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Fishing Strategy Under Species Migration Via Utilizing Cellular Automata And Optimization

Summary

The change of global ocean temperature affects a large number of marine organisms in cold environment. As a consultant to the North Atlantic Fisheries Management Alliance of Scotland, this paper studies the management strategy of the Scottish Fisheries Company in terms of species migration.

First, we collected the sea surface temperature changes of the Northeast Atlantic and North Sea in recent 17 years. According to the development trend of sea surface temperature, the periodic variation of sea surface temperature is described, and ARIMA model is established to predict the sea surface temperature in the next 50 years, and the validity of the model is tested. According to the calculation, the average sea water temperature in Scotland in 2070 was $1.442°C$ higher than that in 2004.

To locate herring and mackerel, we built a cellular automata. The rule of cellular automata is that if there is no suitable temperature around the fish, then the fish (cells) move one step randomly. If the fish has the right temperature around it, move one unit in the right direction. Combined with the predicted temperature data, the model accurately shows the migration direction and location of herring and mackerel in 2070. The model shows that in 2070, herring was located near the coast of clonakilty, Ireland. Mackerel is located $937.0812km$ north of Aberdeen port in Scotland.

Secondly, the relationship between ship speed and ship design parameters is studied, and the relationship model between ship range and fuel consumption is established. At the same time, we consider the fishing value of two kinds of fish. Finally, the interest rate calculation model is established. A large number of results accurately estimate the longest, shortest and most likely operation time of the port. After calculation, the longest operation time of fishery company is 49 years, the shortest is 3 years, and the most likely operation time is 16 years.

Based on the above analysis, we believe that small fishery enterprises should change their business model. We believe that port location and small fishing boats are necessary. According to the change of port location, an optimization model is designed to maximize the profit, and it is calculated that all fishing companies should move to the port of ness in Scotland. For small fishing boats (non port fishing boats), we get rid of the land limitation in the optimization model, and get that the non port fishing boats should be located $157.9460km$ in the west of nesport, near the Borre island.

According to the situation of port migration to neighboring countries, we design an optimization model, in which the migration cost is regarded as a conventional condition to constrain the profit. Similar to the previous model, we solve the optimization model through direct traversal. The calculation shows that the benefits can be maximized by moving some companies to the coastal area near Cape Marin in Northern Ireland. Reasonable calculation results show the effectiveness of the model.

Finally, the sensitivity analysis of the factors affecting the income is carried out. At the same time, we have written an article, hook line and sinker magazine, to help fishermen analyze the severity of the current problems and provide solutions in a simple way to improve their business.

Keywords: Species migration, Prediction, Cellular automata, Optimization

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1 Introduction

1.1 Problem Background

Global ocean temperature affects the habitat quality of some marine organisms. When temperature changes are too large for their continued reproduction, these species will migrate to other habitats that are more suitable for their present and future life and breeding success. The consortium hopes to better understand the potential for Scottish herring and mackerel to migrate from their current habitats near Scotland in the face of rising global ocean temperatures. These two species represent an economic contribution to Scotland's fisheries. Changes in the location of herring and mackerel populations may make it economically impractical for smaller Scottish fishing companies to use fishing vessels without on-board refrigeration to catch fresh fish and transport them to the market in Scottish fishing ports.

In the process of biological migration, those companies that use these organisms for profit will face livelihood problems. Scottish herring and mackerel are the main fishes in the UK and Scotland. Climate impacts may cause these fish to migrate north. The change in the position of these two types of fish is undoubtedly a challenge for small fishing companies. Small fishing companies do not have sufficient technical support. When the school of fish is far from the continental shelf, if the fishing boat sails a long distance from the mainland, it will face problems such as danger, insufficient energy, and the inability of the fish to return to the shore.

1.2 Restatement of Problem

The rise in global ocean temperatures has caused certain ocean-dwelling species to migrate from their habitats to other places suitable for their survival and reproduction. The Scottish North Atlantic Fishery management consortium hopes that the modeling team can help solve this problem as this migration may affect the livelihood of some small-scale fishing companies.

Please help analyze possible changes in the distribution of Scottish herring and mackerel populations in order to allow these fishing companies to survive without refrigeration equipment on their fishing vessels.Under some assumptions, we need to model to solve the following series of problems:

- If population migration occurs due to large changes in water temperature, establish a mathematical model to help analyze where Scottish herring and mackerel may live in the next 50 years.
- If the operating positions of these fishing companies remain unchanged, please predict the time required for the event to exceed their fishing capacity due to fish migration, and give a best and worst case respectively.
- Please judge whether the fishing company needs to change the operation mode based on the results of the forecast and analysis. If so, please help develop business strategies (including relocating fishing companies, using more advanced fishing vessels, or other reasonable options). If not, please give a reason.
- Please help analyze this problem. If the fishing scope of the fishing company has entered the territorial waters of other countries according to the scheme designed above, what will be the impact of this scheme.
- In order to introduce the seriousness of the fish migration problem to fishermen and page article for the magazine.

