Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
A		**2003469**

Hundred Years War between Scotland and Fish

Summary

The topic of global ocean warming has attracted wide attention around the world, and the resulting migration of marine fish has also directly affected the relevant fishing companies. Therefore finding solutions for the future has become an important task.

Firstly, We need to predict the temperature change and distribution over the next 50 years. We first establish **the Kriging Interpolation Model** to preprocess the data, then establish **the Grey Prediction Model** to predict the temperature of each data point. Finally we use **the Empirical Bayesian Kriging Model** to draw the SST surface.

Secondly, we have collected data such as fish school distribution, port distribution, and annual catch in previous years, analyzed the benefits and costs of small fisheries companies, and established a Profits Model to calculate the time span from now to the time when profit cannot be obtained. According to the speed of temperature change, the best time span is about 38 years, and the worst time span is 49 years. The average time span is 43 years.

Thirdly, we have adopted two measures. The first is to completely transfer the company's property, and the second is to install refrigeration equipment on the ship. After processing and adjusting the parameters of the second question model, we find that the profits obtained by the above two measures are greater than the original profits without measures. Therefore, these two measures are taken to solve the migration problem.

Finally, in the case where some fishing areas enter the seafront of other countries, we adopt the strategy of abandoning this part of the fishing area, and delete the fish school points entering the territorial sea of other countries based on the original model. The findings did not have much impact on the profits made.

Keywords: Kriging; Arcgis; SST; Empirical Bayesian Kriging; GPM; Profit Model; Fishery

Contents

1 Introduction

1.1 Problem Restatement

Today, due to global ocean warming, certain marine life has to find other habitats to ensure its future life and successful reproduction. However, this phenomenon poses a potential crisis for companies that profit from fishing. Scottish herring and mackerel have a huge supporting role for the Scottish fisheries economy. Their migration will bring instability to small Scotland-based fishing companies. We need to establish models to analyze the possible whereabouts of fish stocks and propose reasonable solutions to the changes.

In order to address problems, we conclude five sub-problems to tackle in our paper.

- Analyze the sea temperature data in recent years, and build a model to predict the sea temperature changes in the next 50 years.
- Based on changes in seawater temperature, predict the migration routes and locations of these two species in the next 50 years.
- By changing the speed of ocean warming within a reasonable range, find out the longest duration, shortest duration, and the most likely duration of small fishery companies from now to the time when they cannot meet the profit conditions.
- Establish a model of profits and loss, analyze the changes in costs and benefits after taking corresponding measures, optimize to maximize profits and compare them with the original location to determine whether to take the measure.
- Use the previously established profit and loss model to analyze the impact of the territorial sea problem on the model.

1.2 Problem Analysis

In the first step, we tried to find the temperature data as detailed as possible on the Internet as the basis of the prediction model, and divided the obtained data into units. Based on the already matured gray prediction model, we can achieve prediction for each data unit. Image generation can be done by using ArcGIS.

In the second step, we seek to find out the relationship between the profits and the distance from port to fish population. We could suggest that the distance is correlated to the changing speed of ocean temperaure. And different profits may indicate where the best and worst cases are.

In the third step, we consider to use some proportion of small fishing vessels capable with on-board refrigeration, which means the freshness of the fish can be better guaranteed, and the navigation distance can be farther. In the model of the previous question, we appropriately changed the parameter values and critical values, and compared the changes of profits to evaluate the effectiveness of this measure.

Finally, in the case where some fishing areas enter the seafront of other countries, we adopt the strategy of abandoning this part of the fishing area, delete the fish school points entering the territorial sea of other countries based on the original model.

2 Assumption and Justification

To simplify our model, we make the following assumptions, each of which is well justified.

1. Ocean temperature is regarded as sea surface temperature(SST), that is, ocean temperature is not correlated to ocean depth. Because Scottish herring and mackerel belongs to coastal fish, and global warming first affects the sea surface, it simplifies the SST prediction model.

2. There is little change in water quality near Scotland, and interspecific relationships and other environmental factors do not affect the migration of species.

3. Establish the relationship between the sea sruface temperature(SST) spatial distribution and the fish school spatial distribution. Assume that the number of fish was normally distributed in the temperature range and the distribution of fish school is related to isotherm.

4. We suppose that the total number of fish in each year does not change, but the distribution changes.

5. Only consider fishing in Scotland and its northern waters, ignoring the impact of fish in the south.

6. Based on the fact that Scottish herring and mackerel do not have a direct predator relationship, we do not distinguish the distribution of these two types of fish. [2]

3 Notation

We use the following symbols in our model and analysis for convenience, cf. Table 1.

