Problem Chosen	2020	Team Control Number
A	**MCM/ICM Summary Sheet**	**2008996**

Migration of herring and mackerel and Countermeasures for fishery

Summary

In recent years, global warming has become an unavoidable topic due to the increase in human activities. Many industries have been affected to varying degrees. The income of fishing companies in Scotland has decreased, because herring and mackerel are moving north. Studying the migration routes of fish is important for them to survive the crisis.

First of all , we counted the **SST**(sea table surface temperature) of a sea area of the north-west of Scotland, and established **SARIMA**(autoregressive moving average seasonal difference model) to predict SST from 2018 to 2068. For simplicity, we chose 59N, 356E to study its SST changes in the next 50 years. On this basis, with the **best approximation of optimal squares method**, we obtained the function of SST and longitude, and of SST and latitude. Based on the above research, we obtained the SST during the fishing season in the next 50 years. Secondly, at decade intervals, we drew the **isotherms** of this area. For herring and mackerel swimming towards to the sea area which has the SST close to its own suitable temperature, which we fixed in a reasonable range. Then we drew the migration routes of herring and mackerel through the next 50 years. And we concluded that, herring and mackerel are predicted to be around the **coastline near Faroe Islands**. Next, at five years intervals, we analysed the best and worst cases of herring and mackerel migration. It turns out that **earliest in 2038**, fishermen won't catch fish at all.Then, we built a cost-effectiveness model to analyse the earnings with two measures(transferring fishing vessels and setting up a sea **transfer station**)respectedly taken. And we concluded that if the assets of the company is greater than a certain value, they should take measure1, otherwise, they should take measure2.Finally, we considered the case that herring and mackerel migrates into the territorial waters of other countries. And we suggested fisherman to reconstruct their equipment to adapt catching **other marine creatures** migrating from sea areas a little south from Scotland.

In addition , in the sensitivity analysis, we analyzed the possible effects of sudden factors such as severe weather, ocean current movement on the model, and drew graphs about the upper and lower bound of the prediction. We also submitted an article to the *Hook Line and Sinker* magazine in order to explain the impact on the fishing industry of global warming to fishermen, and provided them with some recommendations. At last, we called on all the human to stand up and fight this war against global warming.

Keywords: **SST**; **SARIMA Model**; **Best Square Approximation**; **Cost-Benefit Optimization**; **Shortest Migration Path**

Contents

1 Introduction

With the global warming and the ocean temperature rising, some sea areas gradually no longer suit for the survival and multiply of certain ocean-dwelling species, which have to migrate to other areas. Mackerel and herring are two of the main fishery products in the Scottish fishing industry. Changes in ocean temperature and fish migration may have a significant impact on the local fishing industry.

As the consultant of the Scottish North Atlantic fishery management consortium, we were asked to analyze the move of Scottish herring and mackerel with changes of ocean temperature, in order to figure out the most likely locations of the two species over the next 50 years. Then we need to take further steps to measure the effects of fish migration on Scottish fishing companies, and offer some practical proposal.

2 Analysis of the Problem

In this article, we need to solve these problems:

1. Based on the data of sea surface temperature in the past few decades, establish a model to predict sea surface temperature changes in the next 50 years.[11]

2. According to the habits of herring and mackerel, forecast the migration paths and different habitats of the two kinds of fishes based on rising sea surface temperatures which was predicted.

3. Taking into account the uncertainty of the fish migration, the farthest fishing range is determined by the time which is cost by small fish companies to catch and return the fish to the port while ensuring the fresh of the fish. Furthermore, analyzes the response time left by fishermen in the best and worst cases before the fish are completely unavailable.

4. Based on the dilemma encountered by the small fishing companies, analyze their economic costs and benefits if they take some actions. Consider the following two countermeasures:

   Relocate their fishing sites to bring them closer to the fish.

   Apply new small fishing vessels which do not require land support for fishing.

   Recommend the best response to the dilemma based on the financial situation of the fishing company.

5. Taking into account the circumstance that herring and mackerel may migrate into territorial waters of other countries. Analyze its impact on the Scottish fishing industry and the measures we have proposed, and put forward some new suggestions.

2.1 Assumptions

- Assume that the migration of mackerel and herring is only affected by sea surface temperature. We do not consider the indirect effects of temperature changes on the trophic level and ecological environment of the fish.

- Assume that the fish of the same population have the same and ideal living habits and will not adapt to environmental changes. We do not consider the diversity of living habits within the population, and all fish can respond sensitively when the ambient temperature changes to be unsuitable for survival.

- Suppose mackerel and herring survive the same ocean depth. That is, mackerel and herring will not move to deep water due to the increase in sea surface temperature.
- Based on the reality, make some assumptions of herring and mackerel[4]:

  The optimum survival temperature of herring is about $3.0-7.0°C$,and its fishing season is September.

  The optimum survival temperature of mackerel is about $4.5-10.0°C$,and its fishing season is March.
- Assume that (59N, 355E) is the ideal location for herring and mackerel.

  (Note: To express clearly, we don't distinguish the between the east longitude and the west longitude . We use the east longitude to express it uniformly. For example, we use 355E for 5W)
- Assume that fishermen only catch one kind of fish at a time, they can Go fishing twice in each fishing season without encountering bad weather.
- Assume that the prices used in this article will remain unchanged for the next 50 years.

3 Notations

Notation	**Definition**
T	Sea surface temperature
T_h	Optimum survival temperature for mackerel
T_m	Optimal survival temperature for herring
x	Longitude
y	Latitude
d_h^b	The distance between herring to port in best case
d_m^b	The distance between mackerel to port in best case
d_h^w	The distance between herring to port in worst case
d_m^w	The distance between mackerel to port in worst case
v	The speed of small fishing boat
t_h	The time that herring can stay fresh
t_m	The time that mackerel can stay fresh
t_h	The time that herring can stay fresh
C	The cost of fishing
s	The proportion of relocated vessels
P_h	The price of herring
P_m	The price of mackerel
W	Weight of fish caught
G	The gain of fishing

4 Fish Migration and Cost-Benefit Model

4.1 SST in the waters near Scotland

With global temperature increasing, SST increases along[11]. Under the assumed conditions, herring and mackerel originally growing near Scotland will migrate to low-latitude area. Small fishing companies have a fixed time for fishing, that is, the fishing season. Mackerel and herring are both shallow-water fish, and live in a fixed level in the sea. Therefore, the sea level temperature during the fishing season can be used to represent the suitable living temperature of mackerel and herring[5].

Here we take the mackerel as an example to carry out research:

Temperature Distribution: We chose a sea area in the northwest of Scotland as the research object. First, the local SST data in the past decades are used to predict the SST in the next 50 years. The table below is a data sheet of 65N-356E from 1982 to 2017:

Table 1: SST in March Changes with Years

Time/Year	1982	1983	1984	1985	1986	1987	1989
T/°C	3.52	2.64	2.19	3.85	4.06	3.62	3.66
Time/Year	1992	1993	1994	1996	1997	1998	1999
T/°C	3.4	3.09	3.22	3.26	2.48	2.03	2.51
Time/Year	2002	2003	2004	2006	2007	2009	2010
T/°C	3.64	4.4	3.94	3.03	3.27	3.42	2.89
Time/Year	2011	2012	2014	2015	2016	2017	
T/°C	3.11	3.22	3.80	3.70	3.58	4.58	

These data constitute unequidistant time series. We use the SARIMA(Seasonal Autoregressive Integrated Moving Average) model to predict the data for the next 50 years. Here is the simplified principle of SARIMA:

Suppose we have a sequence of length t whose period is s. So it is a seasonal-like sequence of periodic changes. To eliminate the periodic variation of the sequence, we define the seasonal difference operator as follows:

$$\Delta_s = 1 - L_s \tag{1}$$

Each value of the sequence is expressed as y_t, then the expression of a seasonal difference is:

$$\Delta_s y_t = (1 - L_s)y_t = y_t - y_{t-s} \tag{2}$$

After this operation, we successfully converted a non-stationary seasonal time series into a stationary time series.

