Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
A		2001958

Habitat Migration Model of Herring and Mackerel Based on Markov Chain

Summary

Global ocean temperature change can affect some habitat range and location of Marine organisms, this paper quantifies the change of ocean temperature by applying the linear regression equations with white noise, and classifies the influencing factors of fishery companies' decision about updating ships. Also, a specific model, namely"Habitat migration model based on Markov transition probability matrix", is adopted to investigate the future tendency of ocean temperature change. In addition, some methods are suggested to improve the management of fishery companies.

On the first problems, after the mean SST over the past ten years has been meshed, a linear regression model is recommended to predict the mean SST of the grid in 2069, and the voting method is explored to establish the Habitat Suitability Index model. Based on this, the Markov Chain is undertaken to simulate the migration of fish populations in the grid based on transition probability matrix. The results of the model are shown that in the future, the fish will leave their current habitat for warmer temperatures, and the habitat of fish populations in the next 50 years will move far north from the waters around Scotland.

Conducting a study on the second problem, assume the fresh-keeping period as the limiting factor of the fishing vessel's voyage distance. Then the longest route model is established to investigate the fishing vessel route .By changing the step number of the transition probability matrix, the number of fish in the intersection of fishing range and habitat range with different migration degrees are estimated, also the shortest or longest time for the fish to exceed the fishing range. The results show that between 2039 and 2063, it is likely that the vast majority of fish will leave inshore fishing zones.

When it comes to the last problem, in the face of different extent fish populations of north marching into other countries territorial waters, even lack of ability of small fishingcompanies can attempt two ways, to add refrigeration equipment to small fishing boats or replace with large fishing boats to strengthen the fishing capacity. And NPV is used to evaluate the profitability of the two improvement strategies under different circumstances. The possibility of establish ocean ports is considered as well.

Contents

1 Introduction

1.1 Problem Background

As global ocean warm up, some sea creatures, such as Scottish herring and mackerel, will migrate to other habitats that are more suitable for them to live and breed. However, the changes in the distribution of these two important economic fish populations may seriously affect their current habitat, the fishery economy in Scotland.

1.2 Problem Restatement

Try to establish a mathematical model to solve the following problems:

(1) Assuming that the water temperature will change a lot that the habitats of herring and mackerel populations will migrate, try to determine the habitat changes of these two species in the next 50 years.

(2) If those small fishing companies that do not have refrigeration equipment on their fishing vessels keep fishing at their current location, predict the minimum or maximum time required for these two species to exceed their fishing zone.

(3) Analyze whether these small-scale fishing companies should change their business methods and give reasons for changing their strategies or maintenance.

(4) What would happen to the scheme described in (3) if the future habitats of the two species of fish were to enter the territorial sea(oceans) of other countries.

Also prepare an article to help the fishermen understand the seriousness of the problem and how the solutions described in (3) will improve their future business prospects.

1.3 Our Work

1. **Analysis of problem I:** Firstly, the sea area around Scotland is selected as the research object, and it was divided into grids at a certain time scale and horizontal spatial scale. The linear regression equation and white noise are used to predict the annual mean SST in certain grid in the next 50 years. Then, combining environmental factors such as temperature and the distribution of fish volume, the habitat Suitability Index was established to describe the migration rule of fish populations in each grid. Based on the certain Habitat Suitability Index, the transfer probability of all grids and their adjacent grids is given, and a one-step transfer matrix is obtained to simulate the migration of the fish population in the habitat after 50 years through the transfer between the grids.

2. **Analysis of problem II:** Due to the lack of refrigeration equipment, two types of fish preservation periods were used to establish a fishing route model for the limiting factors of fishing vessel mileage, and the coastal fishing range of small Scottish fishing companies was delineated. At the same time, by changing the step number of the transfer matrix, the habitat range of fish population under different migration degrees was obtained. Calculate

the intersection area between the fishing range and the habitat range under different migration levels, and then calculate the minimum or maximum time required for the fish to exceed the fishing range.

3. **Analysis of problem III:** Due to the depletion of offshore fish stocks at the earliest 30 years, it is recommended for small fishing companies with insufficient capacity to increase production capacity by adding refrigeration equipment or replacing large fishing vessels. NPV, an economic index commonly used in "Economic Evaluation of Transportation Infrastructure Projects" in transportation economics, was used to evaluate the profitability of two management improvement strategies, and providing data support for the decision-making of small fishery companies.

4. **Analysis of problem IV:** If part of the habitat of two species of fish enter the territorial sea(ocean) of other countries, it not only mean that these fish stocks will be completely lost, but also means that the habitats of the fish species have migrated over a long distance. The challenge facing small fishing companies will be even more serious. Therefore, the possibility of establishing an ocean port is also considered while the two operation improvement strategies in III are re-evaluated.

5. **An overview of the letter to fishermen:** Firstly, the background knowledge of global warming was popularized to fishermen, and then the results of our model predictions were explained. Under the influence of global warming, with the continuous rise of annual SST, we have reason to believe that herring and mackerel, two important economic fish, will move northward on a large scale in the recent 50 years. It may even be possible to face the depletion of fish resources near the sea in just 30 years, which will cases a catastrophe to small fisheries companies. To make fishermen realize that if they don't update their business method, they will suffer economic losses for the foreseeable future. Then explained to the fishermen the benefits can be brought by the upgrading of the fishing boats, and used economic analysis indicators to dispel some fishermen's concerns that investment was difficult to protect. Finally, fishermen are called on to save energy and reduce emissions, not only to protect their future income, but also to contribute to global environmental protection.

2 Preparation of the Models

2.1 Assumptions

- Suppose the habitat adaptation of fish populations was only related to sea temperature.
- Suppose there is no artifical disturbance to the movement of fish populations in the next 50 years.
- Suppose the trend of global sea temperature in the future remains unchanged.
- Suppose the vertical lines of small fishing boats without refrigeration equipment are within 10 meters.
- Suppose the coastline of Scottish fishing ports is uniform and densely distributed.
- Suppose the fishing company has a stable capital chain, it has the ability to upgrade and replace fishing vessels.

2.2 Notations

The primary notations used in this paper are listed in **Table 1**.

Table 1: Notations

Symbol	Definition
SST	Sea surface temperature.
$diff_i$	Poor SST of grid sample i.
$rand$	Uniformly distributed random numbers from 0 to 1.
C_i	Annual fishing yield of grid i.
TAC_{zone}	Total annual catch by sea area $zone$.
$vessle_i$	Number of ships per year in grid i.
ISI	Suitability index of SST.
Ci	Fishing production of grid i.
$Cmax$	Maximum fishing production in each grid.
$Tickets$	The number of votes in voting scheme.
X	Mean annual SST of each grid.
a,b,c	Estimate parameters.
H_{SI}	Habitat suitability index.
$h_{i,j}$	H_{SI} of (i,j).
$P_{i,j}$	Probability of moving from position i to position j when move one step once.
P	Main engine power of fishing vessels.
L	Length between perpendiculars.
Δ	Vessel displacement.
t	Year number.
CI	Annual income of a single fishing vessel.
OI	Annual expenditure per fishing vessel.
i	Discount rate.

3 Model of Part I

3.1 Determine grid range and its division time as well as horizontal space scale

According to *scottish-sea-fisheries-statistics-2018* in the official website of the Government of Scotland, *gov.soct*, the longitude range of fishing waters near Scotland is $20°W - 10°E$ and the latitude range is $52°N - 63.5°N$. Combined with data and after considering the accuracy and calculation amount of subsequent models, the grid horizontal space scale is selected as $1° \times 1°$, and the time scale is year.

In summary, the grid distribution around Scotland is shown in figure 1.