1.3 Literature Review

Cellular automata (CA) is a very active frontier field in scientific research in the 21st century. In 1940s, J. von Neumann first proposed the theory of cellular automata, which was used to simulate the self replication function of life system [1]. In the 1980s, S. wolfram, an American scientist, made a systematic study of cellular automata, and sorted out the original ideas of cellular automata academically, which eventually became a scientific methodology [2]. Cellular automata (CA) model is a kind of grid dynamic model, which has the characteristics of space-time computation and is completely discrete in space, time and state.Cellular automata [3] is deterministic, and the evolution rule is a definite function. The given initial configuration will always evolve into the same pattern. However, there is a certain degree of randomness in the evolution rule, which makes the model very suitable for solving the problem of biological dynamic change [4].

Mackerel and herring are the two main fish species targeted by the Scottish pelagic fleet, primarily during October to March and June to September, respectively. The winter migration of the western mackerel (Scomber scombrus) from feeding grounds in the North and Norwegian seas to spawning areas south and west of Ireland occurs in the months of December to March. The migration path follows the shelf edge for most of its route, with the fish being found generally between the 100 and 250 m contours. Analyses [5] of commercial catch data have shown that the timing of this migration has changed significantly over the last 20 years. From the late 1970s until the early 1990s the migration occurred steadily later in the year, from late summer in the 1970s to January in the 1990s. Walsh [6] and Martin speculated that this change may have been due to hydro-graphic changes in the area following the 1970s salinity anomaly. Walsh showed that the migration pathway coincided with a tongue of warmer more saline water extending along the shelf edge [5].

It has been suggested that the migration of fish may be influenced by "enviroregulation", a process by which the fish select their immediate environments by behavioral means [7]. So if the fish find themselves in some "non-preferred" temperature, they may swim faster or deeper in an attempt to gain more preferred temperatures. For example, Olla showed that mackerel swam faster at water temperatures below 7 $^\circ C$. These suggestions [8] would support the hypothesis that the migration of the western mackerel is, at least in part, influenced by temperature change. Migration may be triggered by the temperature dropping below a threshold, and the migration route constrained by the relatively narrow tongue of warm water derived from the northward flowing current.

1.4 Our Work

In this paper, we propose to tackle the fishing business strategy designing under species migration via cellular automata and optimization. It is assumed that, under certain conditions, the flow of the fish group could be seen as a cell. Thus, we employ the cellular automata in the given area and provide the location of the figh group after 50 years deom now. Then, the optimization model which aims at minimizing the cost and maximizing the profit is established. The final results reveal the effectiveness of the proposed model.

First, we collected 40 years of tempreasure changes in the Northeast Atlantic Ocean and the North Sea. According to the development trend of the tempreature of the sea water, the periodic variation of tempreature of the sea water is described systematically, and the forecast model of tempreature of the sea water in the next 50 years is established. Specifically, we consider time series analysis, which analyze the development process, direction and trend of time series, and to predict the possible goals in the future time domain. In this paper, the sea water temperature in 2004-2020 transformation data has obvious rising characteristics. However, such a transformation also has a certain randomness, not every position of the temperature is monotonous rise. Therefore, a robust and high-capacity analysis method is needed to predict the future seawater temperature. We consider Arima prediction method. Specifically, according to the existing data, we establish the difference equation and use p-order polynomial to establish $ARIMA(p,d,q)$ model for prediction.

To locate herring and mackerel, we built a cellular automaton. The rule of cellular automata is that if there is no suitable temperature around the school of fish, then the school of fish (cells) will move in a random step. If the fish is at the right temperature, move one unit in the direction of the right temperature. Combined with the predicted temperature data, the model accurately showed the direction and location of herring and mackerel migration in 2070.

Secondly, the relationship between ship speed and ship design parameters is studied, and the relationship model between ship range and fuel consumption is established. At the same time, we considered the catch value of both types of fish. Finally, the interest rate calculation model is established. A large number of results accurately estimate the average uptime of each port under best and worst conditions.

Based on the above analysis, we believe that small fishery enterprises should change their business model. We think port location and small fishing boats are necessary. Aiming at the change of port location, an optimization model aiming at maximizing profit is designed. For small fishing vessels (non-harbor fishing vessels), the land-only restriction is removed from the optimization model.

An optimization model is designed for the migration of ports to neighboring countries. In this optimization model, migration cost is used as a general condition to constrain profit. Similar to the previous model, we solve the optimization model by direct traversal. Reasonable results show the validity of the model.

In summarize, our models are as follows:

- The prediction model to predict the tempreature in the future years (5).
- The cellular automata model to predict the position of the fish group (6).
- The cost and profit model (11).
- The optimization model to determine the best position of the port (15).
- The optimization model to determine the best positions of the two ports (17).

2 Preparation of the Models

2.1 Assumptions

Through the full analysis of the problem, in order to simplify our model, we make the following reasonable assumptions.

- The increase of sea water temperature is mainly due to the absorption of heat generated by global warming. The variation trend of sea surface temperature is consistent with that in previous years, and it will not rise or fall suddenly. It can only float within a certain range.