So the expression of the seasonal time series prediction model is as follows:

$$\begin{aligned}(1 - \Phi_1 L - \cdots - \Phi_p L^p)(1 - \alpha_1 L^s - \cdots - \alpha_p L^{Ps})(\Delta^d \Delta_s^D y_t) \\ = (1 + \theta_1 L + \cdots + \theta_q L^q)(1 + \beta_1 L^s + \cdots + \beta_Q L^{Qs})u_t\end{aligned} \tag{3}$$

We defined some notations to simplify the equation:

$$\begin{aligned}\Phi_p(L) &= 1 - \Phi_1 L - \cdots - \Phi_p L^p \\ A_P(L^s) &= 1 - \alpha_1 L^s - \cdots - \alpha_p L^{Ps} \\ \Theta_q(L) &= 1 + \theta_1 L + \cdots + \theta_q L^q \\ B_Q(L^s) &= 1 + \beta_1 L^s + \cdots + \beta_Q L^{Qs}\end{aligned} \tag{4}$$

Note: d,D denotes the number of non-seasonal and seasonal differences.u_t denotes white noise. $\phi_p(L)$ denotes non-seasonal autoregressive operators. $A_p(L^s)$ denotes seasonal autoregressive operators. $\Theta_q(L)$ denotes non-seasonal moving average operators. $B_Q(L^s)$ are called seasonal moving average operators.

Using the notations above to simplify the original model, the formula is as follows:

$$\Phi_p(L)A_P(L^S)(\Delta_d\Delta_s^D y_t) = \Theta_q(L)B_Q(L^S)u_t \tag{5}$$

This is the equation we used to predict the SST. And by using the SARIMA model, we have obtained the SST data map at this point for the next 50 years, see Figure 1

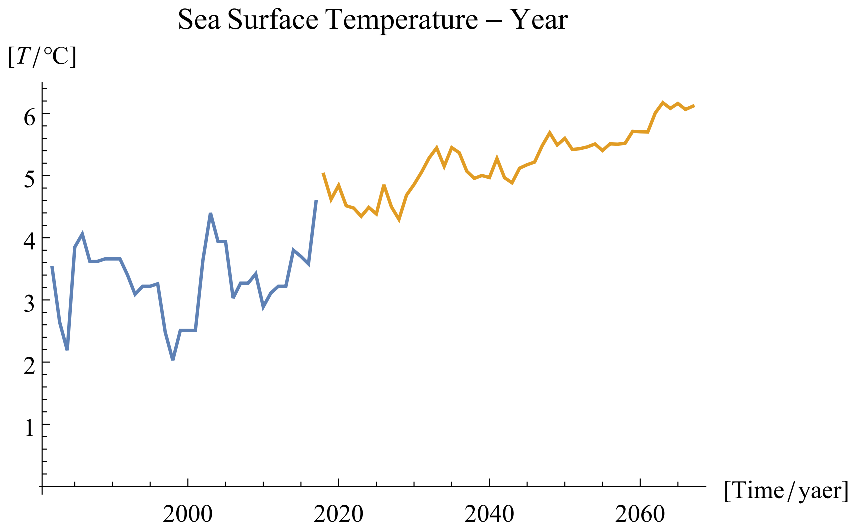


Figure 1: Predict SST in March over Next Fifty Years

The blue polyline represents the known data, and the yellow part represents the forecast data. It can be seen that SST approximately increases. In fact, we obtained the predicted $SST - C(n)$ for each year in the next 50 years[6]. For more obvious effects, we divided the data by ten years, and listed them in the following table:

Table 2: Predicted SST in March over Next Fifty Years

Time/Year	2027	2037	2047	2057	2067
T/°C	4.49777	5.07004	5.48091	5.50575	6.11749

Then, we studied the relationship between SST and longitude then latitude. And represented it with a binary function $T(x, y)$, in which T is SST, x is latitude, and y is longitude. Then, we applied the control variable method to calculate specific expressions of T. First, we fixed the longtitude to 356E, and studied the relationship between SST and latitude. Using the existing sea surface temperature data and the optimal square approximation method to obtain a specific function. The following table is data sheet of SST in 2017:

Table 3: SST Changes with Latitude in 2015

Latitude	59.97917	60.97917	61.97917	62.97917	63.97917	64.97917	65.97917
T/°C	8.48	7.52	6.9	6.12	3.2	3.7	3.72

Here, we need to simply explain the principle of the optimal square approximation method.

This method is to fit discrete data with generalized function families. Assuming that the unknown function $f(x)$ is a list function defined by some discrete data, we construct a generalized polynomial:

$$p(x) = c_0\Phi_0(x) + c_1\Phi_1(x) + \cdots + c_n\Phi_n(x) \tag{6}$$

We aim to choose coefficients to let:

$$\|p - f\|_2^2 \tag{7}$$

reach its minimum. And $c_0, c_1, \cdots, c_n$ are the parameters to be determined, and Φ_0, $\Phi_1, \cdots$, Φ_n are a known set of linearly independent functions. When $\|p - f\|_2^2$ reaches its minimum, $p(x)$ is written as an approximate expression of $f(x)$. $\|p - f\|_2^2$ is called the error function, and $p(x)$ is called the least squares fitting function.

By applying this method, we choose a family of generalized function $1, x, x^2, \cdots$. The fiting is as Figure 2

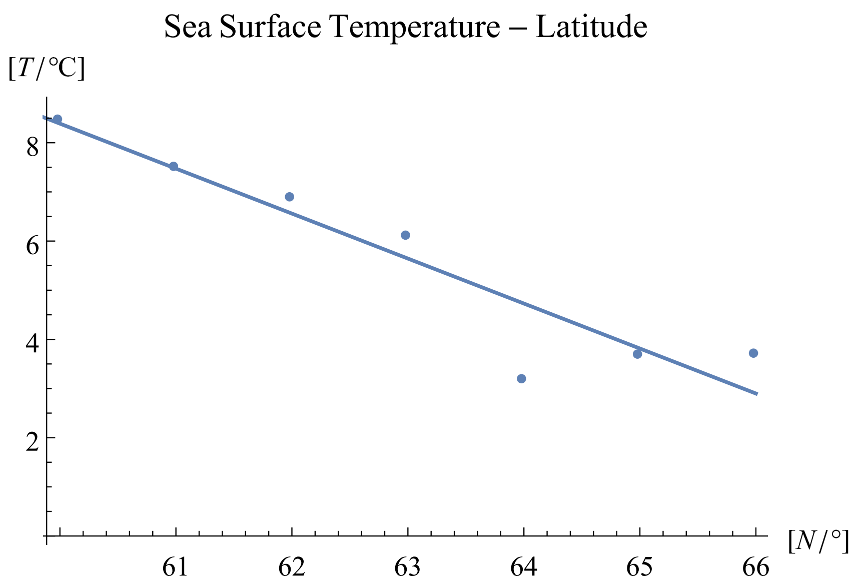


Figure 2: The Relationship between SST and Latitude

When the longitude is constant, the relationship between T_1 and latitude can be expressed as:

$$T_1 = 63.2888 - 0.915x, \chi^2 = 0.8741 \tag{8}$$

The χ^2 value means this fitting is effective.