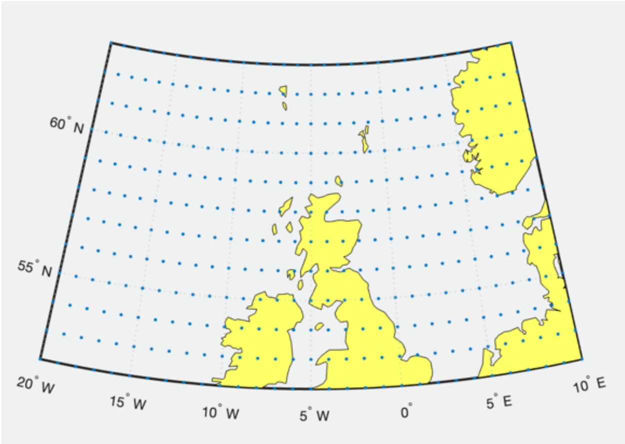

Figure 1: Grid division near Scotland

3.2 Calculation of mean SST in certain grids

3.2.1 Calculation of mean SST for certain years in certain grids

The SST data are based on a month-by-month file of images of the world's oceans from the national oceanic and atmospheric administration (NOAA) website (`https://www.climate.gov/`). The horizontal spatial resolution of the images is $1° \times 1°$. After extracting the temperature data with the multi-dimensional tool of **Arc GIS 10.6 software**, the temperature data from 2012 to 2019 were resampled into the grid distribution map through the annual mean value method to obtain the average SST chart over the years.

Take 2019 as an example. The SST, 3D and isotherm charts near Scotland are shown in figure 2 and 3.

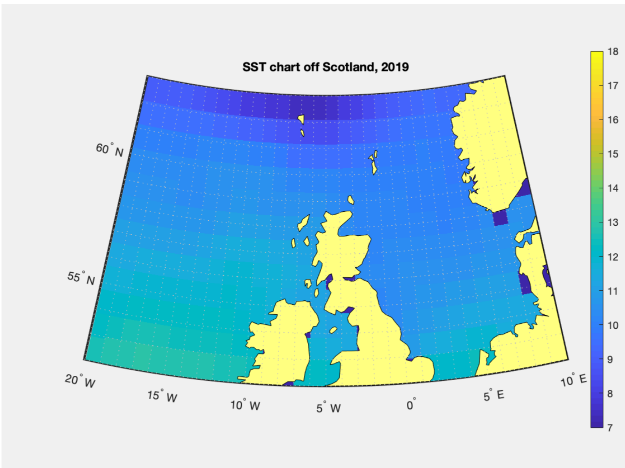

Figure 2: SST diagram near Scotland, 2019

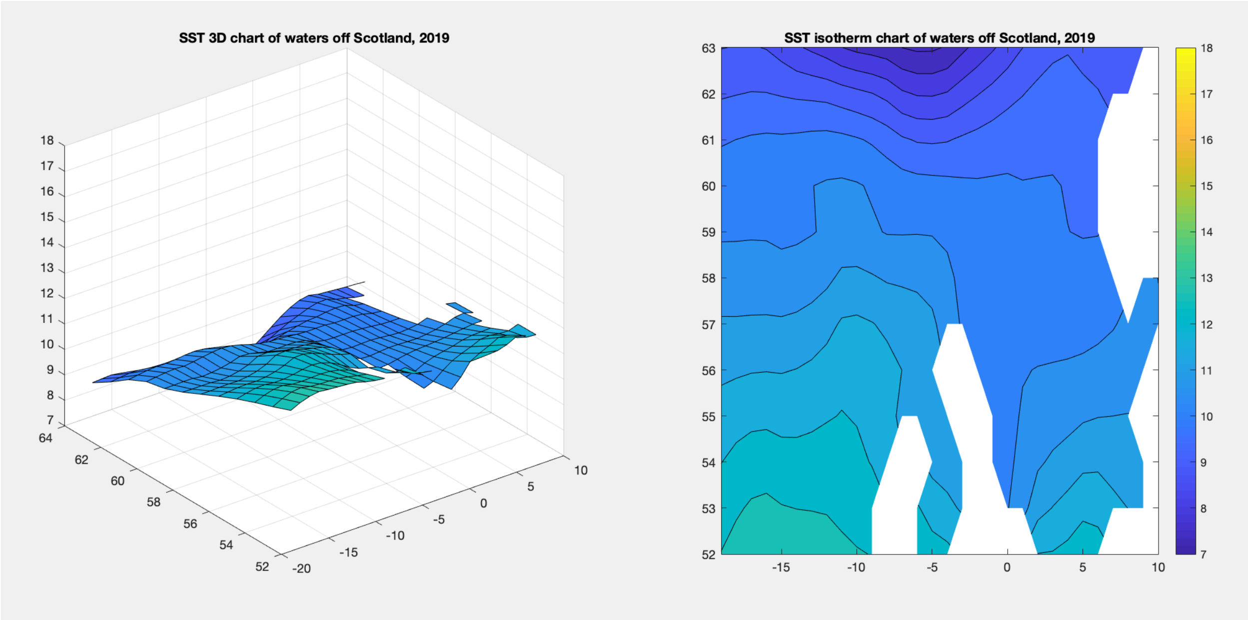

Figure 3: 3D and isotherm diagram of SST near Scotland, 2019

3.2.2 Prediction of future mean *SST* in certain grids

In the past 150 years, the *SST* of most sea areas in the world has increased linearly year by year.[1] So the least squares method is adopted to carry out unary linear regression. Using the linear regression equation and white noise, the grid annual mean *SST* for the next 50 years is predicted.

$$\begin{aligned} SST_{i,yr} &= \hat{b}_1 \times yr + \hat{b}_0 + \varepsilon_{i,yr} \\ \varepsilon_{i,yr} &= diff_i \times (rand_{yr} - 0.5) + 0.2 \times diff_i \times (rand - 0.5) \end{aligned} \tag{1}$$

Among them, $diff_i$ is the range of the grid samples' SST, and $rand$ is the uniformly distributed random number of $0-1$.

Figure 4 shows the SST predicted polyline chart drawn from four points in the sea near Scotland.

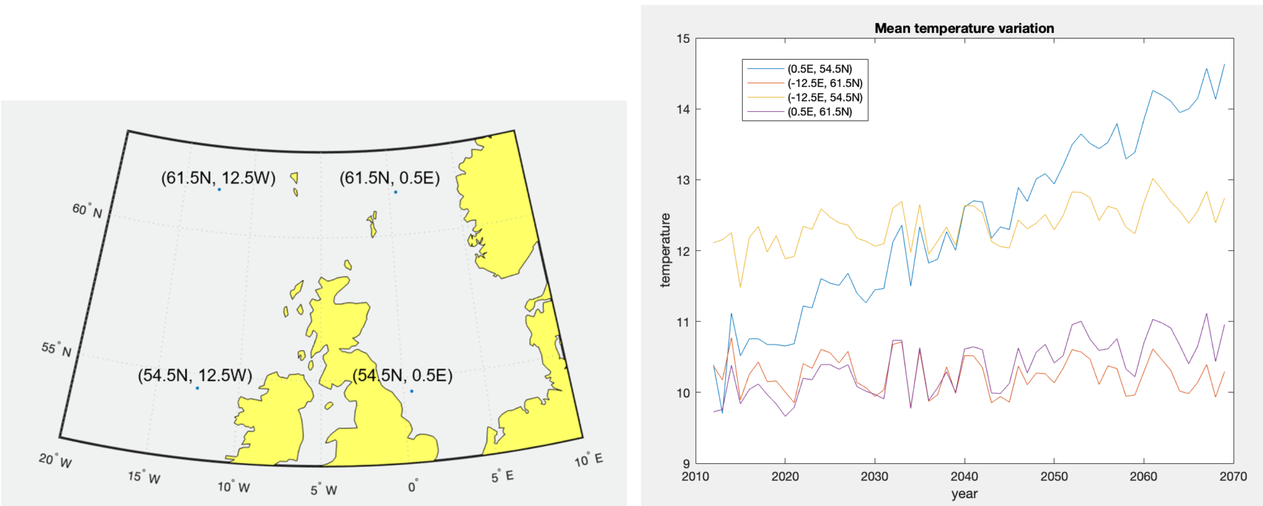

Figure 4: SST prediction diagram for four locations

Figure 5 and 6 show the *SST* chart, 3D chart and isotherm chart of the waters near Scotland in 2069.

