that decades of rapid industrial development, massive emissions of greenhouse gases, accelerate the rate of global warming, and caused the sea temperature to rise significantly.

If the international influence on global warming is controlled, we use a linear function to perform a fitting analysis on sea surface temperature as normal estimation.

If we allow the acceleration of global warming, we use a quadratic function to perform a fitting analysis as the worst estimate.

After getting the water temperature prediction function at each point, all sample points were fitted using the Thin-Plate Spline interpolation method at one-year intervals to obtain the relationship between sea surface temperature and latitude and longitude.

Then consider the functions of the distance *w* from the shore to the fishing point d, the yield of fish *q*, and the value *v* of the fish:

When d is smaller, the time cost is lower and *w* is higher; the number *q* of fish caught in a single shot is higher, *w* is higher; the higher the fish's own value is, the higher *w* is.

Where *d* is the amount that changes with temperature, that is, $d = f(T)$, *q* is related to distance, and depends on the position of the fish at the optimal temperature, that is, the higher the *q* is when the fish is at the optimal temperature.

Based on the assumption that fish gathers as a circle, we believe that *q* has a maximum value at the center *O* of the circle, and the further away from *O*, the smaller *q* is. So, we get:

$$w = k_1 \times q \times v(t)$$

Where k_1 is a undetermined coefficient, and $v(t)$ represents the unit fish price at that time. At the center, the density of the school of fish is considered to be a fixed value, and after a certain distance, it is considered to be an inverse proportional function. Therefore,

$$q = \min\left({}^{k_2}/_{r}, \text{const}\right)$$

In the formula, k_2 is an undetermined coefficient.

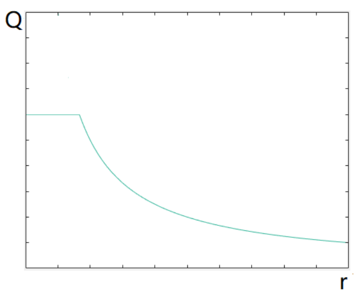

Figure 19 Fish yield vs. Fish distance

So, the company's total revenue is

$$w = k_1 \times v(t) \times \min\left({}^{k_2}/_{r}, \text{constant}\right)$$

Investigate the operating cost c, which is related to the unit fuel mileage m and the distance d per trip, and also includes the necessary additional costs ac such as manpower, power, and maintenance.

$$c = 2 \times m \times d + ac$$

Come back and forth, so multiply by 2. To simplify the model, consider the straight-line distance.

Compare the monthly revenue w with the monthly operating cost *c*. When the revenue w is not sufficient to support the operating cost, this moment is the time point when nothing is obtained. That is, when $w < c$, the fishing company cannot make ends meet, that is, due to the increase in temperature, the position of the school of fish cannot be obtained, and at this time, changes need to be made.

Assume that the small business has 10 people and 1 offshore fishing boat, fishing once a day. It is calculated based on the maximum amount of salvage, regardless of time cost, and calculated based on the average oil price and average wage. When investing in the distance, it will not be able to get enough profit.

Labor costs are wages: 2,000 Euro / person / month; cost of monthly repairs: € 10,000; the longest journey is 200 nautical miles, about 370km; oil price: 1 Euro / liter; the daily fuel consumption is 200 nautical miles per day and costs about 1,000 Euros with a factor of 5. The unit price of two species of fish is around 700 Euros / ton. Maximum salvage amount per time: 5,000lb (mackerel), 6,600lb (herring), corresponds to 2.27ton, 2.99ton. [3, 4]

Therefore, the operating cost:

$$c = 5 \times d \times 30\text{ days} + 2000 \times 10 + 10000 = 150d + 30000 \text{ Euros / month}$$

Calculate the best estimate under optimistic conditions with an average maximum catch of 2.5*t*, and get a return:

$$w = 2.5 \times 700 \times 30 = 52500 \text{ Euros}$$

If w> c, the solution is d> 150 nautical miles, at which point the revenue and expenditure are just in balance.

Considering that as a company, a lot of profit is needed, and this is just an optimistic estimate, so d should actually be far less than 150 nautical miles, that is, approximately less than 100 nautical miles in order to obtain a considerable income.

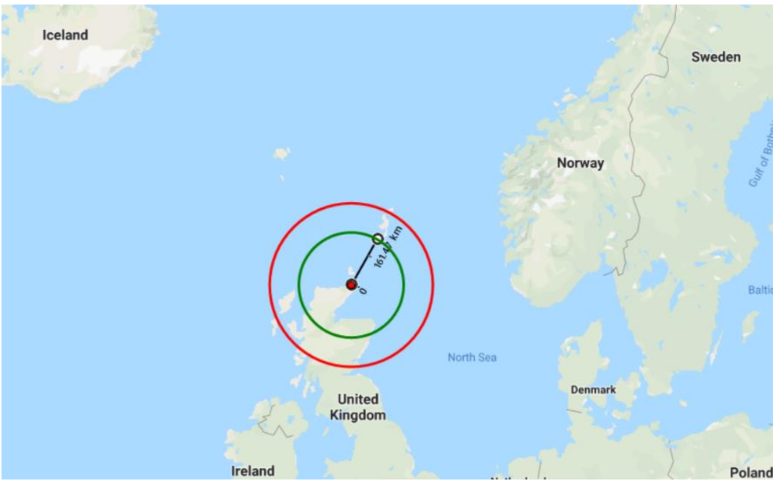

Figure 20 The longest distance to make a profit

In the figure above, the radius of red circle is 150nmi, the radius of green circle is 100nmi.