Using the same method, we fix the latitude to 65N, and the result is as Figure 3:

When the latitude is constant, the relationship between T_2 and longitude can be expressed as:

$$T_2 = 10645.3 - 60.6803y + 0.86489y^2, \chi^2 = 0.9522 \tag{9}$$

So the approximate expression of $T(x, y)$ is:

$$T(x, y) = T_1(x) + T_2(y) = 10708.5888 - 0.915x - 60.6803y + 0.86489y^2 \tag{10}$$

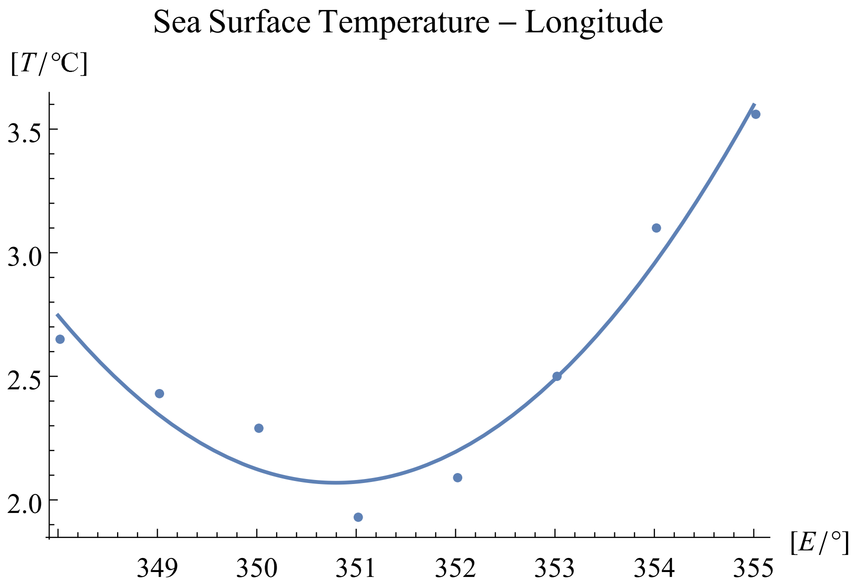


Figure 3: The Relationship between SST and Longitude

Based on a large amount of SST, we found that the distribution relationship between SST and latitude and longitude does not change over time. Therefore, we obtained the SST expressions in the studied area for the next 50 years:

$$T(x,y,n) = 10708.5888 - 0.915x - 60.6803y + 0.86489y^2 + C(n) \tag{11}$$

4.2 Herring and Mackerel's Migration

Suppose the current suitable activity position of mackerel is 59N, 355E, and the year is 2017. And we can calculate that SST is 9.25662^oC. According to the equation $T(x,y) = T_m$, we drew the isotherms in the Figure 4

$$x = -\frac{C(n) - 0.086489y^2 + 60.6803y - 10691.1}{0.915} \tag{12}$$

Similarly, Repeating the above process, we obtained the isotherm graph as Figure 5

$$x = -\frac{C(n) - 0.0092387y^5 + 16.2361y^4 - 11414.y^3 + 4011970y^2 - 7.0508610^8y + 4.95656 \times 10^{10}}{0.568571} \tag{13}$$

We reproduce the migration path of mackerel and herring on the map in the same proportion as Figure 6:

It can be seen from the figure that mackerel and herring will generally migrate in the northwest direction in the next 50 years, although there will be a phenomenon of southward movement for a short period of time[7]. According to effective estimates, the migration destination of mackerel and herring after 50 years are a sea area of 60N-61N and 353E-354E. The most likely migration location is near the territorial sea in the southwest of the Faroe Islands.

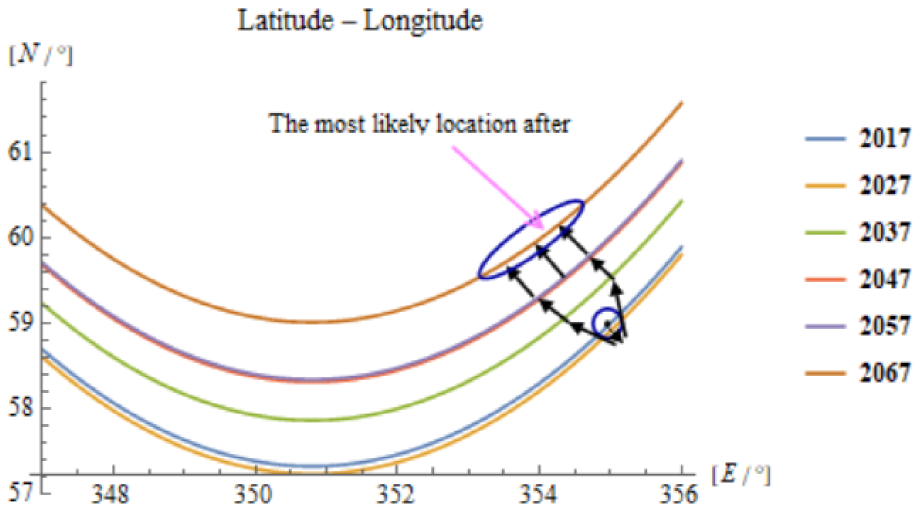


Figure 4: Imigration Path of Mackerel and the Isotherm

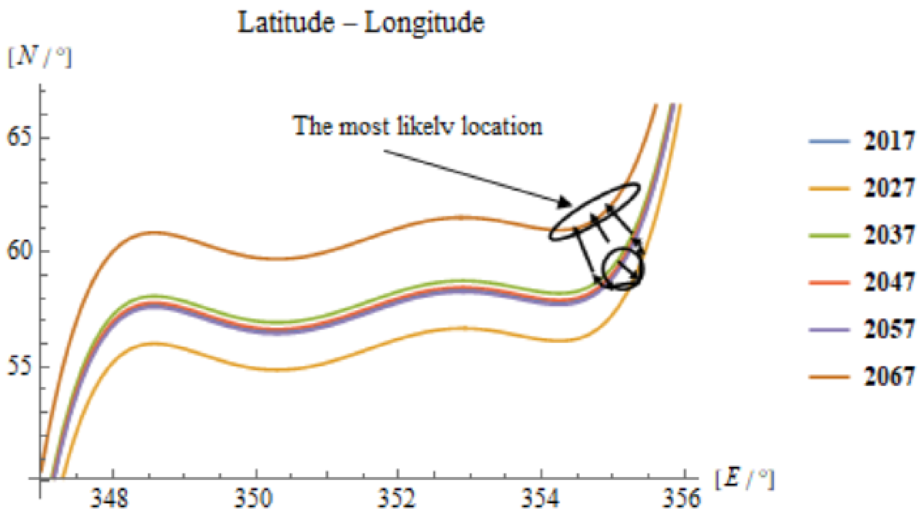
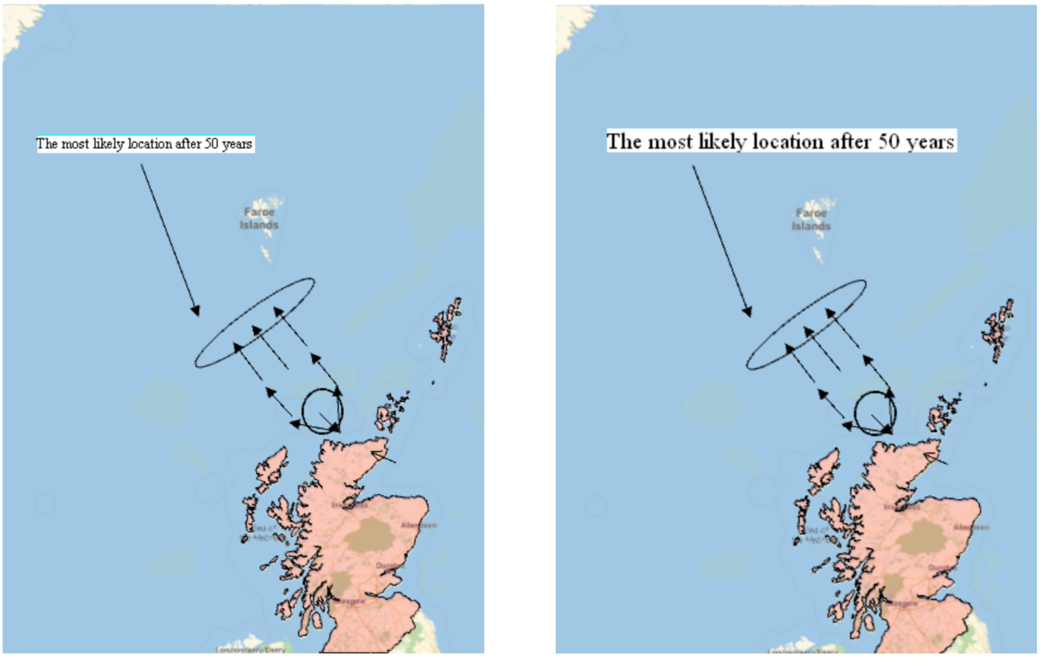