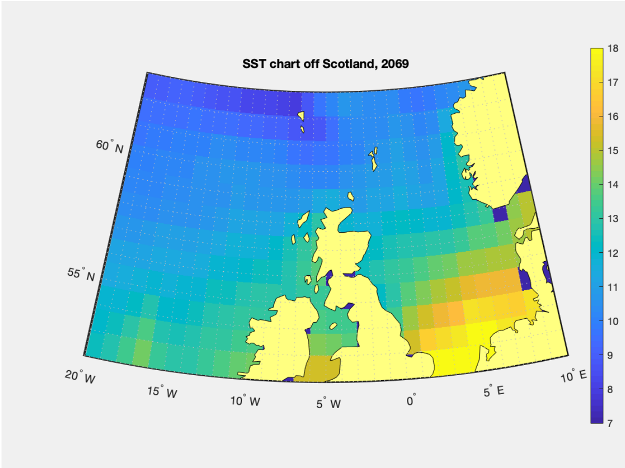

Figure 5: SST forecast diagram near Scotland, 2069

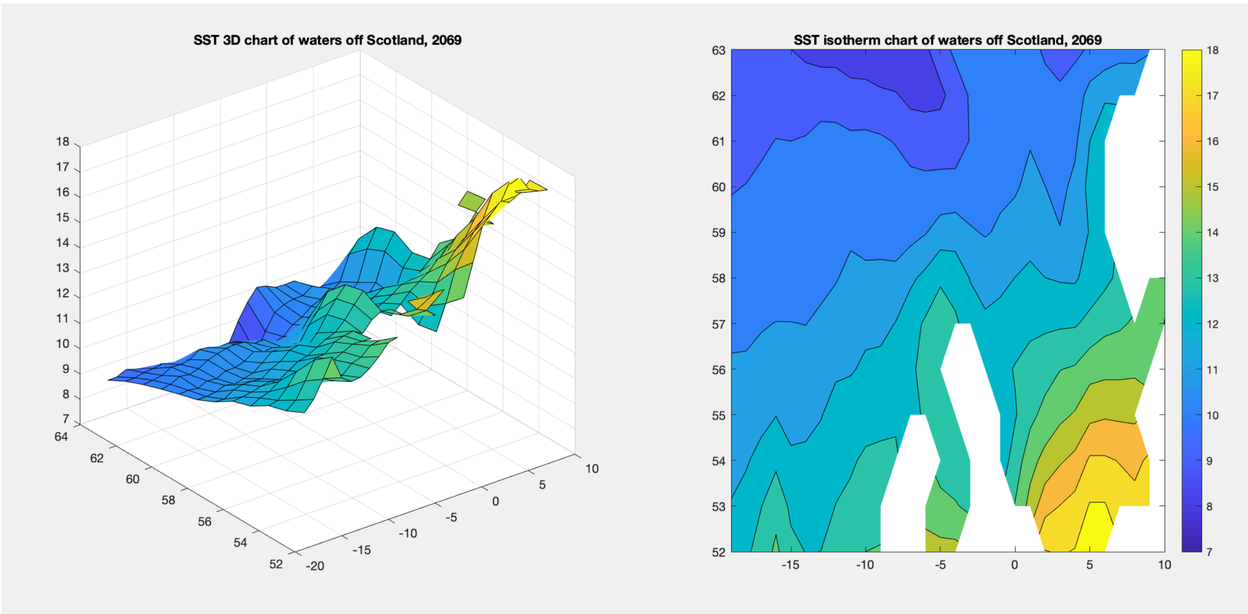

Figure 6: 3D and isotherm forecast diagram of SST near Scotland, 2069

3.3 Establish the Habitat Suitability Index(HSI)

3.3.1 Data source and processing

This model mainly uses fishery production data, *SST*, grid and mainland relative position data. Fishery production data are derived from the annual *scottish-sea-fisheries-statistics* in *gov.soct* from 2014. These data include longitude and latitude, year of operation, number of vessels released annually, total annual fishing in each sea area and other factors. Among them, the total annual fishing volume, the latitude and longitude range of each sea area in 2018 are shown in figure 4 and 5.

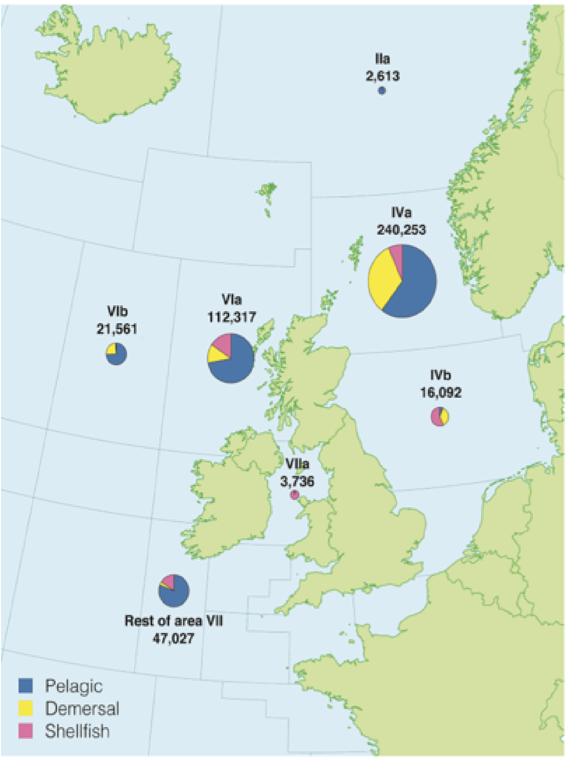

Figure 7: Total annual catch by region, 2018[2]

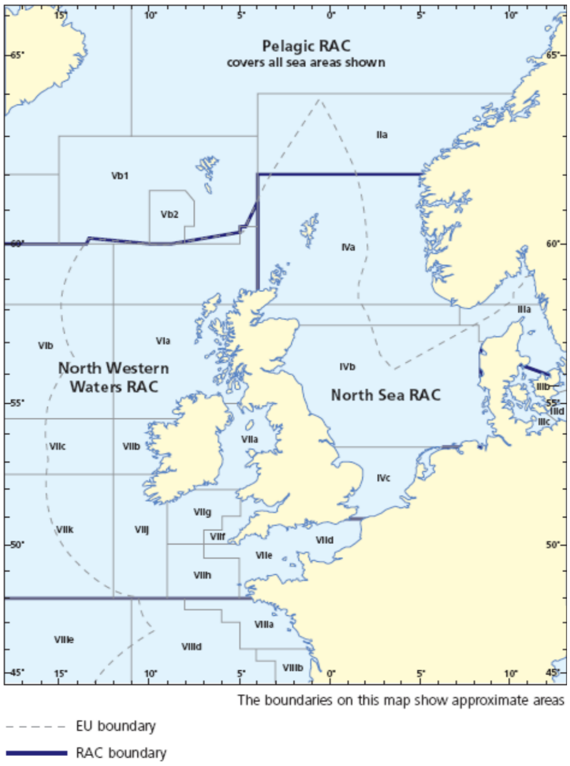

Figure 8: Map of ICES subareas and divisions[3]

The annual fishing volume of each grid was calculated by the total annual fishing volume of the sea subarea and the number of vessels released in the grid yearly belonging to the subarea. After the quality control of the two spatial scale data of the data set, the grid was unified and turned into yield data of $1^\circ \times 1^\circ$ grid by year. The specific formula is

$$C_i = TAC_{\text{zone}} \times \frac{vessle_i}{\sum_i^{zone} vessle_i} \tag{2}$$

s

C_i is the annual fishing yield of the grid i. TAC_{zone} is the total annual fishing volume of the sea subarea $zone$. And $vessel_i$ is the number of vessels released in the grid i yearly.