Table 1: Symbols and its description

Symbol	Meaning
t	The time
$T^{(0)}(i)$	The average SST of each cell in every 10 years
a	The development coefficient
u	The Gray effect coefficient
F_{total}	The total number of Scottish herring and mackerel
P_{total}	The profit of fishery per year
V_{rev}	The revenue of fishery per year
V_{cost}	The cost of fishery per year
v_0	The fish price per ton
a_p	The freshness of fish
n_p	The volume of fishing
d_p	The distance from port to school of fish
d_c	The distance from port to fishing point
d_{fpi}	The distance from port to position of fish cluster
α_i	The weight of the influence of each fish position on the fishing point
β	The coefficient of the freshness of fish

4 SST Prediction Model

4.1 Overview of the historical SST prediction research methods

The research on SST prediction has many different solutions, using a variety of models to simulate the changes and impact of SST in the future. We have summarized a number of model strategies suitable for this problem from many papers, and draw ideas from them to come up with our own model. The first is based on the MODIS sea surface temperature inversion model. This model uses MODIS to invert the sea surface temperature at the split window band of the 10-12 micron atmospheric window, and uses mathematical statistical models for modeling on the mathematical model. The physical model is mainly the thermal radiation transmission equation describing the relationship between the characteristics of the sensor signal and the physical parameters of the sea surface atmosphere. Secondly, the Argo subsurface temperature is calculated based on the sea temperature parameter model. The model calculates its parameters by iterative method, and uses the sea surface observation information to analyze the subsurface temperature structure. Dynamic bioclimate envelop model (DBEM) is a new frontier model that can effectively analyze the influence of various factors on the distribution of animal communities.

4.2 Data Description

In order to predict the temperature in the waters around Scotland in the next 50 years, we have collected data on SST and adopted the temperature data provided by the National Oceanic and Atmospheric Administration (NOAA) for integration. [3]

- The time span of the entire data set is 1955-2014. The temperature data is the average temperature of every ten years in the past 60 years, and the time is divided into six parts: 1955-1964, 1965-1974, 1975-1984, 1985-1994, 1995-2004, 2005-2014. The temperature sampling depth is 20 meters below sea level, which is close to SST.

- According to the habits of Scottish mackerel and herring, the habitat of these two fish is the continental shelf area around Scotland, so we use the range of the continental shelf as the main basis to frame the study area(Shown in figure 1). The area ranges from 55 degrees north latitude to 63 degrees north latitude, and -9.5 degrees west to 5.5 degrees east longitude.

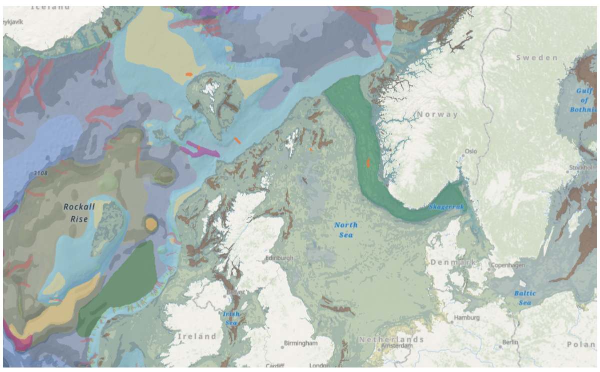


Figure 1: Scotland Seafloor Geomorphology. Source: *Esri, GEBCO, DeLorme, NaturalVue.* `http://www.marineregions.org`

- In this area, we use $0.25° \times 0.25°$as a cell to divide the area and collect the temperature of the cells which represent the ocean from the data. We call these cells as valid cells.
- Since herring and mackerel live at a depth of about 20m to 200m, we need to select the three most representative arrays at depths of 20m, 60m, and 100m. The data of these arrays has not been seriously lost in the selected area of the map. The sample point coverage map is as follows. The coverage of the 64 $\times$ 32 grid is 83.08 %.

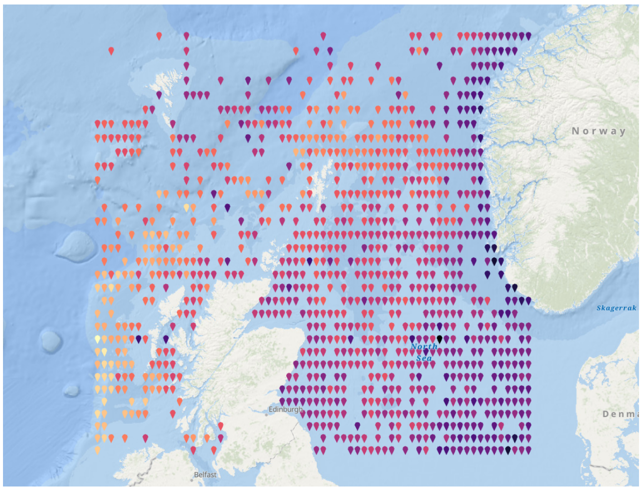


Figure 2: Sample [7]

4.3 Basic Kriging Interpolation Model

Because the SST data we obtained is incomplete and there are cases where some valid cells do not have temperature values, we first use interpolation method to supplement the missing data.