Figure 5: Imigration Path of Herring and the Isotherm



(a) The Imigration Path of Mackerel (b) The Imigration Path of Herring

Figure 6: The Imigration Path of the Two Fishes

4.3 The Most Likely Elapsed Times

In the first problem, we put fish in an ideal state, which means, they migrate to the sea area with the optimal living temperature every five years. But in fact, fish does not have such a keen sense, especially when the SST around the sea area where they live is not much different[?]. For fishermen, the further fish migrates, the more difficult it becomes for them to catch. To specify the problem, we define the best and worst cases:

- Best Case: Every five years, fish migrate to areas that are not too far from the optimal comfort temperature and are close to the starting point, and may even turn around and swim back.
- Worst Case: Every five years, fish migrate to areas that are not far from the optimal comfort temperature and are far from the starting point.

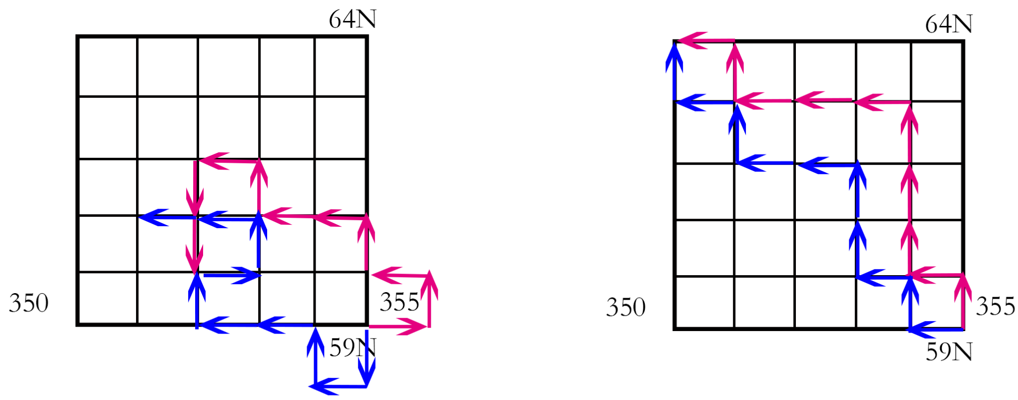
So we drew the migration path of two kinds of fish in two cases, as Figure 7:

Note:The red path is Mackerel. The blue path is herring.

In order to calculate the most likely elapsed time, we need to put some restrictions on the fishing conditions of the fish company. Because this is a small company, we can not use a large processing boat to follow the fishing boat to process the fish in time. So the fish will rot after being put in a boat for a period of time before the boat go back to a port.

According to (10), we can calculate the latitude and longitude of migration destination of herring and mackerel each year. So we can use the longitude and latitude of the port to calculate the distance between them: y_1 and y_2 are the latitudes of the port and fish, and x_1 and x_2 are the latitudes of the port and fish. Then the distance between them is:

$$d = R\arccos[\cos(y_1)\cos(y_2)\cos(x_1 - x_2) + \sin(y_1)\sin(y_2)] \tag{14}$$



(a) Imigration Path in Best Case

(b) Imigration Path in Worst Case

Figure 7: The Imigration Path in Two Cases

In the best and worst case in 50 years, the distance between the two fish locations and the port is as follows:

Table 4: Distance between Port and Settlement of Two Kinds of Fish

Distance/km	Best Case	Worst Case
Herring	283.49	388.75
Mackerel	320.12	392.99

Suppose in year X, in the best case, the distance between herring, mackerel and the port is $d_h^b(x)$, $d_m^b(x)$. And in the worst case, the distance between herring, mackerel and the port is $d_h^w(x)$ and $d_m^h(x)$. Let v be the speed of fishing boats, and the time of keeping fish fresh in December and March respectively is t_h and t_m. The conditions under which fishermen can catch fish are:

$$\begin{cases} d_h^b X \leq vt_h \\ d_m^b X \leq vt_m \\ d_h^w X \leq vt_h \\ d_m^w X \leq vt_m \end{cases} \tag{15}$$

Take the first formula 15 as an example. In the best case, herring keeps migrating away from the port. When a certain year is reached, after the fishermen have caught the fish, they are too far away from the port to rush back before the herring begins to decay. This year is the most likely elapsed year required in the problem.

For the remaining three cases, their most likely elapsed times can be calculated in the same way.

Table 5: The Most Likely Elapsed Times in Two Cases

Year	Best Case	Worst Case
Herring	1963	1939
Mackerel	1955	1938

4.4 Cost-Benefit Model

To ensure the freshness and quality of the fish, small fishing companies without refrigeration equipment on board can only conduct offshore fishing. Due to the migration of fish, the number of fish that can be caught is getting smaller and smaller. If small fishing companies do not take measures, the income from fishing will be less, which will also have a significant impact on the fishing industry in Scotland. Based on the predictions of the above model, we considered the measures that fishermen can take in this, and analyzed these measures to select the best response strategy for fishermen.

Consider two possible actions:

- The fishing company in this port can partially or completely transfer the company's assets to the fish migration status, and can even set up a simple sea transfer station to keep the fish caught fresh and store them.
- Lease or purchase small ocean fishing vessels with refrigeration equipment, so that fishermen can catch fish in faraway seas, while ensuring the freshness and high quality of fish.

4.4.1 Measure1

Based on the previous model, we found that if small fishing companies stay in place, the cost of fishing will become higher and higher, until a certain year, they will not catch fish at all. To this end, there must be some fishing boats that have been docked relatively close to the migration location of the fish. In the first question, the initial point of fish we chose is 59N, 355E. The nearest port is the Port of gill bay. Therefore, the company should gradually transfer all its fishing boats to the Port of gill bay, but not all of them at one time, otherwise the cost is too high for small companies to bear.

Cost Suppose the company can transfer S fishing boats in year X (say the company has a total of 100 boats) to Port of Gill Bay, then we can calculate the company-wide fishing costs in year X.

$$C = 100gp \times df + (100 - s) \times gp \times de \tag{16}$$

gp is the fuel cost per kilometer, df is the distance from the port to fish, and de is the distance from the original company address to the current port.

A small fishing boat consumes 1 liter of diesel every 372 seconds. Let the density of diesel be ρ, then the formula for calculating gp is:

$$gp = \frac{3600p \times \rho}{372v} \tag{17}$$

So the fishing cost calculation formula is:

$$C = \frac{3600p \times \rho}{372v}[100df + (100 - s) \times de] \tag{18}$$

At the same time, the number of fishing boats transferred in year X is related to the migration position of fish. The overall migration of fish to the north can be regarded as the part of them that moved to the far north of fish. So the company only needs to transfer a part of the fishing boat to catch this part of fish. In summary, we can use the ratio of the migration distance of fish and the distance between the port and the original address as the percentage of the fishing boat transferred by the company.

$$S(X) = \frac{100d(fish\ location\ of\ year\ X,\ original\ location)}{d(new\ port,\ original\ address)} \tag{19}$$

Obviously, after a period of time, the numerator will be greater than the denominator, and this time point is the time when the company will move all fishing boats to the new port. Consequently the previous formula can be simplified to:

$$S(X) = \frac{100d_1(X)}{d_2(X)} \tag{20}$$

Substitute it into the cost calculation formula and we have:

$$C(X) = \frac{360000p \times \rho}{372v}[df + \frac{1 - d_1(X)}{d_2(X)} \times de] \tag{21}$$