- Mackerel and herring populations will not change for 50 years. Regardless of predators, living environment and human activities, every fish in the school is an adult fish and is very sensitive to temperature.
- The ships of small fishing companies do not have refrigeration devices, so they return to the port immediately after fishing, and there is no intermediate stay.
- Due to the fishing facilities, the longer the transportation time, the lower the freshness of the fish on the fishing boat, so the lower the value.
- We assume that there are enough people on board to change shifts for continuous work. Thus, the fishing boats can work all the time.
- Small fishing companies make money mainly from herring and mackerel.
- The number of fish around Scotland remains the same, except that some are found near Scotland and others may be farther away.
- The prices of all kinds of fish remain unchanged.

In addition, the data we collected is not directly from the question provided. Thus, the historical ocean surface temperature data of fishery company, herring data and mackerel data have no obvious measurement deviation, which is considered to be false. Therefore, a more reasonable quantitative model can be established on this basis.

2.2 Notations

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

Table 1: Notations

Symbol	Definition
y_t	The tempreature data
$\mathscr{B}$	Delay operator
L	lag operator
F_i	$\in \mathbb{R}^2$, Cell represeting fish group
S_j	$\in \mathbb{R}^2$, The positions around the cell F_i
t_i	The most suitable temperature of F_i
P	$\in \mathbb{R}^2$, Poistion
C_{P_i}	A class with center P_i
W	Profit
N	The number of fish caught
d	Distance
a, b	The price coefficients of different types of fish
m	Scale factor
λ	Trade-off parameter of the regularization term
Ω	A set containing multiple positions on the discrete map

2.3 Data Acquisition

In this paper, we collected the sea teapreature data from 2004-2020 as the basis of this question. The data we collected is from `https://www.metoffice.gov.uk/hadobs/hadisst/data/download.html`.

The collected data is a third-order tensor that contains the temperature data at various longitudes, latitudes, and times. The data format is shown in Fig. 1.

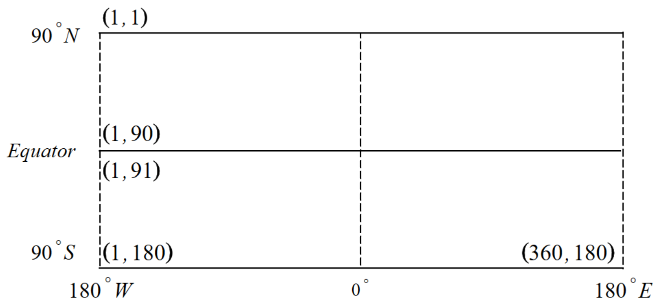


Figure 1: The data format diagram. This is a two dimensional matrix temperature data.

The studied area (in view of the longitude and latitude) is shown in Fig. 3. We mainly consider the waters around Scotland, as well as Scotland's own territory. At the same time, other territories, such as Northern Ireland, will also be taken into account in future issues. This is because we will put forward different fishing plans and company relocation plans according to the problems. Therefore, this map well covers the scope of our research.

In order to make the data graphical, we convert the data into RGB format, and get the global temperature map. Corresponding to the data we collected, our studied area can be easily found in the spatial domain. In order to simplify the problem as well as to well correspond to the data collected, we simplify the region to a discrete two-dimensional coordinate system, as seen in Fig. 2.

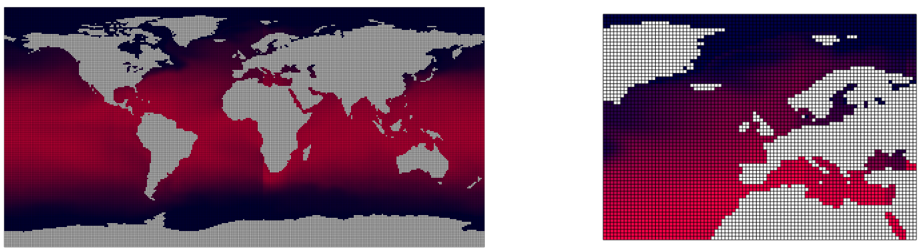


Figure 2: Left: The studied discrete two-dimensional coordinate system of the global temperature map. Right: The studied discrete two-dimensional coordinate system of the Scotland area.

It is worth noting that the advantages of our two-dimensional discrete coordinate system are the better use of cellular automata for simulation. At the same time, the two-dimensional discrete coordinate system can efficiently simulate the geographical location, the movement of fish and fishing boats, and the calculation of distance.

3 The Models

3.1 Fish Movements

Atlantic herring is widely distributed in the northeast of the Atlantic Ocean, from the Arctic ocean to the southern English channel. The number of mackerel in the ocean depends on the number of juveniles every year, from spawning to entering adulthood as a recruit. The two types of studied fish are very sensitive to the change of water temperature, and can adapt to a narrow range of temperature changes. The stability of seawater temperature is the premise of raising good seawater fish.

Although the swimming direction of each individual does not necessarily follow the migration law, according to the law of large numbers, the behavior of the group will exclude the existence of unpredictable accidental factors, so we can predict the migration direction of fish by predicting the change of ocean temperature. Thus, we first conduct the tempreature prediction. Then, we employ the cellular automata to simulate the movments of the fish in order to give the specific position of the fish after 50 years.