The kriging method was first proposed by French geographer Matheron and South African mining engineer Krige for mine exploration. [8]This method considers that the properties that change continuously in space are very irregular. Simulation with a simple smoothing function will cause errors, and it will be more appropriate to give a description using a random surface function. The regionalized variable is first a random function, which has local, random, and anomalous properties.Secondly, the regionalized variable has general or average structural properties, that is, the variable at the point X and the deviation from the spatial distance h. Value $Z(x)$ at point $x+h$ It has a certain relationship with $Z(x+h)$. Covariance function and variation function are the two most basic functions of geostatistics based on the theory of regionalized variables. Let $Z(x)$ be a regionalized variable that satisfies the second-order stationary and eigen assumptions. Its mathematical expectation is m, the covariance function $c(h)$ and the mutation function $\lambda(h)$ exist. which is

$$E[Z(x)] = m$$

$$c(h) = E[Z(x)Z(x+h)] - m^2$$

$$\gamma(h) = \frac{1}{2}E(Z(x) - Z(x+h))^2$$

The most commonly used Original Kriging (OK) formula is as follows:

$$Z_V^* = \sum_{i=1}^{n} \lambda_i Z(x_i)$$

λ_i is the weighting coefficient. According to the principle and optimality of linear unbiased estimation, the estimated variance is minimized, and the Kriging equations are obtained according to the Lagrange multiplier method.

$$\left\{ \begin{array}{l} \sum_{j=1}^{n} \lambda_j \bar{c}(v_i, v_j) - \mu = \bar{c}(v_i, V) \\ \sum_{i=1}^{n} \lambda_i = 1 \end{array} \right.$$

When the variogram exists, you can get

$$\gamma(h) = c(0) - c(h)$$

We use the variogram to represent the Kriging equations and get

$$\left\{ \begin{array}{l} \sum_{j=1}^{n} \lambda_j \bar{\gamma}(v_i, v_j) + \mu = \bar{\gamma}(v_i, V) \\ \sum_{i=1}^{n} \lambda_i = 1 \end{array} \right.$$

Finally, the mutation function formula is obtained through substitution.

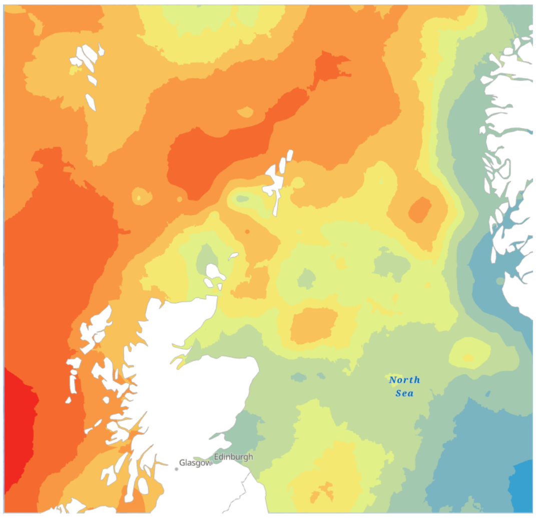
$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2$$

N (h) is the number of observation sample pairs divided by the distance segment h. Our variation function uses The most widely used spherical model in geostatistical analysis, the formula is

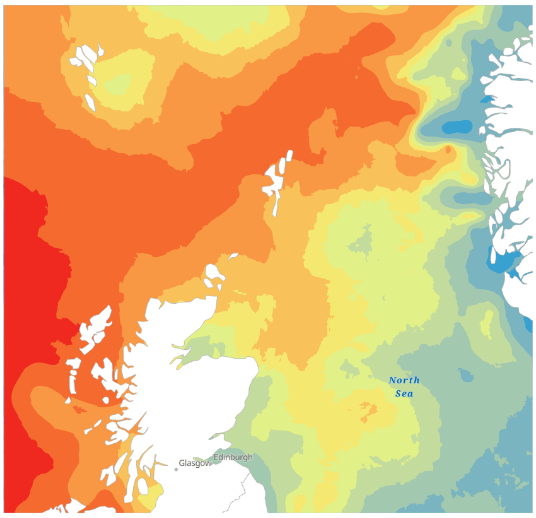
$$\gamma(h) = \begin{cases} 0 & h = 0 \\ c_0 + c\left(\frac{3h}{2a} - \frac{h^2}{2a^3}\right) & 0 < h \leqslant a \\ c_0 + c & h > a \end{cases}$$

Obtain the specific variation function model of the above formula from the observation point values, substitute it into the Kriging equations to solve the dd weight coefficient $\lambda_(i)$ and the Lagrange multiplier μ, and then substitute it into the definition of Original Kriging. $Z_V^\star$ is the optimal unbiased estimate of Z_V. [9]

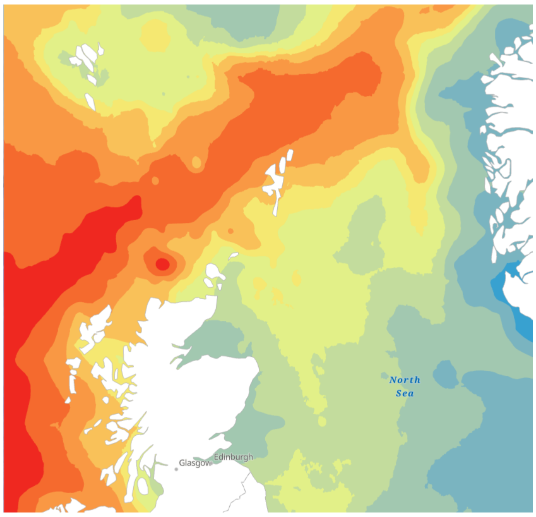
We use the most basic Original Kriging (OK) to perform a small amount of missing data interpolation. Note that a trick does not interpolate all missing points, but only interpolates some points with high confidence. Shown below are six winter average sst distribution charts after full interpolation, with a time span of 60 years. [10]