After the fishing boat was transferred to the new port, because fish moved farther and farther, it was not enough for the fishing boats to go out only once and ensure that it could return before the fish rots. Our suggestion is to use the company's ship that can keep freshly caught fish independently at sea as a transit point for fishing vessels. After the fishing boat finishes fishing every day, the fish can be stored nearby at the transfer station. After 15 days (the rotation cycle of the personnel), the port sends another boat to transport the saved fish back, and at the same time, changes the staff with the transfer station. The whole process is as Figure 12

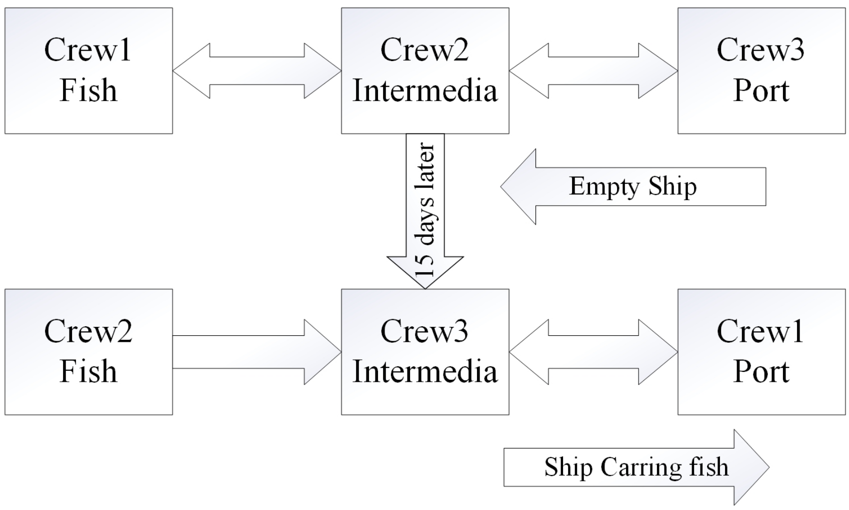


Figure 8: The Process of transfer station

After 40 years, the fish migrated farther. At this time, more than one transfer station is needed, but the process is similar:

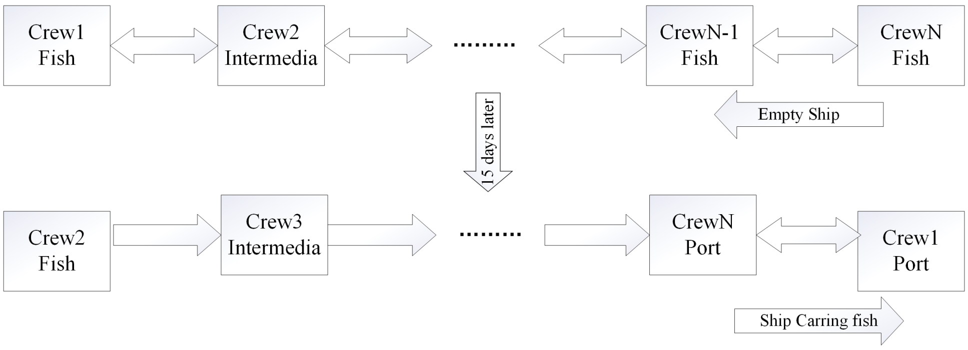


Figure 9: The Process of Many transfer station

After joining the transfer station, the cost of fishing for each boat needs to be added with the cost of operating the transfer station and the fish carrier. The expression of fishing cost is modified as:

$$C = \frac{360000p \times \rho}{372v}[df + \frac{1 - d_1(X)}{d_2(X)} \times de] + m \times P_r + T_c \tag{22}$$

Benefits Suppose the prices of herring and mackerel are P_h and P_m. A boat can catch up to $W(kg)$ fish a day. Therefore, the average daily fishing income of a boat during the fishing season is:

$$G = W \times \frac{P_h + P_m}{2} \tag{23}$$

In summary, the daily net income of each fishing boat is:

$$G_0 = W \times \frac{P_h + P_m}{2} - \frac{360000p \times \rho}{372v}[df + \frac{1 - d_1(X)}{d_2(X)} \times de] + m \times P_r + T_c \tag{24}$$

Calculating the data, we found that after switching to the new port, the net income of each fishing boat is still \$8113.7 per day, and the company should switch to the new port.

4.4.2 Measure2

Cost Consider the cost of a fisherman going out in two parts:

Cost of Purchasing a New Fishing Boat C_v Use the monthly depreciation D of each fishing boat to represent the monthly cost C_1 of leasing or purchasing a fishing boat. The price of a small ocean-going fishing boat is about P_v. Assuming the useful life is T_v years, taking the net residual value of N_v into account[10], depreciation is calculated by the straight-line method, and the monthly depreciation should be accrued, that is, its cost can be expressed as:

$$Cv = D = \frac{P_v - N_v}{12T_v} \tag{25}$$

Fuel Cost The annual fuel consumption Q_0 of a fishing boat is related to the total weight W_v of the fishing boat and the main engine power P. Related data show that the fuel consumption coefficient of fishing vessels is 0.2296 (t/km). We can calculate the annual fuel consumption of fishing vessels from the fuel consumption formula of ocean-going cruise ships:$Qo = 0.2296W_v \times p$ Then the cost of fuel going abroad each month:$C_f = Q_0 \times gp/12$. So the total Cost is:

$$C = C_f + C_v \tag{26}$$

Assume that the specifications of a fishing boat that a small fishing company is considering buying are as follows:

Table 6: Parameters of The Vessel

Weight of the vessel	Load	Main engine power	Price of the vessel
810t	1200t	3.5kw	$800,000

As calculated, the total monthly cost of purchasing an ocean fishing boat is $Ct = 2.759 \times 10^5$ (Labor costs are too low compared to the above two costs and are not considered[1])

Benefits From the prices of herring and mackerel P_h, P_m and the monthly fishing volume Wkg, the monthly income of fishing in the fishing season can be calculated as:$G_h = P_h \times W = 8.97 \times 10^5$, $G_m = P_m \times W = 5.92 \times 10^5$

In summary, the monthly net income of each fishing boat is $G_m = 10054$

According to calculation, $Gm > 0$, indicating that fishing companies are profitable when buying offshore fishing vessels, and this measure can be taken; With $G_m > 30G_0$, it is more profitable to purchase ocean-going vessels than to build a sea transfer station to change fishing sites. However, considering that the purchase of fishing vessels requires a lot of financial support and high barriers to entry, we measure the capital strength of the fishing company's current assets C_A:

- If $C_A < P_v$, the company can choose measure one.
- If $C_A > P_v$, the company should take action two.

4.5 Impact of Migrating to High Seas

Based on the SST prediction model, if this trend develops, herring and mackerel will continue to migrate northward until they completely leave the Scottish waters and even enter the territorial waters of other countries. Herring and mackerel are predicted to enter the Faroe Islands at around year 2067, the territorial waters of Denmark. In the territorial waters of other countries, vessels are only allowed to pass harmlessly. Scottish fishermen can not fish without permission, otherwise they will be considered illegal fishing.

Therefore, in the process of herring and mackerel gradually entering the territorial sea of other countries, the number of fish that can be caught will be smaller and smaller, and the distance will be further and further, which will have different impacts on the fishermen who take different measures in the above analysis.

For fishing companies that change their fishing locations, because the time and place of changing locations are based on a comprehensive consideration of fish distribution and cost, and due to the migration of fish schools, the fewer needed support provided by land ports becomes, the more expensive it is to build a transit station. Small fishing companies are also facing higher cost inputs.

For fishing companies that purchase offshore equipment, their fishing locations and equipment are more flexible. After purchasing equipment, they no longer need to generate a large amount of fixed capital investment. Therefore, compared with the construction of transit stations, it has more economic benefits. However, as fish getting further and further, the larger cost of fuel consumed by ocean fishing will be, Until all of their incomes are used to support off-land fishing. The net profit will reduce to 0.