3.1.1 Tempreature Prediction Using ARIMA

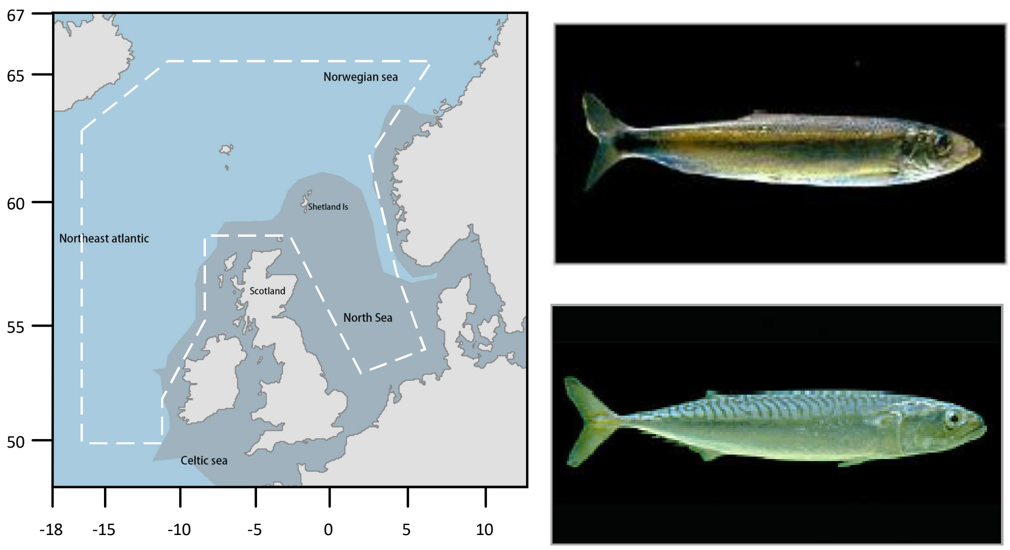


Figure 3: Left: the studied area of this paper. Right: the studied two types of fish herring and mackerel.

In determining the location of fish, we need to know the sea water temperature and the change of sea water temperature after many years. Since the temperature data is limited to 2004-2020, it is necessary to expand and forecast the temperature data. Generally speaking, this is a typical time series prediction problem. Therefore, ARIMA [10, 11], which is widely used and has good effect, is used to predict the sea water temperature.

ARIMA is one of the time series prediction and analysis methods. In ARIMA(p,d,q), AR stands for autoregressive, p is the number of autoregressive terms. MA is moving average, q is the number of moving average terms, and d is the difference degree (order) to make it a stationary sequence. Although the word "difference" does not appear in the English name of ARIMA, it is a key step.

After eliminating the local level or trend, non-stationary time series show some homogeneity, that is to say, some parts of the series are very similar to others. This kind of non-stationary time series can be transformed into stationary time series after difference processing, which is called homogeneous non-stationary time series, and the degree of difference is the homogeneous order. Let Δ be the differetial operator, then we have

$$\Delta^2 y_t = \Delta(y_t - y_{t-1}) = y_t - 2y_{t-1} + y_{t-2}. \tag{1}$$

As for the delay operator $\mathscr{B}$, we have

$$y_{t-p} = \mathscr{B}^p y_t, \forall p \geq 1. \tag{2}$$

Then, there derives

$$\Delta^k = (1-\mathscr{B})^k. \tag{3}$$

If d-order second non-stationary time series y_t is set, then there is a stationary time series $\Delta^d y_t$, then it can be set as ARMA(p,q) model, which could be described as

$$\lambda(\mathscr{B})(\Delta^d y_t) = \theta(\mathscr{B})\varepsilon_t, \tag{4}$$

where $\lambda(\mathscr{B}) = 1 - \lambda_1\mathscr{B} - \lambda_2\mathscr{B}^2 - \cdots - \lambda_p\mathscr{B}^p$ and $\theta(\mathscr{B}) = 1 - \theta_1\mathscr{B} - \theta_2\mathscr{B}^2 - \cdots - \theta_p\mathscr{B}^p$ are the autoregressive coefficient polynomial and moving average coefficient polynomial, respectively. ε_t denotes the white noise sequence. The ARIMA(p,d,q) model can be expressed as

$$(1 - \sum_{i=1}^{p} \phi_i L^i)(1-L)^d X_t = (1 + \sum_{i=1}^{q} \theta_i L^i)\varepsilon_t, \tag{5}$$

where L denotes the lag operator, $d \in \mathbb{Z}$.

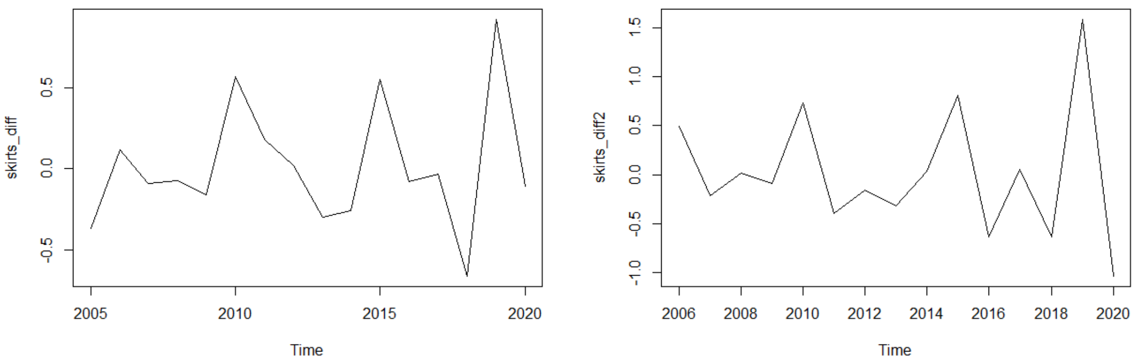


Figure 4: Left: first order difference of the collected data. Right: second order difference of the collected data.