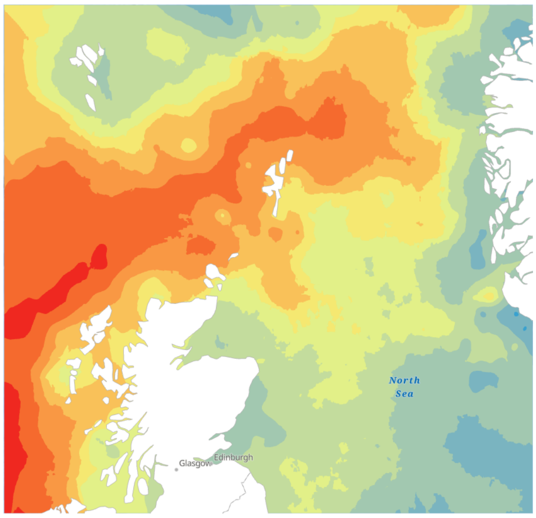
(a) Winter SST of 1955-1964



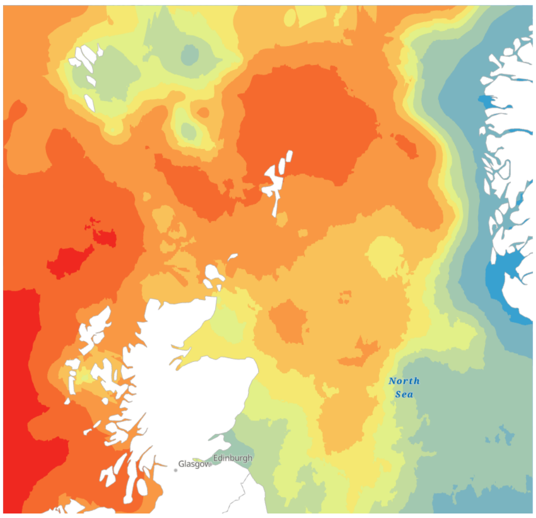
(b) Winter SST of 1965-1974



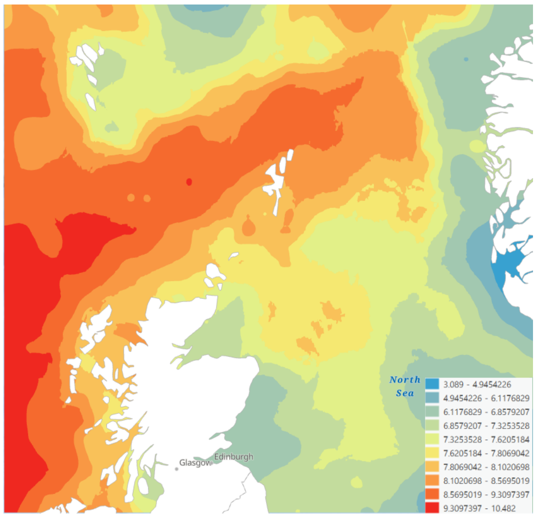
(c) Winter SST of 1975-1984



(d) Winter SST of 1985-1994



(e) Winter SST of 1995-2004



(f) Winter SST of 2005-2014

Figure 3: Past 60 Years Winter SST Kriging Prediction [11]

4.4 Grey Prediction Model

We use GM(1,1) to predict the SST in the next 50 years. The principle of the GM(1,1) model is to generate a set of new data sequences with obvious trend by accumulating a certain data sequence and establish a model to predict according to the growth trend of the new data series. Then the reverse calculation is carried out by using the method of cumulative reduction to restore the original data sequence. Finally, the prediction results are obtained.

For every cell, denote SST by:

$$T^{(0)} = \left(T^{(0)}(1), T^{(0)}(2), \cdots T^{(0)}(n)\right)$$

where $T^{(0)}(i); i = 1, 2, \ldots, n$ represents the average SST of each cell in every 10 years. Under the rule of accumulated generation operation, we get

$$T^{(1)} = \left(T^{(1)}(1), T^{(1)}(2), \cdots T^{(1)}(n)\right)$$

where $T^{(1)}(k) = \sum_{i=1}^{k} T^{(0)}(i); k = i, 2 \cdots n$.

Then we obtain a series with n elements by generating equal weight sequence of $T^{(1)}$:

$$z^{(1)} = \left\{z^{(1)}(2), z^{(1)}(3), \cdots z^{(1)}(k)\right\}, k = 2, 3 \cdots n$$

where $z^{(1)}(k) = 0.5T^{(1)}(k-1) + 0.5T^{(1)}(k), k = 2, 3 \cdots n$. And we establish a first-order one-variable albino differential equation for t according to gray theory for $T^{(1)}$:

$$\frac{dT^{(1)}}{dt} + aT^{(1)} = u \tag{1}$$

Use the least square method to solve the parameters, and plug the parameters into the equation 1 to solve the differential equation. The soultion is as followed:

$$\hat{T}^{(1)}(t+1) = \left(T^{(1)}(1) - \frac{u}{a}\right) e^{-at} + \frac{u}{a} \tag{2}$$