In this case, we have made two new proposals for the Scottish Fishing Company for their reference:

- Develop offshore fishing industry and expand fishing scope. Scotland is surrounded by the sea on three sides, and the area available for fishing is vast, and fish entering other countries' territorial waters are only part of it. The small fishing methioned above companies are limited by funds and technology and can not afford the costs of fishing in farther and wider seas. Therefore, if Scotland concentrates on the development of large-scale offshore fishing industries, so that fishing companies can obtain sufficient financial support to expand the scope of fishing. It can effectively reduce the impact of fish migration on the longevity of the fishing industry.
- Switch herring and mackerel fishing to other marine creatures. As the rise of SST is a global trend, while Scottish herring and mackerel are gradually moving northward to make fishing more difficult, some warm-temperature creatures may migrate into Scottish waters, and fishing companies can shift fishing targets in a timely manner to make up for the economic loss of Scottish fishing caused by the migration of two major fish species[9].

5 Sensitivity Analysis

In the process of solving the problem, we have established many different models. For different models, we will set different factors for sensitive analysis:

5.1 Impact of Environment Sudden Factors on SARIMA

First, in the SARIMA temperature prediction model, environmental sudden factors will have a certain impact on the prediction results of the model. This includes the convergence of cold and warm currents, the effects of temperature chambers, and the policies in different countries on environmental protection[2]. We can not consider the factors above one by one. For the SST forecast in the next 50 years, we consider a certain range of fluctuations, and then obtained a 95% confidence interval. The graph below simplifies this impact:

Through the diagram, we can find that in the normal development, the temperature change will not produce too much bias, and our prediction model has a certain reference value.

5.2 Impact of time on temperature-longitude-latitude fitting model

In fact, the fishing season of mackerel and herring is fixed every year, because the earth revolves around the sun and repeats its movements on a yearly basis. This indicates that the climatic conditions of a certain location on the earth are similar at a fixed date, which further indicats that the relationship between temperature and longitude, latitude should be consistent in

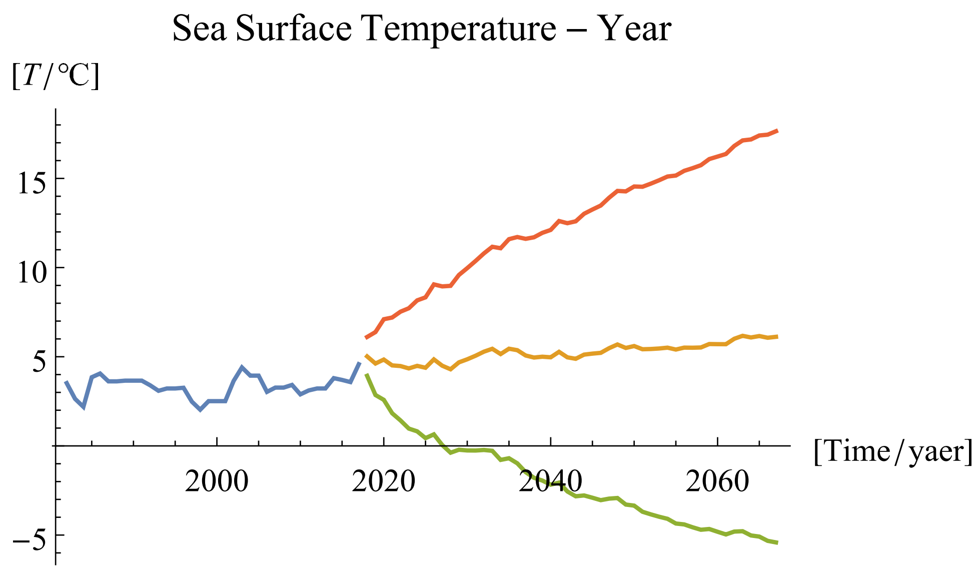


Figure 10: Confidence Interval of SST prediction of March

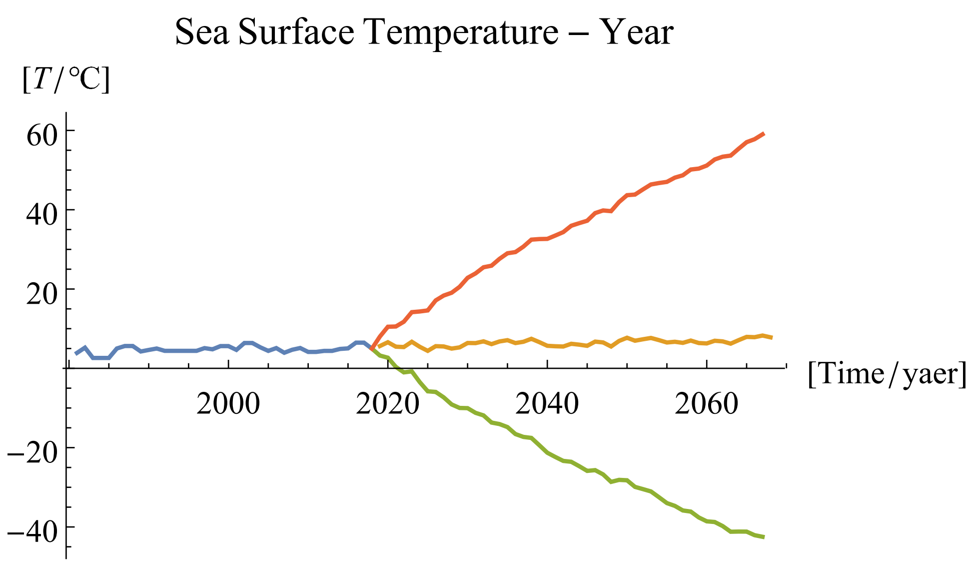


Figure 11: Confidence Interval of SST prediction of September

a certain area. And the specific SST of the computer test also confirmed our inference. Based on the above analysis, we can obtain that time has little effect on the temperature-longitude-latitude fitting model, and the model is reasonable.

5.3 Impact of Uncertainty in Migration Direction on the Most Elapsed Times

In the model, we chose the SST every five years. For simplicity, we let herring and mackerel migrate in a certain direction. But the fact is that they do not swim towards a fixed direction, but change their direction at any time according to the temperature. So each migration will not be an arrow, but a smaller fan-shaped area:

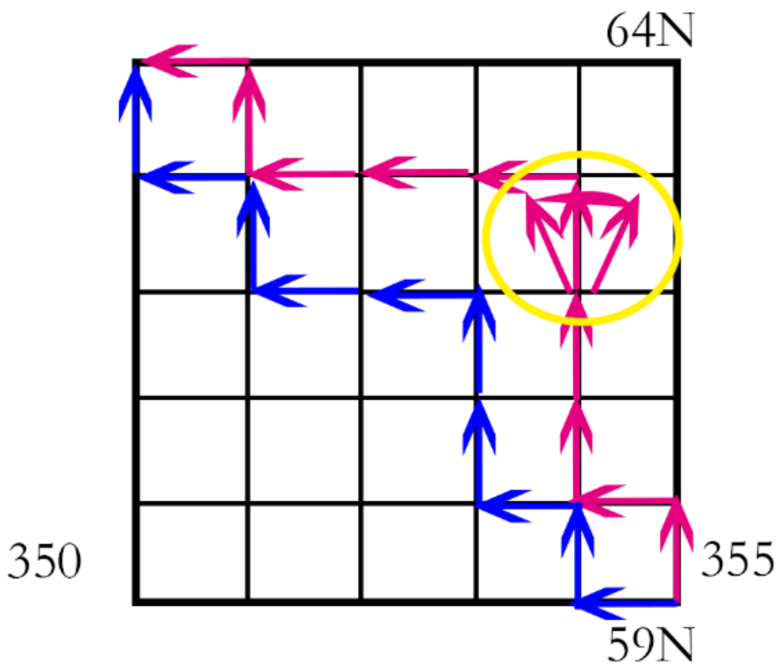


Figure 12: The Uncertainty in Migration Direction

This will result that the actual destination and the model calculation will differ by 0.5 longitudes or 0.5 latitudes, but the general migration direction is consistent, and the most elapsed time may be advanced or delayed by one year.