3.3.2 Establishment of Habitat Suitability Index(HSI)

Using annual fishing volume data of each grid from 2014 to 2019 with the corresponding period of the SST data to construct Suitability Index (SI) model[4] of single factor. The single-factor SI construction method in each year is as follows:

(1) Calculate the single factor suitability index for each year according to formula 3.

$$I_{SI} = \frac{C_i}{C_{max}} \tag{3}$$

I_{SI} is the suitability index of SST. C_i is the fishing yield of the grid i. C_{max} is the maximum fishing yield in each grid. When the fishing yield of one grid is C_{max}, the highest fishing yield in each grid, the environment of this grid is optimal for fish habitat. And its I_{SI} is determined to be 1. When the fishing volume of a grid is 0, its environment is the most inappropriate for fish habitat, whose I_{SI} is 0.

(2) Since there are many remote grids without vessels or fishing yield, we cannot conclude that the grids are not suitable for fish habitat. Therefore, this paper adopts the voting method to study the relationship between SST and habitat suitability index. First, divide the SST interval into appropriate number of cells. Obviously, the higher the suitability index I_{SI}, the more suitable the SST is for this kind of fish. Therefore, we determined that when $I_{SI} \le 0.1$, the number of votes of the sample is 0. When $0.1 < I_{SI} \le 0.3$, the number of votes is 1. When $0.3 < I_{SI} \le 0.5$, the number of votes is 2. When $0.5 < I_{SI} \le 0.7$, the number of votes is 3. When $0.7 < I_{SI} \le 0.9$, the number of votes is 4. When sample $I_{SI} > 0.9$, the number of votes was 5.
Taking the midpoint of each interval as the abscissa and the total number of votes of the interval as the ordinate, the sample points to be fitted are obtained.

(3) *Matlab software* was used to solve the parameters of unitary nonlinear regression equation. The unitary nonlinear model formula is

$$Tickets = ae^{-(\frac{X-b}{c})^2} \tag{4}$$

$Tickets$ is the number of votes. X is the annual mean SST of each grid. a, b and c are estimated parameters.
Herring and mackerel's goodness of fit are as follows:

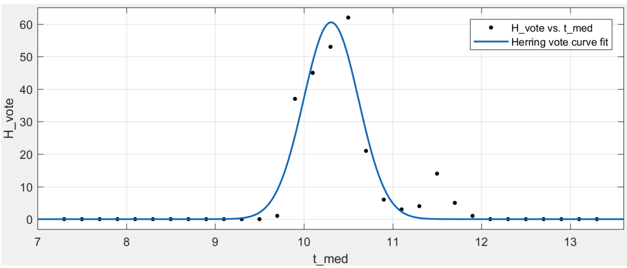

Figure 9: Votes fitting curve diagram of Herring

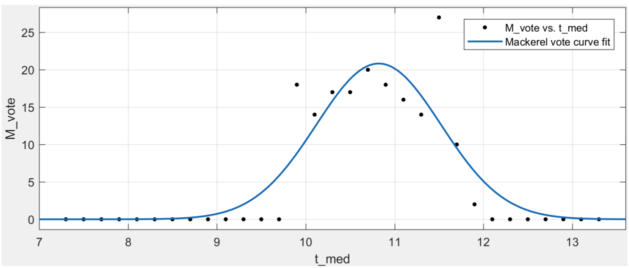

Figure 10: Votes fitting curve diagram of Mackerel

	SSE	R-square	Adjusted R-square	RMSE
Herring	698.6	0.9199	0.9142	4.995
Mackerel	404.9	0.8109	0.7974	3.803

Table 2: Goodness of Fit

(4) normalize the fitted function in (3) to obtain the relationship between the habitat suitability index H_{SI} and SST:

$$H_{SI} = e^{-(\frac{temp-b}{c})^2} \tag{5}$$

The closer it is to 1, the more suitable it is for habitat. Conversely, the closer it gets to 0, the less suitable it is for habitat.

3.4 Establish Markov Chain(MC) for habitat transfer

Markov Chain (MC) is a stochastic process with Markov property existing in discrete index set and state space in probability theory and mathematical statistics. If the random sequence $\{N(t), t \in T\}$ represents the grid in which the shoal is located at the t moment, the state space is $E = \{1, 2, ..., D\}$. Considering that shoal movement has "no aftereffect", the process of shoal movement is a Markov process with countable set of state space, namely Markov Chain. In other words, the grid a shoal will be on next year depends only on the grid it was on this year, not on the grid it was on before this year. Therefore, Markov model is used to predict the distribution of fish in the next 50 years. According to the SST of t, the habitat suitability index matrix of the year is obtained.

$$H(t) = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,n} \\ h_{2,1} & h_{2,2} & \dots & h_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m,1} & h_{m,2} & \cdots & h_{m,n} \end{pmatrix} \tag{6}$$

$h_{i,j}$ is the suitability index of the i^{th} row and the j^{th} column.

The fish in each grid may appear at five locations at the next time, as shown in figure 11.

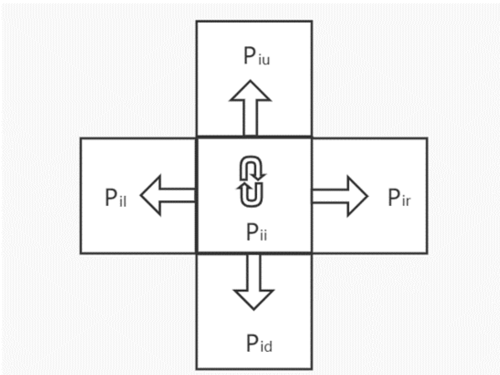

Figure 11: Transition probability diagram

The one-step transition probability matrix is

$$P = \begin{pmatrix} p_{1,1} & p_{1,2} & \cdots & p_{1,m\times n} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,m\times n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m\times n,1} & p_{m\times n,2} & \cdots & p_{m\times n,m\times n} \end{pmatrix} \tag{7}$$

$$p_{i,i} = \begin{cases} 0 & h_{imodm,[i/m]+1} = 0 \\ h_{imodm,[i/m]+1} & 0 < h_{imodm,[i/m]+1} < 0.1 \\ \frac{h_{imodm,[i/m]+1}}{sum_i} & otherwise \end{cases} \tag{8}$$

$$p_{i,j} = \begin{cases} (1 - h_{imodm,[i/m]+1}) \times \frac{h_{jmodm,[j/m]+1}}{sum_i} & 0 < h_{imodm,[i/m]+1} < 0.1 \\ \frac{h_{jmodm,[j/m]+1}}{sum_i} & otherwise \end{cases} \tag{9}$$

$$(j = i+1, i-1, i+m, i-m)$$

$$\begin{aligned} &\mathrm{sum}_i = h_{imodm,[i/m]+1} + \sum_j h_{jmodm,[j/m]+1} \\ &(j = i+1, i-1, i+m, i-m) \end{aligned} \tag{10}$$

By the definition of one-step transfer probability, $p_{i,j}$ represents the probability of moving from position i to position j when one step can be moved.

3.5 Simulation for habitat migration of herring and mackerel

According to the definition of Markov Chain, $P(n) = P^n$. There is no doubt that the number of steps that different kinds of fish can move in a year is different. If the number of lattices a fish can move in a year is s, the probability matrix of one-year transfer is $P_{yr} = P^s$. Use *SST* prediction data of next 50 years to obtain the one-step transition probability matrix P, and the one-year transition probability matrix $P_{2020}, P_{2021}, ..., P_{2069}$ were obtained.