When the difference order d is 0, the ARIMA model (5) is equivalent to ARMA model (4), that is, the difference between the two models is whether the difference order d is equal to zero, i.e., whether the sequence is stationary. ARIMA model corresponds to non-stationary time series, ARMA model corresponds to stationary time series.

The visualizations of the data difference and the self / parital correlation of the collected original data are shown in Fig. 4 and Fig. 5, respectivelt. It is notable that the first-order difference of the data is still unstable. However, the second-order difference of the data shows some stationarity. Thus, we set $p = 5$ as the order of λ, θ. In Fig. 5, it is notable that the self-correlation is high in the first lag, and the correlation value converges smoothly to a smaller value. For the partial correlation, we can see that there is a considerable correlation between different data we collected. Therefore, we set $q = 1, d = 0$ for the further implementation.

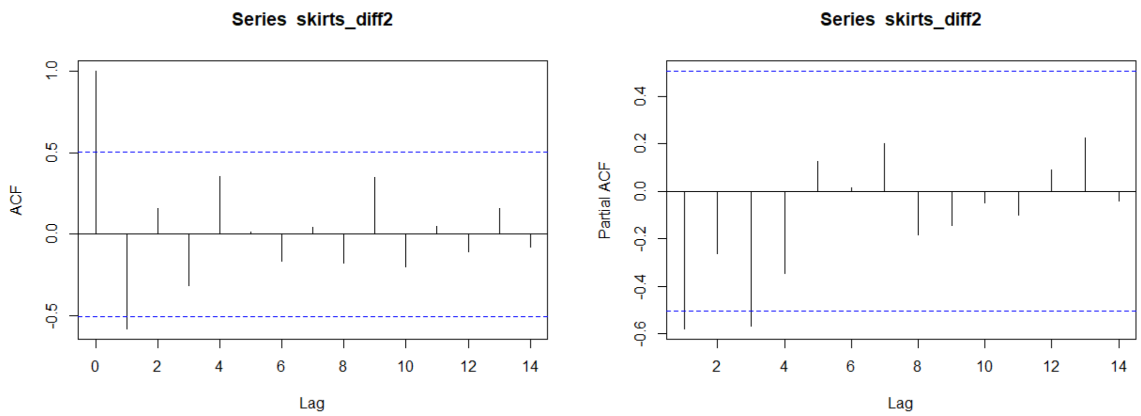


Figure 5: Left: visualization of autocorrelation degree. Right: partial correlation degree visualization.

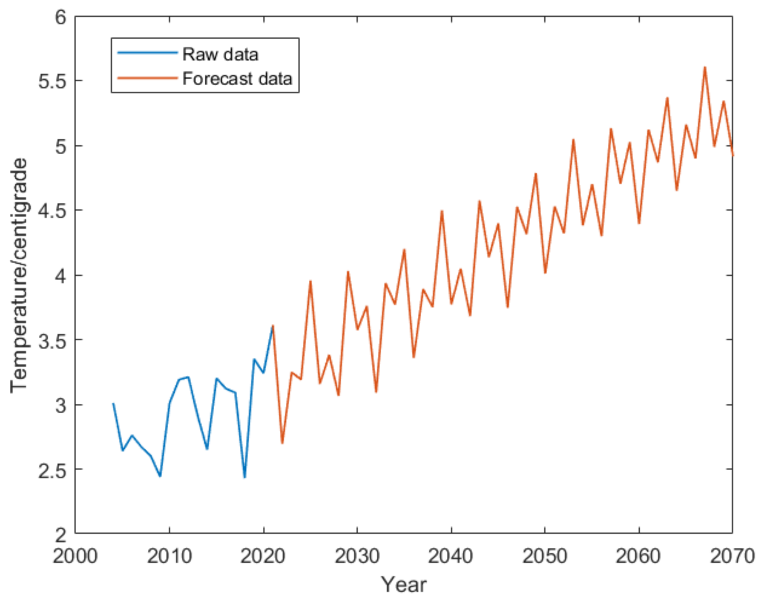


Figure 6: The visualization of prediction results using ARIMA model (5).

The visualization of prediction results in a certain position is shown in Fig. 6. We can see that on the basis of time series, our ARIMA model can well predict the temperature and transformation of seawater in the future. This provides a good foundation for our future work.

The forecast error is shown in Fig. 7. We can find that the prediction error of the model is concentrated around 0, which demonstrates the effectiveness of model (5).

After predicting the sea tempreature, we subsequently use the cellular automata to simulate the discrete process of the movements of the fish group.