Handling the above results by using relational expression $\hat{T}^{(0)}(t+1) = \hat{T}^{(1)}(t+1) - \hat{T}^{(1)}(t)$, and we could get our prediction as:

$$\hat{T}^{(0)} = \left(\hat{T}^{(0)}(1), \hat{T}^{(0)}(2), \cdots \hat{T}^{(0)}(n), \hat{T}^{(0)}(n+1), \cdots \hat{T}^{(0)}(n+m)\right)$$

All steps mentioned above are programmed with **MATLAB**. [1]

4.5 Sensitivity Analysis of GPM

Due to the uncertainty of the system, the shortcomings of using the traditional single prediction model to show the sensitivity to the model setting form, we use 64×32 matrix split prediction to have this problem. In this part, we try to test the models sensitivity to change the methods of data interpolation and pretreatment, using different ways to fix missing data, we tried Moving average over a window of length windowspline and some other interpolation methods, and the prediction mean error is about 8.473.

4.6 Optimized Global and Local Outliers analysis

Given a set of weighted features, we can use Anselin Local Moran s I statistic to identify statistically significant hotspots, cold spots, and spatial outliers. The clustering and outlier analysis (Anselin Local Moran s I) tool can identify statistically significant spatial outliers (high values surrounded by low values or low values surrounded by high values). Local outliers are defined as the elements that differ from the local median by more than three times the local converted MAD within the window length specified by window. The converted MAD is defined as c $\times$ median (abs (A-median (A))), where c = -1 / (sqrt (2) $\times$ erfcinv (3/2)). Extract the forecast data for 2025-2034 for analysis, and finally get the correct result as shown in the figure 4.

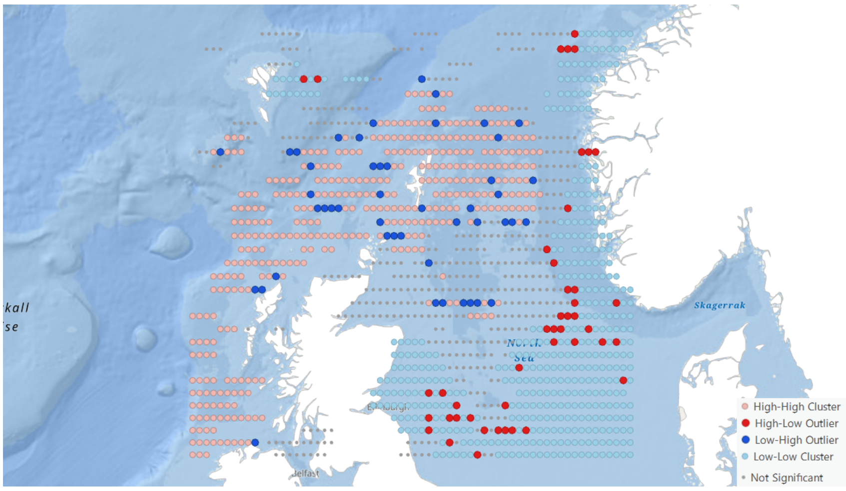


Figure 4: Global and Local Outliers analysis

The graph reflects the abnormal changes in these points. One possibility is that the water temperature in the area changes rapidly and is not suitable for long-term survival of fish. When making decisions, fishing companies can consider choosing these abnormal potentials as far as possible. Another possibility is the shortcomings of the gray prediction model itself. Each point is used to predict the future temperature separately, and there is no correlation between adjacent points.

5 Geostatistical Interpolation with GIS

5.1 Explore Data

In Geostatistical analysis, kriging or Gaussian process regression is built on the basis of stationary hypothesis.In addition, some Kriging interpolations (eg. ordinary Kriging, simple Kriging) assume that the data follow a normal distribution. [6]If not, we can apply certain data transformation to make it it closer to a normal distribution. Thus, before creating a surface with geostatistical analysis, it's of importance to understand how the data is distributed. We used The Histogram and Normal QQ plot to test the data. [12]

Use GM (1,1) to forecast results, select 2035-2044 sets of data in the forecast data, and use ArcGIS to analyze, we can see that the SST is really close to normal distribution, and the mean and median are very close together , which is another good indication that the distribution is normal.