This indicates that based on the assumptions of the current model, when fish schools move from the original Scottish fishing ground to Shetland, the company in Scotland will not be able to survive normally.

Based on the previously established temperature-time (TT) model, optimistic / pessimistic estimation of the time required for this process, still take the optimal temperature for survival of the two fish around 10°C.

Optimistic situation: According to the previous assumptions, for the optimistic situation, the migration distance of the school of fish is not large, and most of them are still within the range of the current fishery. Therefore, under the condition that the other conditions are not changed, it can be considered that the operation of fishery companies has not been greatly affected. It will remain profitable for 50 years.

General case: Fitting by linear growth of temperature.

The temperature-time equation is:

$$T(t) = 0.004026\, t + 1.727$$

t represents year, $T(t)$ represents temperature in the year t. Solve $t = 2044$. The company can continue to operate until 2044.

Pessimistic: Fitting by quadratic growth of temperature.

The resulting temperature-time equation is:

$$T(t) = 5.409 \times 10^{-5} \times t^2 - 0.2063\, t + 202.1$$

Solve t = 2029. The company can only continue to operate until 2029.

In fact, the main fishing site of herring and mackerel is Shetland. Based on the above considerations, it is necessary for Scottish fishing companies to take measures to ensure that they still have good returns within 50 years.

3.4 Feasible Strategy Analysis

According to the results of Model Three, after a period of time, the small fishing company will eventually have nothing to fish and the fish will move north. If it wants to make a profit, it must adopt a change in business model.

3.4.1 Relocating from Current Position

Part or all of the fishing company's assets are relocated from the current location in the Scottish port to a location where both fish species are migrating. The additional cost of relocating the assets is:

$$C = c_0 + K \times R$$

Where K is the parameter, R is the relocation distance, and C0 is the other costs including the construction of a new building.

We consider whether the relocated investment can recover the principal and turn a profit in a short period of time (such as within five years), assuming that the company sails 30 times a year, taking $T = 5 \times 30$. Then use the formula given in Model 3 to find the difference in operating costs before and after the relocation

$$C = 2 \times m \times (d - d\_new)$$

Where m is the cost of fuel consumption per unit distance, and d is the straight-line distance from the company's starting point to the fishing point, c is the reduced navigation cost after relocation than before relocation.

Compare C with $T \times \Delta c$. If C is greater than $T \times \Delta c$ by any means, this strategy cannot make the company obtain considerable profits in a short period of time. If this strategy is not good, on the contrary, you can find a R to make $T \times \Delta c - C$ the largest, which is the new address of the company after the relocation. (The relationship of *r_new*, *R*, *r* can be derived from the cosine theorem).

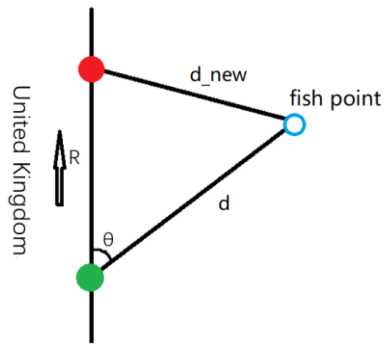

Figure 21 Company relocation

C_0 = 100,000 Euros, K = 1000 Euros / nautical mile

Suppose the original site of the company is in Edinburgh and go to the No. 1 position in Model 1 for fishing, θ = 0, r = 200 nautical miles.

As a result, C and $T \times \Delta c$ can only be achieved when R = 200 nautical miles.

Based on this assumption, this strategy cannot allow companies to obtain considerable profits in a short period of time. It should use a different business strategy or further reduce the relocation expenses and operating costs.

3.4.2 Using Non-land-based Support

With a small percentage of small fishing vessels, these vessels can operate for a period of time without land-based support, while still ensuring the freshness and quality of the catch. Let the function of fish freshness as a function of fishing time be

$$h = a^t \qquad (0 < a < 1)$$

The relationship between value and freshness is

$$p = p_0 \times h$$

Value is sale price $\times$ catch

$$v = p \times q$$

The use cost of the new refrigeration equipment is

$$c = k \times t$$

k is the parameter and t is the sailing time.

Using the results of model three, compare the price situation of using refrigeration equipment and not using refrigeration equipment, v and *v_new*, let a = 0.5 / day when refrigeration equipment is not used, and a = 0.8 / day when refrigeration equipment is used.