According to the distribution of fish in 2019, the initial population is set as $p(0) = (p_1(0), p_2(0), ..., p_{360}(0))$. The formula for calculating the habitat of fish populations after 50 years is

$$p(50) = p(0)P_{2020}P_{2021}...P_{2069} \tag{11}$$

Through *Matlab* simulation, the results are shown in figure 12 and figure 13

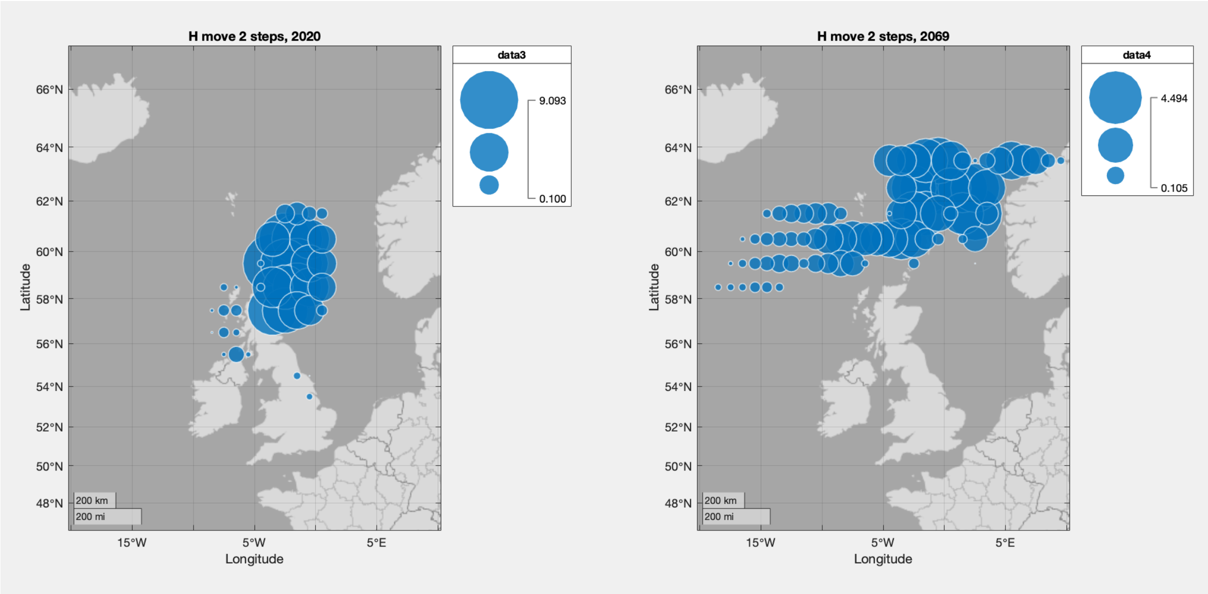

Figure 12: Distribution diagram of Herring, 2020 and 2069

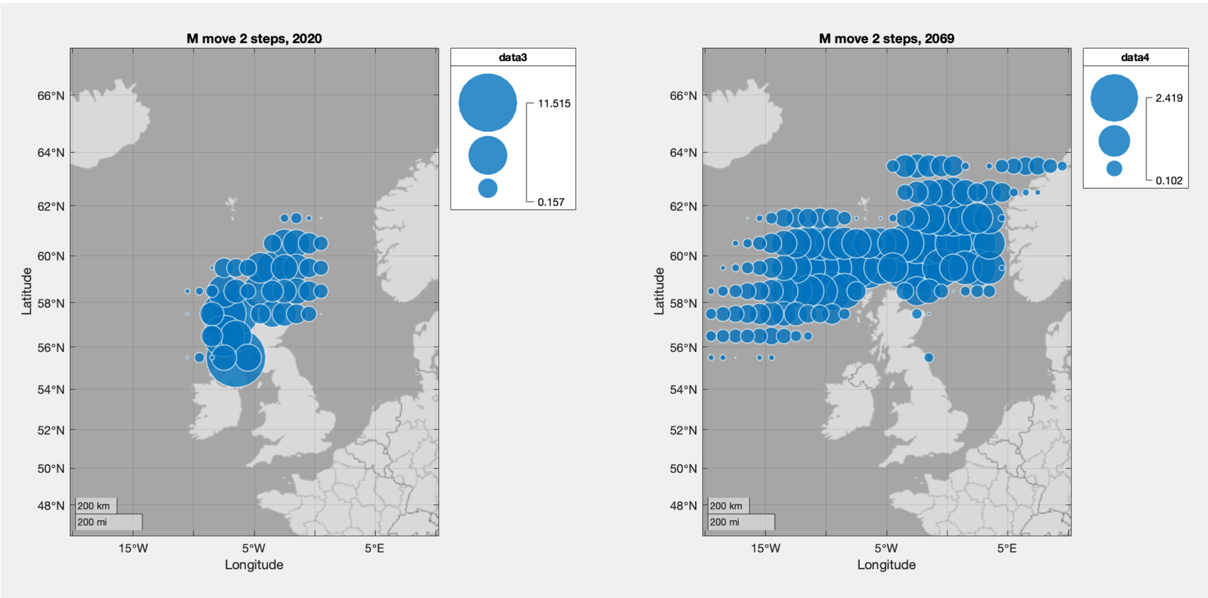

Figure 13: Distribution diagram of Mackerel, 2020 and 2069

4 Model of Part II

4.1 Determine the speed of small fishing vessels

According to the international uniform standard, Marine fishing vessels with a length of less than 12m are small fishing vessels[5]. Noting that the schedule 35 of the *scottish-sea-fisheries-statistics* separated statistics for vessels with a length of 10 meters above and below. It can be considered that the length between perpendiculars of small Scottish fishing vessels without refrigeration equipment is less than 10m. The Chinese 8503 section steel fishing vessel with a total length of 9 meters was taken as the Scottish small fishing vessel for further calculation.

Li Ming, once discussed the approximate estimation formula of fishing vessel speed in the literature *"fishing vessel design"*, and compared the calculated speed with the actual speed and resistance chart of fishing vessel[6]. Finally, a fast estimation formula of fishing vessel speed was obtained.

$$v = 1.84\left(\frac{P}{\Delta}\right)^{0.237}\sqrt{L} \tag{12}$$

P is the main engine power (kW), and the average main engine power of a small fishing vessel over a ten-year period is $53KW$ in the schedule 35 of *scottish-sea-fisheries-statistics*. L is the length between perpendicular lines (m), $9m$ is taken for fishing vessel $no.8503$. Δ for displacement (t), small fishing vessel displacement to an average of $3.67t$ in the same schedule. It is calculated that $v = 10.37km/h$ through the formula. That is, the normal speed of a small Scottish fishing vessel without refrigeration equipment in the sea is $10.37km/h$.

4.2 Determine the width of the coastal fishing zone

Since both mackerel and herring are perishable fish, especially the mackerel has already begun to rot when just coming out of the water, it is generally believed that the return trip within 12 hours can maintain the freshness of the fish to a certain extent. Therefore, for small fishing boats without refrigeration equipment, return to the port before the time limit when mackerel and herring can keep a certain freshness. Only in this way can profits be guaranteed. In other words, the straight-line distance from the shore of a single voyage is no more than 120 kilometers.

The distribution map of Scottish ports is shown in figure 6, which indicates the dense distribution along the coast of Scottish ports.

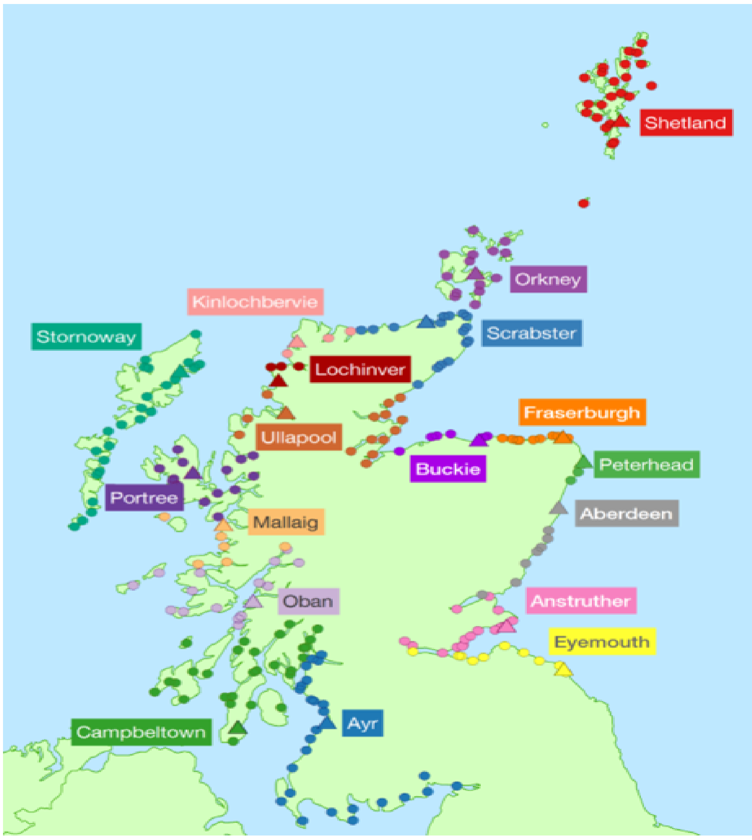

Figure 14: Map of Scottish ports

4.3 Calculate the time required for fish to overstep the fishing range

On the premise that the area of the coastal fishing zone cannot be expanded, as the fish population's habitat gradually moves north, the overlap area between the fish activity range and the fishing zone becomes smaller and smaller. It directly leads to a substantial decline in the number of fish in the fishing zone and the decrease in the inshore fishing income of fishing companies. It can be argued that small fishing companies that rely on inshore fishing operations will be on the brink of bankruptcy when fish stocks in the zone drop to the current 35 percent.