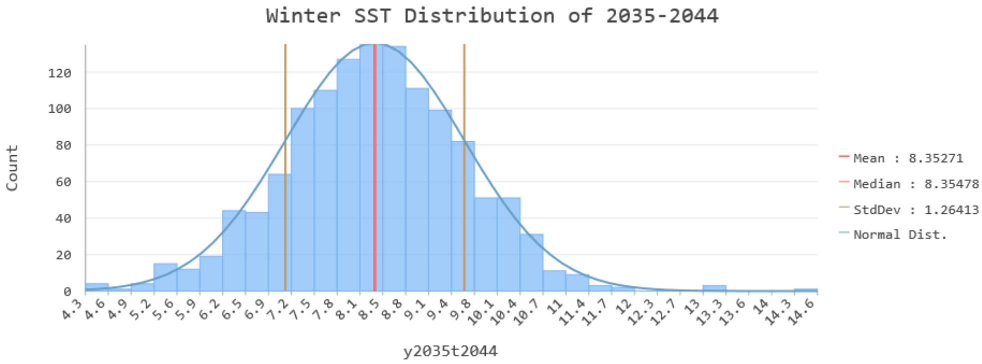


Figure 5: Histogram of SST

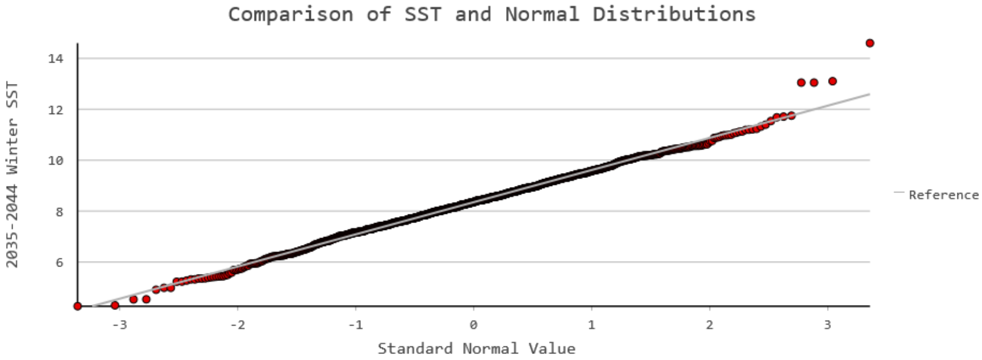


Figure 6: Normal QQ plot

5.2 Inverse Distance Weighting

Inverse distance weighting (IDW), which inverses distance to a Power, is a common and simple method of spatial interpolation. IDW is based on the basic assumption of *the first law of geography*: the similarity of two objects increases with the distance they see. Large and reduced. It uses the distance between the interpolation points and the sample points as weights to perform weighted average. The samples closer to the interpolation points give greater weight. This method is simple, easy, intuitive, and efficient. When the known points are uniformly distributed The interpolation effect is good, the interpolation result is between the maximum and minimum values used for the interpolation data, but the disadvantage is that it is susceptible to extreme values. We use the IDW method to predict the results from 2025-2034 by interpolation.

5.3 Original Kriging and Universal Kriging

As we introduced earlier, Original Kriging (OK) is a linear estimate of the regionalized variable. It assumes that the data changes into a normal distribution and that the expected value of the regionalized variable Z is unknown. The interpolation process is similar to a weighted moving average, and the determination of weight values comes from spatial data analysis. This is a method of unbiased and optimal estimation of the value of regionalized variables in a limited area starting from the correlation and variability of variables.

Universal Kriging(UK) is similar to Orginal Kriging, however, the value of the map changes more smoothly.

We use OK and UK methods. The interpolation results for 2025-2034 are as follows.

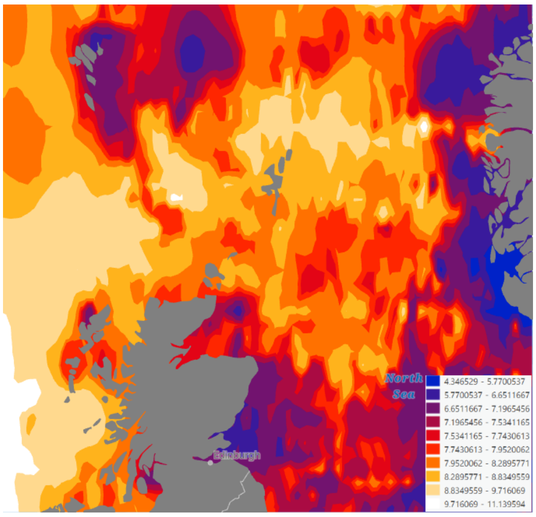
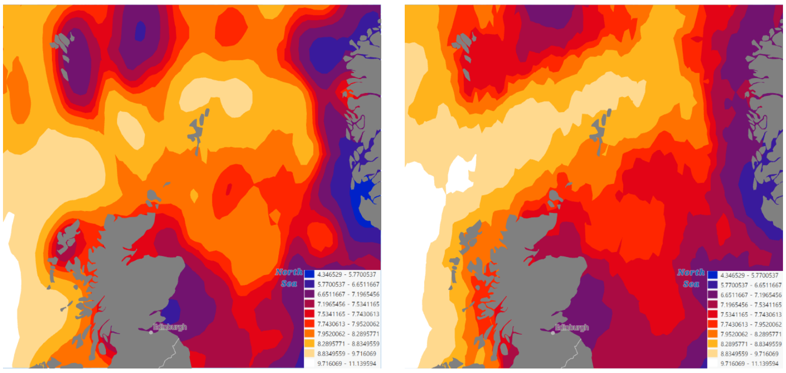


Figure 7: IDW Interpolation



(a) OK Interpolation (b) UK Interpolation

Figure 8: Kriging Interpolation

5.4 Empirical Bayesian kriging

Empirical Bayesian kriging (EBK) is a geostatistical interpolation method that can automatically perform the most difficult steps in the process of building an effective kriging model. Other kriging methods in Geostatistical Analyst require you to manually adjust the parameters to receive accurate results, while EBK can automatically calculate these parameters by constructing a subset and simulating the process. [13]

EBK accounts for the errors introduced by estimating the underlying semivariogram. This process implicitly assumes that the estimated semivariogram is the true semivariogram of the interpolation area.