3.1.2 Fish Position

In order to simplify the problem, we discuss it in two-dimensional discrete space. This is because the change of ocean depth is ignored in the process of fish migration. In fact, in a relatively long time span, the migration range of fish is far larger than its depth change range, so the depth change in the process of fish migration can be ignored. In this way, cellular automata can be used. Specifically, each fish group is set as a cell $F_i \in \mathbb{R}^2$. The rule of cell position updating is: If there is an optimal temperature around the cell (defined as the temperature closest

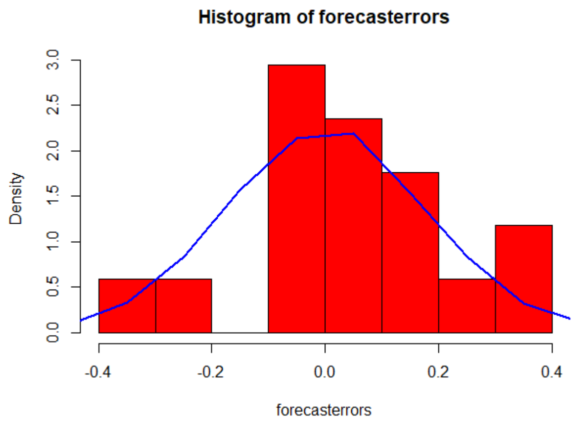


Figure 7: The forecast error of our ARIMA model (5).

to the ideal temperature of the fish), the cell moves one unit to this position. Otherwise, the cells of the fish swarm move one unit at random. The total simulation time is 50 years. Let S_j denote the 8 pixels around F_i, the updating process can be described as

$$\begin{cases} F_i \leftarrow F_i + S_{best}, \ |S_{best} - t_i| < |S_j - t_i| \ \forall j, \\ F_i \leftarrow F_i + S_{rand}, \ \text{else}. \end{cases} \tag{6}$$

It is assumed that at the begining stage, the fish groups are located at multiple positions with suitable tempreature and is under the fishing ability of the port. That is, we use d to denote the sailing distance (the distance between the port and the position of the fish group). And the initial position of the fish groups is located inside the circle, as shown in Fig. 8.

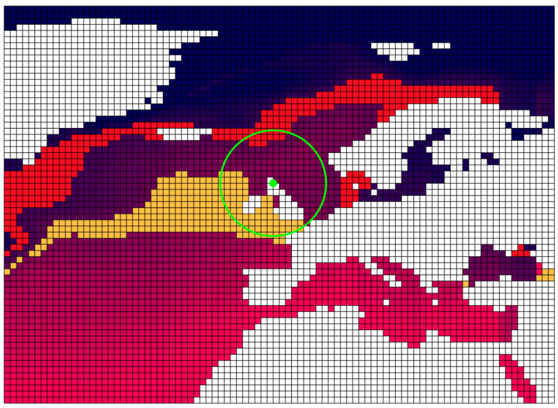


Figure 8: The fishing range of the original port: a circle centered on the port.

Thus, after the simulation process, there are multiple possible positions of the fish. Thus, it is of needs to determine the final position by using other techniques. This is expected to be achieved via splitting the target groups into different classes, and choose the class with the most fish groups.

We employ the K-mean algorithm to split the fish group into different classes. Specifically, there are 5 random initial positions $P_i, i = 1, \cdots, 5$. For each fish group F_j, we iteratively solve the optimization problem

$$P = \arg\min_{P_i} \sqrt{(P_i(1) - F_j(1))^2 + (P_i(2) - F_j(2))^2}. \tag{7}$$

The optimization is solved by traversing all the positions. Then, the group F_j is set as a member of P. And the class center is updated based on the groups that belong to this class, i.e.,

$$P = \arg\min_{(x,y)} \sum_j \sqrt{(x - F_j(1))^2 + (y - F_j(2))^2}. \tag{8}$$

This model is also solved via traversing. Collectively, we do the above process until the process convergent.

At last, five classes are established. The final position of the fish group is selected by counting number of the groups in each class. The class center whose corresponding class has the most groups is picked as the final position, i.e.

$$P_{final} = \arg\min_{P_i} |C_{P_i}|, \tag{9}$$

where $|C|$ denotes the number of groups in class C.

3.1.3 Final Model

Based on the above anaylasis, the final model that determine the final position of the fish after 50 years is expressed as

$$\begin{cases} (Tempreature\ prediction) \\ (1 - \sum_{i=1}^{p} \phi_i L^i)(1-L)^d X_t = (1 + \sum_{i=1}^{q} \theta_i L^i)\varepsilon_t, \\ (Cellular\ automata) \\ F_i \leftarrow F_i + S_{best},\ |S_{best} - t_i| < |S_j - t_i|\ \forall j, \\ F_i \leftarrow F_i + S_{rand},\ \text{else}, \\ (K - mean) \\ P = \arg\min_{P_i} \sqrt{(P_i(1) - F_j(1))^2 + (P_i(2) - F_j(2))^2}, \\ P = \arg\min_{(x,y)} \sum_j \sqrt{(x - F_j(1))^2 + (y - F_j(2))^2}, \end{cases} \tag{10}$$

3.1.4 Model Solution

The algorithm to solve model (10) is shown in Table 2. The best tempreature S_{best} for each types of fish is $[9.7°C, 12.2°C]$ for herring and $[3.7°C, 6.2°C]$ for markerel. In order to simplify the simulation process, we simply consider the optimum temperature are $9.7°C$ and $3.7°C$. The best tempreature data of the two types of fish is collected from [9].