Therefore, with a threshold of 35% for inshore fishing failure, fish stocks in the fishing zone in certain future year are considered to be out of range when the number of fish in the fishing zone falls to 35% of the 2019 fish population. If the rhythm of fish population moving north is slow, that is, when Markov Chain is used to describe the migration of fish population, one-year transition probability matrix is only one-step transition probability matrix. And *Matlab software* is used to calculate the number of fish in the fishing zone in each year in the future. For the worst case, that is, the fish population tends to accelerate northward, the one-year transition probability matrix is described by a three-step transition probability matrix.

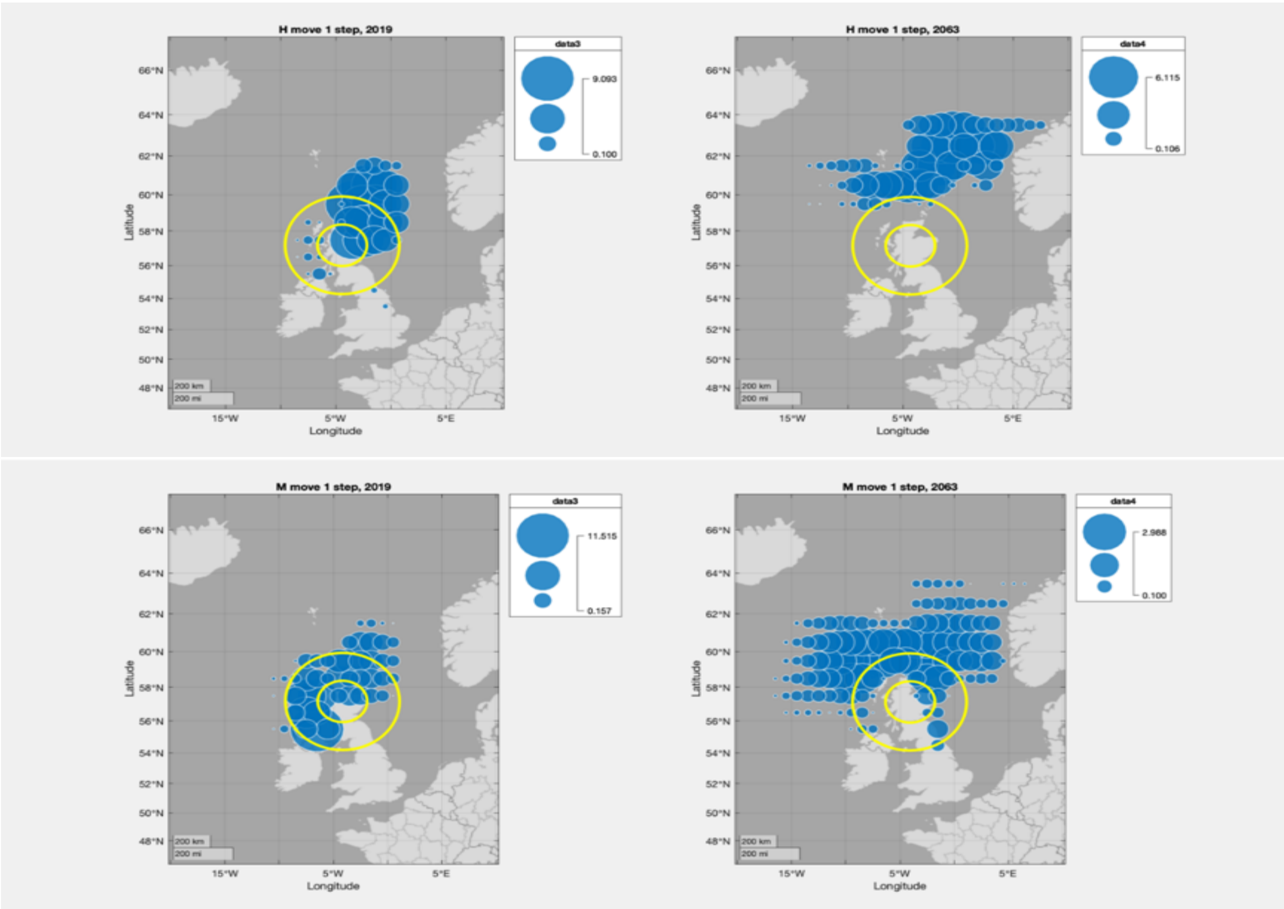

Figure 15: Habitat and inshore fishing coverage of Herring and Mackerel, 2063(Best Case)