EBK is offered in **ArcGIS** as a geoprocessing tool. We use this model to form a continuous temperature heat map, and use **ArcGIS** to map and generate existing temperature heat maps and predicted future temperature heat maps. [4]

We use KBP method to predict the results of 2025-2034 by interpolation.

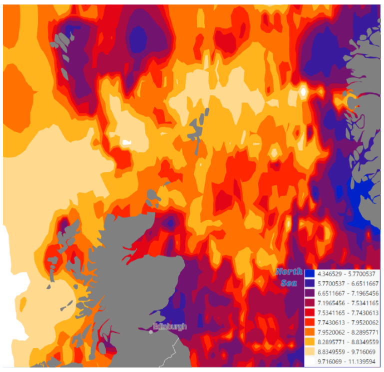
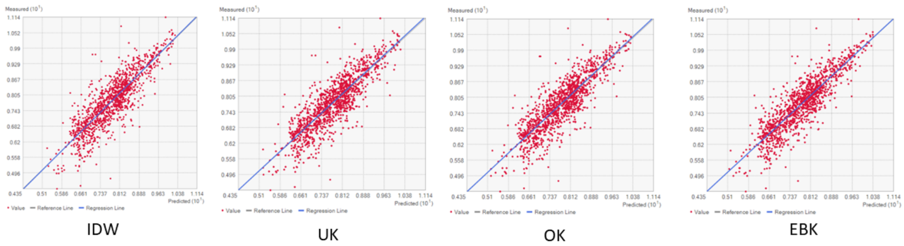


Figure 9: KBP Interpolation

5.5 Results and Discussion



(a) 1

Figure 10: This is a Demo of 2×2

The simulated values obtained from the interpolation module of ArcGIS are compared with the actual collected values, and cross-validation is performed to obtain the MEAN and RMS values of the following different methods. The error table is analyzed. RMS), Mean Standardized (MS), Average Standard Error (ASE) to evaluate.

Model	MEAN	RMS	MS	ASE
IDW	0.005372	0.547370	–	–
OK	-0.001734	0.545757	-0.003403	0.542228
UK	-0.001143	0.551263	-0.003068	0.377388
EBK	-0.002973	0.514937	-0.005719	0.534349

From the table we can see that the MEAN values of the four methods are all close to 0, and the MEAN value of UK Interpolation is relatively small. In general, the one with the smallest overall MEAN and RMS of the interpolation method has better interpolation The effect of value, especially the smaller the RMS, the better. When considering the value of RMS as the basis for evaluation, the RMS of EBK is the smallest, and the results of EBK can be considered to be more reliable.

6 Profits Model

When analyzing the effects of fish migration caused by warming ocean temperatures on small fisheries companies, we established a model that takes the distance from the port to the fishing point d_c as the independent variable to represent the average profits of a port in a quarter. Profits are expressed as the difference between revenue and cost:

$$P_{total} = V_{rev} - V_{cost} \tag{3}$$

Where income can be expressed as the following expression:

$$V_{rev} = v_0 \times a_p \times n_p \tag{4}$$

For the variables in the formula, v_0 represents the price per ton of fish. We query the previous Scottish fishery data to know that the average price of Scottish herring and mackerel in 2016 was 700 pounds per ton. The Scottish fishery data also shows that the total catch of pelagic fish is 200-300 kilotons per year. Winter is the concentrated period of fishing, and Scottish herring and mackerel are the main species of pelagic fish. The ratio of the catch to the number of fish is approximately 0.42: 1, and the number of fish can be roughly estimated from the catch. So to simplify the model, the unit price of fish in the next 50 years is approximately 700 pounds per ton, and the total number of Scottish herring and mackerel in winter is approximately 714 thousand tons.

Peterhead was selected as the port location in the model analysis based on the historical data of the total catch. According to the information, in the absence of on-board refrigeration, the freshness period of the fish is maintained at about one week. The freshness of fish is abstracted as a value in the range of 0-1. Establish an inverse proportional relationship between freshness and d_c, the expression is as follows:

$$a_p = 1 - \frac{1}{\ln(2)} \ln\left(\frac{1}{d_{max}}\left|\overrightarrow{d_c}\right| + 1\right) \tag{5}$$

To calculate the catch at a fishing point, you need to analyze the distance between the fishing point and the distribution points in each fish cluster, and establish the following expression:

$$n_p = \left[\frac{\alpha_1}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fp1}} - \overrightarrow{d_c}\right|} + \frac{\alpha_2}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fp2}} - \overrightarrow{d_c}\right|} + \cdots + \frac{\alpha_n}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fpn}} - \overrightarrow{d_c}\right|} + \right] \times F_{total} \tag{6}$$

This formula shows that if the distance between the fishing point and the school of fish is farther, the fishing catch will be less, and the common influence of multiple fish school positions on the fishing point will be considered. The weight of the influence of each fish position on the fishing point is expressed by a coefficient $\alpha_i (i = 1, 2, \cdots, n)$, and the weight is positively related to the number of fish at the distribution point in the fish cluster.