Take k = 1000 Euros / day, d = 200 nautical miles, the price is 700 Euros / ton when refrigerating equipment is not used, and the catch is 2.5 tons. Suppose it sail for 2 days after fishing.

It is calculated that the price of the refrigeration equipment is 1792 Euros / ton, the fishing value is increased by 2,730 Euros, and the cost of refrigeration equipment is 2,000 Euros. Using refrigeration equipment to improve the freshness of fish is a strategy that can obtain greater benefits.

3.4.3 Territorial Waters Issue

According to our model's predictions, fishing sites will not enter the territorial sea of other countries such as Iceland and Norway over the next 50 years.

However, if some proportion of the fishery moves into the territorial waters of another country, like neighboring countries Norway and Iceland, it may cause trouble. For example, in the case of serious violations, fishing boats and catches will be confiscated.

In order to protect the interests of fishery companies, we suggest as follows:

- Before every fishing trip, care about the weather and plan the route.
- When a fishing boat enters the territorial sea of another country, just transit and move out, but not catch any fish.
- Fishermen and companies should follow the United Nations Convention on the Law of the Sea and territorial sea laws of related countries, make profit within the sphere permitted by law， and use the law to protect your legitimate rights and interests, avoid disputes and conflicts.

4 Sensitivity Analysis

In predictive analysis of impact on fishing company behavior, we make simple assignments to parameters in the company's operating costs.

Ignoring the influence of factors such as prices, the factor that has the biggest impact on the fishery company's cost is the distance traveled by fishing boats. Considering the change in actual distance, we increase the value of d. As showed below, it can be found that there is no significant change in the company's cost.

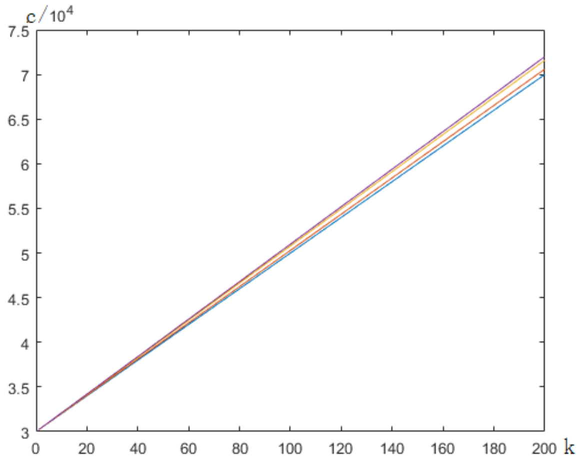

Figure 22 Influence of different distances on the cost model

5 Strengths and Weaknesses

5.1 Strengths

- Our model is concise and powerful. By processing the temperature of the North Atlantic Fisheries in the past, selecting feature points, and using different methods of regression, we make a variety of predictions for future temperature changes.
- A large number of images are combined to visually analyze the sea temperature in the North Atlantic Fisheries, taking into account the impact of different seasons on temperature, rather than simply predicting the annual average temperature without special distinction, and clearly giving the migration route of the two fish. It also shows that our model is close to reality and has high credibility.
- After predicting the migration trend of fish schools in the future, and querying relevant information, we conducted a comprehensive economic modeling of the operating methods of fishing companies and discussed possible changes in business models in the face of fish school migration.

5.2 Weaknesses

- The selection of feature points in the temperature-space model is limited (only 10 points), and our research is limited to a relatively small range. Part of the fitting result has a certain deviation from the actual.

- Fish food, ocean currents and other factors are ignored. In practice, there is more than one factor influencing temperature. These need to be considered.

5.3 Future work

- For the temperature prediction model, we will combine existing models such as CO_2 changes and related policies for comprehensive consideration, not just based on past data sets.
- For the model of temperature vs. space, we will combine all data points to make relevant visualization programs that dynamically change to better and more accurately predict the temperature situation in the space range.
- The model for temperature to fish migration will refer to more literature, introduce more variables, and quantify the migratory behavior of fish in a better way.
- Improve the economic model, add more considerations, build a multi-objective optimization model, and make more comprehensive recommendations.

6 Conclusion

In this paper, we make an analysis and prediction of the most likely location of mackerel and herring in North Atlantic Fishery over the next 50 years. Besides, we analyze the impact of fish moving on small fishery companies and analyze possible approaches for them to profit. Here we conclude our findings.

Firstly, as to find the most likely locations for two fish species, we establish the Time-Temperatures Model and Temperature-Location Model. It is referred that two fish species may move towards Norway in the northeast, Faroe Islands and Iceland in the northwest over the next 50 years.

Secondly, the impact of this change on business of small fishery companies, under three predictions are analyzed, and we concluded the best case is 50 years later, the worst case is in 2029, and most likely time is in 2044.

Then, in order to enable fishery companies to make profits in the future, we discuss possible strategies models and conclude that using fresh-keeping equipment on board can improve the quality of the fish and thus the profit. And we talk about potential territorial waters issue.

At last, we conduct an analysis of sensitivity, strengths and weakness of our model, and further expand it to make our model and method more reasonable and practical.

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