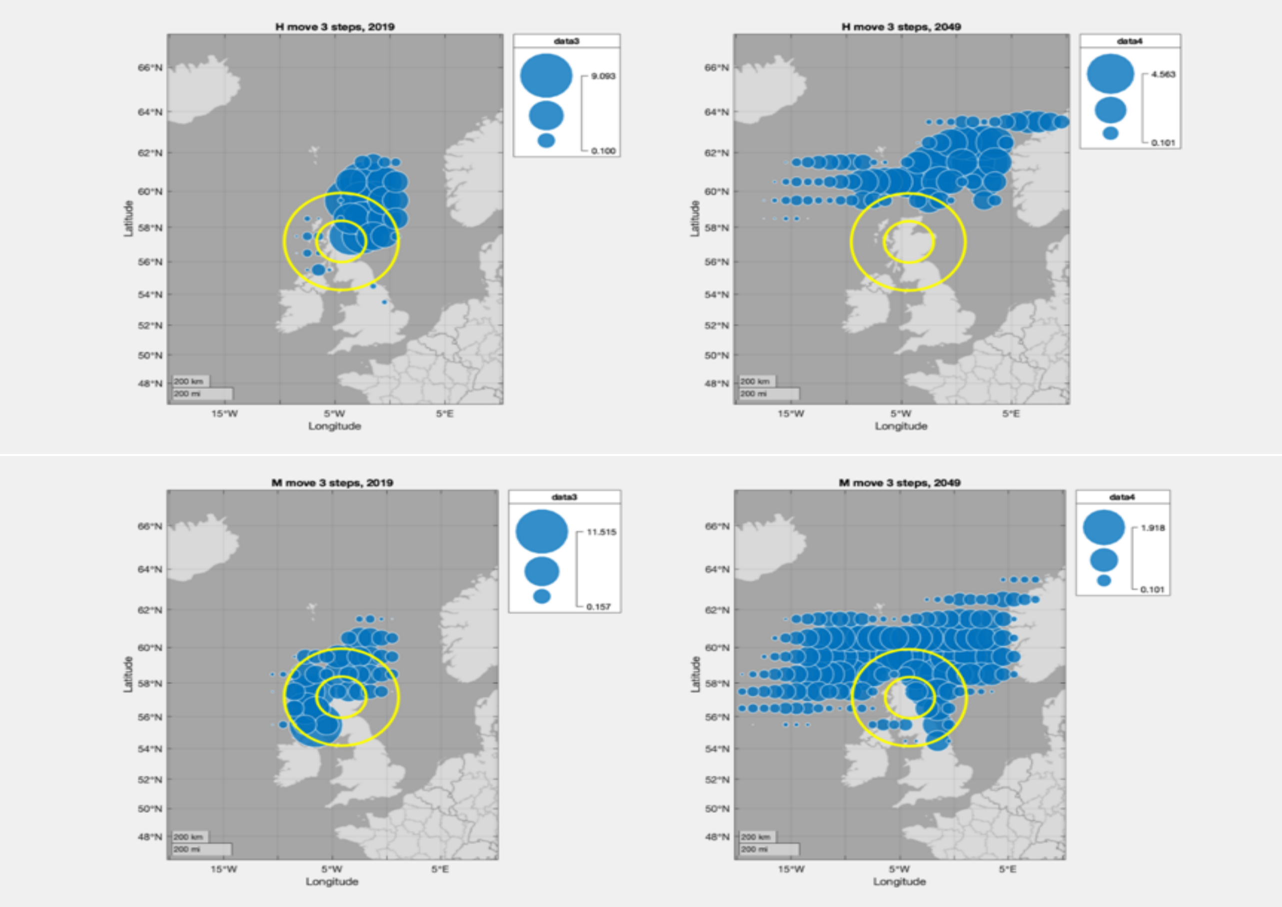

Figure 16: Habitat and inshore fishing coverage of Herring and Mackerel, 2049(Worst Case)

In a nutshell, if current operating tradition continue, at the latest in 2063 and at the soonest in 2049, that is, three decades from now, fish stocks will be out of coastal fishing range. That could have a big impact on a part of companies that depend on the stability of marine life.

5 Model of Part III

5.1 Propose the strategy for changing business pattern

According to the results of problem II, it is likely that inshore fishing operations will be severely impacted in the next 30 years. Therefore, fishery companies should plan ahead and seek more efficient operational improvement strategies to improve the potential loss of fish stocks in the future.

Due to the model in problem II, keeping fish freshness and returning to port within a certain time after fishing are the main limiting factors of fishing zone. Therefore, fishing companies can consider to equip some small vessels, which has available space, with refrigeration equipment. This approach would increase the extent of fishing by raising the limit on how much fishing vessels can do. This is one way to deal with the possibility that in 50 years' time, large areas of fish population habitat will move north.

However, the addition of refrigeration equipment can only enable small fishing boats to have the ability to refrigerate fish and maintain their freshness. From the perspective of endurance, stability, speed, fish cabin capacity and arrangement of mechanical and electrical equipment, it is difficult to meet the requirements of far-sea navigation. Small fishing companies may not be able to cope if fish populations have more northerly. So for those fishing companies with stable capital chains, they can consider replacing small vessels. That means they can replace small vessels with vertical lengths of about 10 meters, which are not suitable for ocean operations, with semi-distant vessels with lengths between 15 meters and 24 meters, which can be used for medium-ocean fishing operations. These semi-oceangoing vessels can serve as an important reserve for fishing in the distant ocean.

5.2 Conduct economic evaluation of vessel replacement project

In this section, NPV, an economic indicator commonly used in project economic evaluation, is used to evaluate the profitability of two kinds of business improvement strategies. The net present value of a project is the present value of current and future benefit minus the present value of current and future costs. This is one of the most common and important indicators of engineering evaluation at home and abroad[7].

The calculation formula of NPV is

$$NPV = \sum (CI - CO)(1+i)^{-t} \tag{13}$$

The cost of installing additional refrigeration equipment for a small fishing vessel is \$100,000. The annual income of a small fishing vessel is \$85,000, according to schedule 34 of *scottish-sea-fisheries-statistics* and other relevant data. After the addition of refrigeration equipment, the annual income increases by 30%, and the net profit is two-thirds of the annual income, \$74,000, and increases by 5% annually. And take the discount coefficient $i = 0.14$. The five-year NPV calculation table for adding refrigeration equipment for small fishing boats is as follows

Year Number t	Discount Factor $[\frac{P}{F}, 10, n]$	Cost	Earnings	Net Cash Flow	Present Value of Net Flow	Cumulative Net Present Value
1	0.877	15	7.4	-6.6	-5.8	-5.8
2	0.769	0	7.8	7.8	6.0	0.2
3	0.675	0	8.2	8.2	5.5	5.7
4	0.592	0	8.6	8.6	5.1	10.8
5	0.519	0	9.0	9.0	4.7	15.5

Table 3: NPV calculation table for additional refrigeration equipment for small fishing vessels(5 years)

Similarly, the five-year NPV calculation table for the addition of semi-ocean fishing vessels and large ocean fishing vessels is as follows

Year Number t	Discount Factor $[\frac{P}{F}, 10, n]$	Cost	Earnings	Net Cash Flow	Present Value of Net Flow	Cumulative Net Present Value
1	0.877	300	164	-136	-119	-119
2	0.769	0	173	173	133	14
3	0.675	0	181	181	122	136
4	0.592	0	190	190	112	248
5	0.519	0	200	200	103	351

Table 4: NPV calculation table for additional refrigeration equipment for semi-ocean vessel(5 years)

Year Number t	Discount Factor $[\frac{P}{F}, 10, n]$	Cost	Earnings	Net Cash Flow	Present Value of Net Flow	Cumulative Net Present Value
1	0.877	1200	527	-673	-590	-165
2	0.769	0	553	553	425	0.2
3	0.675	0	581	581	392	260
4	0.592	0	610	610	361	621
5	0.519	0	641	641	332	953

Table 5: NPV calculation table for additional refrigeration equipment for ocean-going fishing vessel(5 years)

It can be seen that under the current data conditions, the payback period of investment is two to three years, and the cumulative net present value is positive and increasing in 5 years. Even if the current data are of partial idealized, but it still can be sure that for fisheries, adding refrigeration equipment or reserving semi-oceangoing vessels is not costly. And this kind of investment pays off quickly. Combined with the relevant supportive policies of the local government, it can also create employment opportunities, increase fishermen's income and promote the development of companies in response to the northward migration of fish population habitats.

6 Model of Part IV

6.1 Improvement for Model III

The map of Europe with fishing zone as shown in figure 17. When parts of the fish population's habitat enter the territorial waters of other countries, such as Norway or Iceland, it means that Scottish fishermen are temporarily deprived of that part of their fish stock, which means that fishermen will face more difficulties: with large Numbers of offshore herring and mackerel in decline, ocean fishing in some directions will yield much less than it does today.

In this context, the need for additional refrigeration for small fishing vessels in the third issue is greatly reduced. Fishery companies should vigorously develop semi-ocean fishing vessels and ocean fishing vessels to ensure their competitiveness in offshore fishing grounds; It is also possible to consider working with the government to establish cargo transfer stations in offshore islands to improve the capability and efficiency of offshore operations.

Figure 17: The map of Europe

6.2 Re-evaluate the economic value of the project

Since ocean-going fishing operations are impacted by the migration of fish habitat, we chose to halve the income of ocean-going fishing vessels and recalculate the NPV within 5 years, as shown in the table below

Year Number t	Discount Factor $[\frac{P}{F}, 10, n]$	Cost	Earnings	Net Cash Flow	Present Value of Net Flow	Cumulative Net Present Value
1	0.877	1200	264	-936	-517	-517
2	0.769	0	277	277	213	-304
3	0.675	0	291	291	196	-108
4	0.592	0	305	305	181	73
5	0.519	0	321	321	172	245

Table 6: NPV calculation table for ocean-going fishing vessel revenue halved(5 years)

Even in the case of a substantial decline in pelagic fish stocks, the payback period for fisheries companies to increase their investment in pelagic fishing vessels is still within five years; increasing the number of ocean-going fishing boats can not only increase the interests of enterprises, but also promote the distribution of ocean-going fish resources in the future, forming a virtuous circle. Therefore, it is reasonable to believe that in the future, the large migration of fish population habitat to the north may exacerbate the gap between the rich and poor of fishing companies, leading to the imbalance of industry development.