Eventually we can deduce the expression of P_{total}:

$$\begin{aligned} P_{total} =& v_0 \times \left[1 - \frac{1}{\ln(2)} \ln\left(\frac{1}{d_{max}}\left|\overrightarrow{d_c}\right| + 1\right)\right] \\ & \times \left[\frac{\alpha_1}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fp1}} - \overrightarrow{d_c}\right|} + \frac{\alpha_2}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fp2}} - \overrightarrow{d_c}\right|} + \cdots + \frac{\alpha_n}{1+\frac{1}{\beta}\left|\overrightarrow{d_{fpn}} - \overrightarrow{d_c}\right|} + \right] \times F_{total} \end{aligned} \tag{7}$$

Table 2: Parameters List

Parameter	Value	Parameter	Value
v_0	700 £/ton	F_{total}	714 kiloton
V_{cost}	10,000,000 £	β	10 km
d_{max}	200 km	d_{fp1}	(-1.26,59.65)
d_{fp2}	(-3.14,59.39)	d_{fp3}	(-1.93,58.26)
d_{fp4}	(3.61,58.27)	d_{fp5}	(-0.65,57.17)
d_{fp6}	(3.76,56.85)	d_{fp7}	(-1.2,56.06)
d_{fp8}	(-0.91,59.78)	d_{fp9}	(-5.84,61.32)
d_{fp10}	(-3.28,62.01)	d_{fp11}	(3.15,61.91)
d_{fp12}	(4.05,60.65)	d_{fp13}	(4.29,59.23)

7 Strengths and weaknesses

The advantage of our Profits Model is that by correlating the profit with the sailing distance, and taking the position of each fish population into consideration comprehensively, the catch quantity of each fishing point can be obtained, which is a good guide for the selection of sailing route. The disadvantage is that there is no discussion on flexible choice of navigation routes for multiple ports.The movement of fish population is comprehensively reflected in the model as the change of the optimal fishing point, which makes the specific movement less reflected.

8 Article for the Magazine

There are some scenarios in disaster films: high buildings submerged in the sea, house debris floating on the sea, helicopters hovering in the air to find survivors . . . Due to the effects of global warming, rising sea have flooded many coastal cities, many marine life has died because of high seawater temperatures, and people's lives have been greatly damaged. Although this imagination may seem unrealistic, we can still see the phenomenon of global warming with our own eyes.

Global warming has led to rising sea temperatures, and the overall trend has not declined. The rise in ocean temperature has affected the habitat and living habits of marine life, and many fish species have begun to migrate in order to find suitable habitats. This migration will cause many troubles for fishery-based companies. In Scotland and its surrounding areas, there are many fisheries that mainly focus on ocean fishes, and most of the ocean fish are mainly Scottish herring and mackerel. According to Scottish sea fisheries statistics 2016, Mackerel remains the most valuable stock to the Scottish fleet at £169 million, accounting for 30 per cent of the total value of Scottish landings. As the ocean temperature rises, over the next 50 years, their habitats will move and cause great losses to fishing companies, especially small fishing companies.

Temperature data over the past 60 years shows how temperatures have changed. Since 1955, the average temperature has gradually increased every decade, and the proportion of waters with high temperatures has become larger and larger. If we predict the temperature in the next 50 years, this growth trend will be more obvious. Counting in decade, you will find that it will increase by about 0.5°C every decade. By 2074, the sea surface temperature in winter near Scotland may reach an amazing 14 °C. According to this prediction result, the distribution of fish population will be affected more significantly. According to Scotland's annual fishing data, the distribution of Scottish herring and mackerel in 2010 was mainly concentrated near the Scottish continental shelf. However, by predicting the distribution in 2074, these two types of fish migrated significantly northward, and the average distance can reach 100 kilometers. For the fishing industry, migration brings increased distance and decreased freshness, which will have a negative impact on the profitability of fisheries.

This is a strong warning that we need to respond to the status quo. On the one hand, we must do everything possible to curb the trend of global warming and improve the environment by reducing carbon emissions and green environmental protection. On the other hand, in order to ensure the annual catch and income, we must adopt measures to reduce the losses. Here are two suggestions for fishermen:

The first proposal is to move the entire assets of the company to a new location. This method seems to be very human capital consuming, but the transportation cost is only temporary. Moving to a suitable new location can effectively reduce the distance to the school of fish, reduce the cost of the annual fishing trips, and improve the freshness of the fish. Through the accumulation of each year, the profits obtained can completely offset the extra expenses caused by the transfer of assets.

The second suggestion is to prepare some fishing vessels with on-board refrigerating equipment for fishing. The refrigerating device on board can effectively ensure the freshness of the fish and make use of the remaining time to catch more fish. In this way, the same time and place to go to sea can catch more fish and maintain better freshness. This long-term revenue model can quickly make up for the cost of maintenance, repair and purchase.

People are paying more and more attention to the problem of rising ocean temperatures. However, before a bad situation comes, the best option is to be fully prepared.

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