For the first question, the simulation results are shown in Fig. 9.

We can clearly see from Fig. 9 that the cellular automata model considerably predicts the flow position of the fish groups. Based on the results, we would give theoretical analysis to the fishing strategy.

Table 2: The solution of the proposed model (10).

1 Question 1
1: **input** : Tempreature data y_t, map of Scotland
2: Predict tempreature via (5) and y_t
3: Initialize fish positions F_i
4: **for** $t = 2020 - 2070$
5: Update F_i via (6)
6: **end for**
7: Split the groups via (7) and (8)
8: Determine the final position via (9)
9: **output** : P_{final}

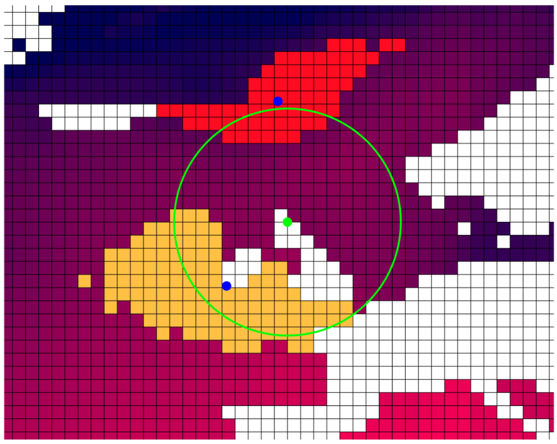


Figure 9: The trajectories of the two species in 50 years. The yellow denotes the herring and the red denotes the markerel. The green circle represents the fishing range. The final positions are represented by blue.

3.2 Company Strategy

This section fisrtly answer the second question based on a cost and profit model. Then, in question 3, it is expected to determine if the company needs to change its fishing strategy. We think from two perspectives. First of all, our answer is yes.

If we do not change the mode of operation, we will achieve the economic benefits. From the above analysis, we can see that with the increase of ocean temperature, the fish move northward. Therefore, if the business model is not changed, the amount of herring and mackerel that fishermen can catch will gradually decrease over time. As time goes on, fishermen will have no fish to catch. Obviously, this method is not desirable.

Specifically, we think that we should consider the relocation of some of the company or the whole company to move to other place. At the same time, we should consider the use of fishing boats without subgrade.

In order to quantify the implementation of these strategies, we first build a concise model which describes the relationship of te cost and profit. Then, we build an optimization model to maximize benefits and minimize costs to tell the company what to do. We use traversal algorithm to solve our optimization models.

3.2.1 Cost and Profit

In the actual fishing process, the sailing distance may greatly affect the fishing cost. As seen in Fig. 8, it is assumed that the original fishing range of the port is a circle centered on the port. Thus, the sailing distance is different for each position of the fish and the cost is then different.

For the position of the original port, we chose the largest port in Scotland, i.e., Aberdeen port. The location of the original port is shown in Fig. 10. In order to simplify the problem, we

Figure 10: The location of the original port. The port is pointed by blue cross.

determine the position of the port in the two-dimensional coordinate system. In this way, the initial position of the port and its fishing range can be determined.

Meanwhile, the benefits of fishing are different for different species. Therefore, it is necessary to establish an effective cost-profit model for the follow-up work.

The cost of $1km$ of the ship (mostly spend on oil) is c, and the profit is fixed as $a = 5$ for mackerel and $b = 9$ (The unit is \$) for herring. The final profit is

$$W = N(a+b) - d \times c, \tag{11}$$

where N is the catch for both types of fish.

For the second question, we need to determine the best and worst case scenarios for the duration of harvesting. Here, it is considered that once $W < 0$, then it is impossible to gain profit. Thus, in such condition, there is no harvest in fishing.

For the fishing range, it is considered that the deep sea fish can be preserved for two days by salting. According to the data, the speed of the fishing boat is about $18.52km/h$, so the control range is about $888.96km$ (We convert it to discrete distance). If the fish position is out of this range, we consider that $N = 0$.

The ergodic process of the second question is shown in Fig. 11. Finally, based on the cellular automata and the profit model whose simulation process based on randomness, we have the worst condition is in 2023, the original port could not gain profit anymore ($W < 0$). However, the best condition shows that it is until 2069 that the port can still gain profit. The most possible condition is in 2036, the port could not gain profit.

3.2.2 Optimization Model

In the third question, it is expected to determine whether the company should change the position of some of its assets. Then, it is expected to determine whether the fishing boats without subgrade should be employed.