7 Testing the model

7.1 Advantages of the model

In the model of the first problem, the habitat of the fish population is divided into grids according to a certain level of spatial scale, and the migration process of the habitat of the fish population is specific to each longitude and each dimension, which greatly improves the accuracy and accuracy of the model prediction. Moreover, the convergence property of Markov Chain is well utilized to ensure that the migration of fish population is not too divergent.

In the model of the second problem, after analyzing the fishing characteristics of small fishing boats, the concept of inshore fishing zone is geometrically transformed on the map, and some calculation methods are given. In this way, the overlap of the habitat range in the first model is well compared, and the time interval given by the calculated results is also relatively realistic.

In the model of the third problem, classic indicators in engineering economic analysis are innovatively introduced to prove with figures that the payback period of investment is very short, which not only gives advice to fishermen, but also eliminates the company's suspicion of capital chain rupture.

7.2 Limitations of the model

Using only the global temperature data of the past decade to predict the average annual temperature of the ocean surface in the future inevitably affects the accuracy of the forecast .In addition, the unitary linear regression equation is used in the process of prediction, which is difficult to deal with the change of future temperature trend accurately.

Secondly, when establishing the habitat adaptation model, only the environmental factor temperature is taken into account, which makes it difficult to accurately describe the complex Marine environment, thus affecting the transfer result of Markov Chain.

In the calculation of NPV, due to the large amount of data, only typical values of various fishing vessels are selected for calculation, which is difficult to represent the payback period of all types of ships.

7.3 Model generalization

This model establishes a habitat adaptation model with temperature as the environmental factor to cope with the habitat migration of fish caused by the rising ocean surface temperature. Therefore, this model can also be applied to other studies on the evolution of biological habitats, or the impact of environmental factors such as global climate change on biological migration.

Similarly, in the decision-making process of fishery companies, the results of the model and other economic evaluation indicators can be integrated to analyze the multi-dimensional decision-making of fishery companies.

8 Conclusions

Based on the analysis of the annual mean temperature of the waters off Scotland and the statistics of Scottish Marine fisheries over the past decade, this paper simulated the migration process of the habitat of the fish population and reached the following conclusions.

(1) As global temperatures rise and sea surface temperatures continue to rise, the habitat of fish populations in the next 50 years will move far north from the waters around Scotland, into the upper north sea and even into the territorial waters of countries such as Norway.

(2) Over the next 30 to 50 years, Scotland's offshore fish stocks are likely to decline dramatically. For smaller vessels that do not have refrigeration, inshore fishing income will be greatly reduced, and these vessels will not be able to navigate the ocean, and fishing companies may face bankruptcy.

(3) Fishing companies may choose to add refrigeration equipment for small vessels to enhance their inshore fishing capacity.Or the fishing vessels shall be replaced by semi-ocean fishing vessels or ocean-going fishing vessels of more than 15 meters.In this way, while strengthening inshore fishing capacity, fishing scope can be expanded to cope with the larger migration of fish populations.

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Letter

To: Hook Line and Sinker
From: Team 2001958
Date: February 17th, 2020
Subject: Global warming come to be a serious problem, it is imperative to update the way of operation.

Dear Scottish fishermen:

I have been always dreaming of navigating in a ship in the endless ocean, enjoying the beauty of nature and making my life in nature. I am extremely keen on and look forward to your life, but the life which focuses on the fishing always depends on the sea. However, the power of nature is huge and silent, which could not be resisted by us human. Our life is changed by it almost unnoticed.

Recently, by studying some related data, we have found that effected by the global warming, the temperature of the ocean has gone up steadily, which can make the oceanic condition worse, and will have a great influence on your fishing business. Hope you can read this letter patiently and let me show you why.

As we all know, global warming is a steady process. Whether it is due to fluctuations in solar activity or the greenhouse effect, whether it is due to aerosol particles or changes in the trajectory of the earth's periodic revolution, we cannot deny the fact that global warming causes rising sea levels and rising sea temperatures. And global ocean temperature will affect a large part of the scope of Marine habitats and migratory routes. For example, the main economic fish in fish farms in Scotland — herring and mackerel will migrate to other places which can provide a suitable environment and condition as sea temperatures continue to rise. Because they cannot normally live and breed in the original environment. This migration is the inevitable result of the rising of the water temperature, which will definitely do harm to the fishery production activities and even lead to a decline in the operating level of some companies that depend on the stability of Marine life in the future. Thus have made some analyses here. Hope it can help you in some degree.

We have used mathematical modeling methods to scientifically analyze the average annual temperature in the seas around Scotland and Scottish marine fishery statistics in the past ten years, mainly including:

1. The number of fishermen working on Scottish registered ships;
2. As of December 31, 2018 Number of Scottish Registered Ships divided by main fishing method and length group on a daily basis;
3. Number of active Scottish Registered Ships by tonnage group, tonnage and engine power as of December 31, 2009 to 2018;
4. Number of active vessels registered in Scotland by region and length group as of December 31, 2018.

Through the analysis and research of relevant data, it can be seen that as the global temperature rises, the surface temperature of seawater is also rising. In the next 50 years, the habitats of fish communities will continue to be far away from the offshore waters near Scotland and go north significantly, transfer to the North Sea, and some even will enter the territorial waters of Norway and other countries. At the same time, in the next 30 to 50 years, the offshore fish resources in

Scotland may be greatly reduced. For small fishing vessels without refrigeration equipment, the income from offshore fishing operations will be greatly reduced. Without the ability to navigate the ocean, operators may not be able to make ends meet, and fishery companies may face the dilemma of declaring bankruptcy and restructuring.

After reading this, I believe that you must be very interested in my research and must be worried about your future fishery production and operation activities. But don't worry too much. Based on scientific research, we've come up with several strategies for warming the oceans:

First of all, you should increase the capacity of offshore fishing by providing refrigeration for small vessels.

Secondly, you should upgrade the fishing boat, increase the semi-ocean fishing boat or ocean fishing boat more than 15 meters, strengthen the offshore fishing operation capacity, and expand the fishing area to deal with more severe migration.

Of course, fishery production will be affected by many factors such as the marine environment, fishing and processing technology, transportation tools, refrigeration tools and technologies, staffing, eating habits and sales markets. No matter the effects of temperature, ocean current, seawater flow speed, geostrophic bias and even natural disasters. Therefore, our countermeasures are only for the problems brought by global warming.

I hope that you can combine all the factors with specific conditions, adopt our reasonable suggestions, and make early preparations. I sincerely hope that with the help of our research, fishery production can become better and better.

At the same time, the starting point of our research is that global warming is causing problems in the oceans that are having a negative impact on production and business operations. Environmental issues have always been at the center of our attention.

Protecting the earth and the oceans is the direction and goal of the global humanity. For this reason, under the efforts of some major countries, they have successively signed the Basel Convention, the Kyoto Protocol, the Stockholm Convention, the International Convention for Intervention of Oil Pollution Accidents on the High Seas, and the United Nations Framework Convention on Climate Change International conventions have raised environmental issues to legal and political levels, and each country has transformed and incorporated international law into the domestic legal system, relying on legal methods to restrict people in various countries and regions. It is enough to see the urgency and reality of environmental protection. Do not take excessive damage and give our mother earth a better future.

These protocols are not only signed in the name of countries, but also require that every one of us living on the earth depend on the gift of the earth to survive and develop. The obligation to protect the environment, not only belongs to me, but also you. Changes in the global environment affect not only one person, one industry, one nation, one country, but the destiny of the entire human race. We support each other in the face of constant environmental problems, and constantly improve and change our way of life and production to cope with these difficulties. What's more, we should understand that we must not only passively change the way of life and production, but also actively protect the environment and restore soil and water. This is the task of each individual. Therefore, we study and provide you with methods and countermeasures for coping with environmental changes, and we should also understand that in addition to these, what we should do is to take the belief of environmental protection into our hearts and take practical action. It is hoped that with the joint efforts of all people, the original blue sea and blue sky of Mother Earth can be restored.

Best wishes.