5.4 Impact of Price Changes on Costs and Benefits of Fishing

In the fish company's cost-benefit model, the price of fuel and fish is uncertain, but we can only take the average price over a period of time instead. In real life, the cost of fishing will increase significantly due to rising global oil prices. However, the rise in oil prices will drive other prices up. When the price of fish meat also rises, the company's final earnings will not be affected much.

6 Model Evaluation and Further Discussion

6.1 Advantages

- Our model is based on real data provided by NOAA (National Oceanic and Atmospheric Administration), which means it is closer to the real world, and predictions made from them are more accurate.
- The seawater temperature model applies the optiumal square approximation method to establish the relationship between temperature and longitude, latitude. It can quantitatively calculate the SST corresponding to any longitude and latitude in the area we chose. When used to predict temperature changes in the next 50 years, it is flexible and strongly practical.
- When studying fish migration routes, we set reasonable assumptions, and divided complex sea areas into grids according to longitude and latitude, and considered the best and worst cases to calculate the most elapsed year separately, making the analysis of the model more concise and Clear. And finally through sensitivity analysis, we verified the stability of the model.
- The cost-benefit analysis method is used to consider the measures taken by fishing companies to cope with fish migration. Combining long-term economic factors and the implementability of measures, we gave different suggestions to different groups.

6.2 Disadvantages

- Our model is an idealized model. We have only considered the impact of temperature changes on the habitat of mackerel and herring. In fact, in real world, factors such as oxygen content of seawater and bio-nutrition structure will also affect the migration of herring and mackerel. Therefore, the model has Certain limitations.
- In order to simplify the model and make it operable, we make some assumptions about it and make predictions based on existing data. However, considering the increasing awareness of ocean protection in the future and the impact of glaciers melting and ocean currents, the accuracy of model predictions will be affected.

6.3 Further Discussion

In this article, we analyzed the effects of changes in SST on the migration of herring and mackerel near Scotland. If we add some new variables to our models, like the seawater oxygen content and the response of other marine creatures who eat or are eaten by herring and mackerel, we can more accurately predict the migration route of the two fish and their future habitat conditions.

In addition to studying the migration of herring and mackerel, the model of sea temperature we established is also suitable for predicting the migration of other marine species in response to SST changes and providing data support for future fishery development and marine biological research[3].

7 Article

(See the next two page.)

Make Changs to Fishery Management

Team#2008996

I. Introduction

Since the Industrial Revolution, global warming caused by human activities such as the burning of fossil fuels has become an indisputable fact, which has had a huge impact on many aspects of our lives , one of which is the fishing industry.

For Scotland, a fishing ground formed by the confluence of the North Atlantic Warm Current and the East Greenland Cold Current from the Arctic . Fishermen living in northern Scotland catch two types of fish: herring and mackerel. According to the actual situation, the flood season of herring and mackerel is December and March. According to the reality, we set fish a most suitable temperature for herring and mackerel. At this temperature, they multiply faster and it is convenient for local fishermen to catch. However, due to the global warming, which has led to rising ocean temperatures, the North Atlantic Ocean's waters close to Scotland are no longer suitable for them to live. So, herring and mackerel will migrate to the north, where the sea surface temperature is slightly lower than the original place. So what will the migration path of herring and mackerel look like in the next 50 years? What impact will it have on the lives of local fishermen?

II. Impact

Our team has done a series of researches on this subject in combination with mathematics, physics, ecology, etc. By establishing the SARIMA temperature-time prediction model, temperature-longitude and temperature-latitude model, we have reached the following conclusions:

- In the next 50 years, occasionally in a few years the sea surface temperature will drop, but it rises in the most of the time.
- Herring and mackerel will gradually migrate towards northwest, and reach the sontheast side of Faroe group islands at year 2069 as expected.
- If the fishermen do not do any measures to deal with this phenomenon. As the worst case predicted, in the year 2039, herring and mackerel will both be out of the range that local fishermen can reach.

Mackerel and herring are gradually moving away from the island of Scotland, so for fishermen on the Scotland island, if they want to maintain the previous catch, they must be farther away from the port. Therefore the consumption of fuel and the need of fresh-keeping technology will increase, which means the operating costs rises every year correspondingly. What is more worse? At the sea area far from the coast line in the North Atlantic, unlike the temperate climate in coastal areas, fishermen are more likely to encounter bad weather. Of course they will bear more property damage and loss of human resources.

III. Sugestions

In order to minimize the loss of fishermen, our team established a cost-benefit optimization model and analyzed the impact of different business strategies on the fishing industry. Our sugestions to fishermen and fishing companies are as follows:

- Relocate the port. Gradually transferred the boats to PORT of Gills Bay in northernmost Scotland in order to reduce round-trip time, consequencely fuel cost.
- Establish transafer ships at sea transit point. Fishermen should send slightly larger vessels for keeping fish fresh and temporary storage, so that fishing boats only need to store fish in the transfer station every day. After a period, people in the port should send a special boat to transfer station to transfer the stored fish back to the port.
- Reconstruct fishing equipment to catch other fish. As herring and mackerel move north, other fish originally clustered in southern Scotland will move north near Scotland, and fishermen should pay attention to this new economic source.

All in all, the loss of the fishing industry caused by global warming is caused by human beings. We sincerely hope that all human beings can act actively to this combat with global warming. It is the longest and most effective way to solve this problems.

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Appendices

Appendix A Supplementary Data and Figures

Table 7: SST Changes with Longitude in March 2015

Latitude	348.021	349.021	350.021	351.021	352.021	353.021	354.021	355.021
T/°C	2.65	2.43	2.29	1.93	2.09	2.5	3.1	3.56

Table 8: SST Changes with Years

Time/Year	1981	1982	1983	1986	1987	1989	1990
T/°C	3.89	5.22	2.62	5.01	5.63	4.25	4.64
Time/Year	1991	1992	1997	1998	1999	2001	2002
T/°C	5	4.41	5.1	4.8	5.61	4.65	6.39
Time/Year	2004	2005	2006	2007	2008	2009	2010
T/°C	5.3	4.4	5.11	3.93	4.69	5.13	4.14
Time/Year	2012	2014	2015	2016	2018		
T/°C	4.4	4.89	5.03	6.48	4.97		

Table 9: SST Changes with Longitude in 2015

Longitude	355.021	354.021	353.021	352.021	351.021	350.021	349.021	348.021
T/°C	6.05	5.47	5.4	5.77	4.51	4.81	5.1	4.85

Table 10: SST Changes with Latitude in 2015

Latitude	59.9792	60.9792	61.9792	62.9792	63.9792	64.9792	65.9792
T/°C	9.23	7.92	7.92	7.77	6.4	6.48	5.39

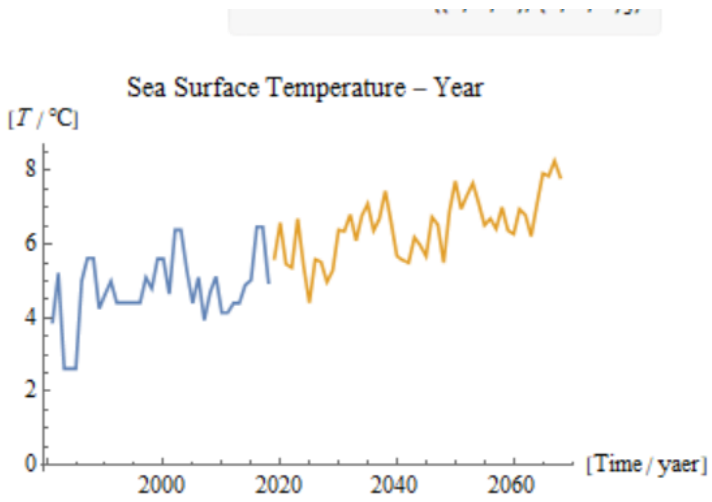

Figure 13: Predict SST in September over Next Fifty Years

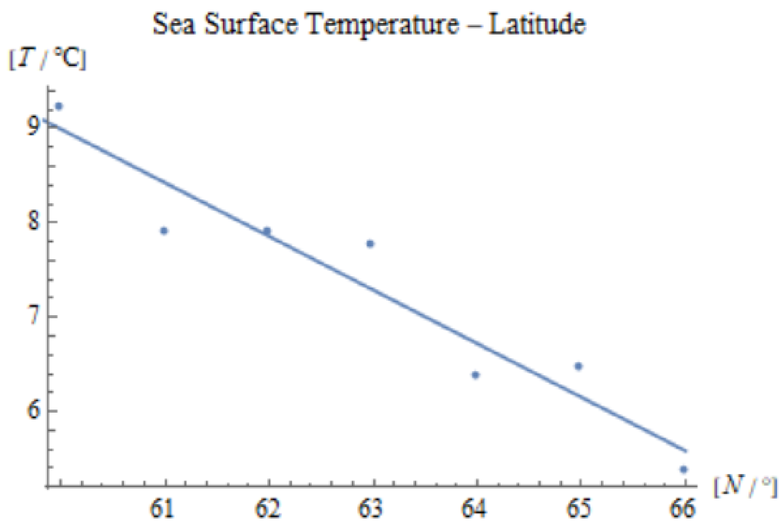

Figure 14: The Relationship between SST in September and Latitude

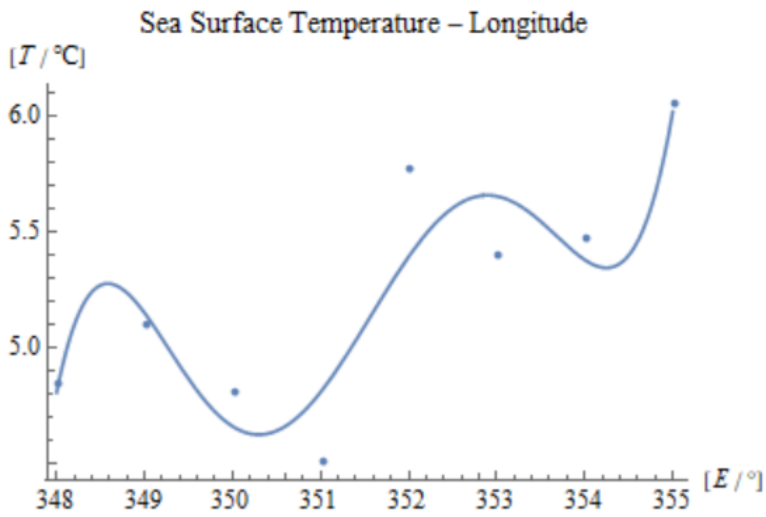

Figure 15: The Relationship between SST in September and Longitude

Appendix B Codes

Take mackerel for example, herring is similar.

Input Mathematica source:

```
data1 = {{1982, 3.52}, {1983, 2.64}, {1984, 2.19}, {1985, 3.85}, {1986, 4.06},
{1987, 3.62}, {1989, 3.66}, {1992, 3.4}, {1993, 3.09}, {1994, 3.22}, {1996, 3.26},
{1997, 2.48}, {1998, 2.03}, {1999, 2.51}, {2002, 3.64}, {2003, 4.4}, {2004, 3.94},
{2006, 3.03}, {2007, 3.27}, {2009, 3.42}, {2010, 2.89}, {2011, 3.11}, {2012, 3.22},
{2014, 3.8}, {2015, 3.7}, {2016, 3.58}, {2017, 4.58}};
tsm = TimeSeriesModelFit[data1, {"SARIMA", {{2, 1, 2}, {4, 0, 2}, 5}}]
ListLinePlot[{tsm["TemporalData"], TimeSeriesForecast[tsm, {50}]},
AxesLabel → {RawBoxes[RowBox[{"[", RowBox[{"Time", "/", "yaer"}], "]"}]],
RawBoxes[RowBox[{"[", RowBox[{T, "/", ""}], "]"}]]},
PlotLabel → HoldForm[SeaLevelTemperature − Year],
LabelStyle → {FontFamily → "Times New Roman", 12, GrayLevel[0]}]
```

TemporalData : .

TimeSeriesModel [□]

```
Do[Print[tsm[2017 + 10 * n]], {n, 1, 5}]
```

4.49777

5.07004

5.48091

5.50575

6.11749

data2 = {{59.97917, 8.48}, {60.97917, 7.52}, {61.97917, 6.9}, {62.97917, 6.12},
{63.97917, 3.2}, {64.97917, 3.7}, {65.97917, 3.72}};
n = Fit[data2, {1, x}, x](*R^2 = 0.8741*)
Show[ListPlot[data2], Plot[n, {x, 59, 66}],
AxesLabel → {RawBoxes[RowBox[{"[", RowBox[{"Time", "/", "yaer"}], "]"}]],
RawBoxes[RowBox[{"[", RowBox[{T, "/", ""}], "]"}]]},
PlotLabel → HoldForm[SeaLevelTemperature − Year],
LabelStyle → {FontFamily → "Times New Roman", 12, GrayLevel[0]}]

$63.2888 - 0.915x$

data3 = {{348.02084, 2.65}, {349.02084, 2.43}, {350.0208, 2.29}, {351.0208, 1.93},
{352.0208, 2.09}, {353.0208, 2.5}, {354.0208, 3.1}, {355.0208, 3.56}};
w = Fit[data3, {1, x, x^2}, x](*R^2 = 0.9522*)
Show[ListPlot[data3], Plot[w, {x, 348, 355}],
AxesLabel → {RawBoxes[RowBox[{"[", RowBox[{"Time", "/", "yaer"}], "]"}]],
RawBoxes[RowBox[{"[", RowBox[{T, "/", ""}], "]"}]]},
PlotLabel → HoldForm[SeaLevelTemperature − Year],
LabelStyle → {FontFamily → "Times New Roman", 12, GrayLevel[0]}]

$10645.3 - 60.6803x + 0.086489x^2$

$$f = 63.2888 - 0.915x + 10645.3 - 60.6803y + 0.086489y^2$$

$10708.6 - 0.915x - 60.6803y + 0.086489y^2$

Plot3D$[f, \{x, 59, 66\}, \{y, 348, 355\}]$

(*59 355*)

$a[\mathrm{x\_}, \mathrm{y\_}] = \mathrm{tsm}[2017] + 0.915 * 65 - 0.915 * x + 60.6803 * 356 - 0.086489 * 356\text{^}2-$

$60.6803y + 0.086489y^2;$

$a[59, 355]$

9.25662

Plot[

$\{x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2017]))/(-0.915),$

$x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2027]))/(-0.915),$

$x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2037]))/(-0.915),$

$x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2047]))/(-0.915),$

$x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2057]))/(-0.915),$

$x =$

$(a[59, 355] - (0.915 * 65 + 60.6803 * 356 - 0.086489 * 356\text{^}2 - 60.6803y + 0.086489y^2+$

$\mathrm{tsm}[2067]))/(-0.915)\}, \{y, 347, 356\},$

PlotLegends → {“2017”, “2027”, “2037”, “2047”, “2057”, “2067”},

AxesLabel → {RawBoxes[RowBox[{“[”, RowBox[{W, “/”, “°”}], “]”}]], RawBoxes[RowBox[{"[", RowBox[{N, "/", "°"}], "]"}]]},

PlotLabel → HoldForm[Latitude − Longitude],

LabelStyle → {FontFamily → "Times New Roman", 12, GrayLevel[0]}]

GeoGraphics [{EdgeForm[Black], FaceForm[Red], Polygon []} ,

GeoRange → {{55, 65}, {−15, 0}}]