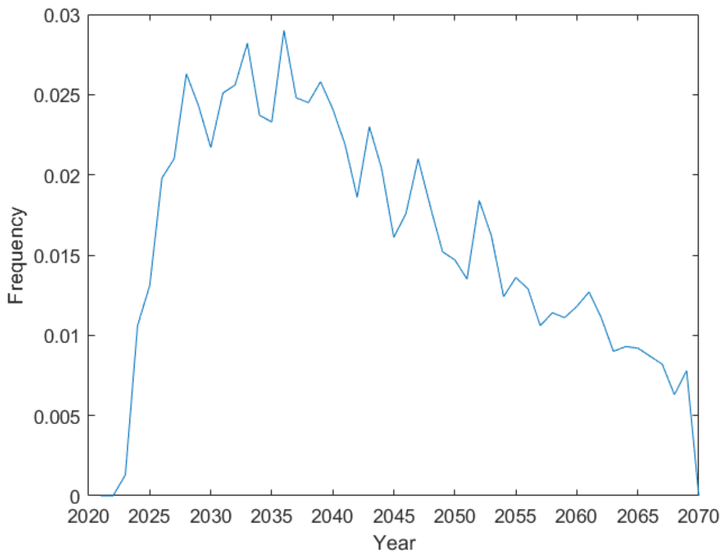


Figure 11: The ergodic process of the second question.

We firstly consider the first strategy, i.e., the position changes. We denote the changed position as $P_{company}$. Also, it should be clarified that whether the company should change all its assets or just part of ite assets. In that case, we employ m to denote the asset ratio of the original company and the company after the change of position. Naturally, the profit of the two ports are divided via m. That is, the total profit from fishing is

$$\text{Profit} = m \times (\frac{a}{d_1} + \frac{b}{d_2}) + (1-m) \times (\frac{a}{d_3} + \frac{b}{d_4}), \tag{12}$$

where d denotes the distance between the fish group and the port a, b denote the coefficient of different types of fish (basically determined via the price and the fishing cost). In the above formula, we use a constant multiple of the reciprocal of the distance as the profit. This is because the shorter the fishing distance, generally speaking, the higher the benefit.

In the other way, it is considered that the relocation distance of some assets of the company is directly proportional to the cost. Thus, we have the reciprocal of the cost, which is expressed as

$$\text{Cost}^{-1} = \frac{\lambda}{d_l}, \tag{13}$$

where λ is a trade-off parameter. In the following potimization model, we add this term as a regularization to constraint the profit term. Thus, we can build a standard fidelity-regularization optimization problem to determine the best position of the changed port. The re-formulated cost and profit model for the question 3 is

$$W = m \times (\frac{a}{d_1} + \frac{b}{d_2}) + (1-m) \times (\frac{a}{d_3} + \frac{b}{d_4}) + \frac{\lambda}{d_l}. \tag{14}$$

Maximizing W is our goal. Note that the port must be on the ground, so we consider the problem inside the scotland Ω_G.

In fact, it is also expected to determine whether the port should be entirely changed or just part of it. Thus, the proportion m is also set as the optimization target. Finally, for the position of the company, we have the following optimization model

$$P_{company}, m^* = \arg\max_{(x,y),m} m \times (\frac{a}{d_1} + \frac{b}{d_2}) + (1-m) \times (\frac{a}{d_3} + \frac{b}{d_4}) + \frac{\lambda}{d_l}$$
$$\text{s.t.} \begin{cases} m \in [0,1] \\ (x,y) \in \mathbb{R}^2 \\ d = \sqrt{(x - P_{final}(1))^2 + (y - P_{final}(2))^2} \\ (x,y) \in \Omega_G \end{cases} \tag{15}$$

For the position of the fishing boats without subgrade, we consider that ships that do not need land support can build fishing systems at sea. As a result, like land ports, such boats can locate and fish at sea.

The problem is to determine the best position of such boat. The number of ships dispatched (i.e., the proportion m) also needs to be determined. Because the model considers the influence of sea surface temperature change on fish migration direction, and then compares and analyzes the fishing strategies adopted by fishery companies before and after fish migration. Only when the external conditions are consistent, this comparison is meaningful. Thus, we neglect other factors and formulate the following optimization model

$$P_{boat}, m^* = \arg\max_{(x,y),m} m \times (\frac{a}{d_1} + \frac{b}{d_2}) + (1-m) \times (\frac{a}{d_3} + \frac{b}{d_4}) + \frac{\lambda}{d_l}$$
$$\text{s.t.} \begin{cases} m \in [0,1] \\ (x,y) \in \mathbb{R}^2 \\ d = \sqrt{(x - P_{final}(1))^2 + (y - P_{final}(2))^2} \\ (x,y) \in \Omega_G \cup \Omega_S, \end{cases} \tag{16}$$

where Ω_S denotes the sea area.

3.2.3 Model Solution

The algorithm to solve model (15) is shown in Table 3. Similarly, the algorithm to solve model (16) is also presented as Table 3, where the only difference is the traversal region. For model (15), the traversal region is Ω_G. For model (16), the traversal region is $\Omega_G \cup \Omega_S$.

After the ergodic, we have the best position of the changed port is located at the very north-west of scotland and $m = 1$, i.e., it is recommended that all the company assets should change to the new location. The position of the result is shown in Fig. 12.

For the fishing boats without subgrade, we have the best position of the boat located at nearly the center of the P_{final} of two types of fish and $m = 1$. The position of the result is shown in Fig. 13. It should be clarified that $m = 1$ in this problem is unrealistic. Thus, if we consider the cost (λ is big), it is better to send fewer boats. However, to gain more fishes and profits (λ is low), more boats could be employed.

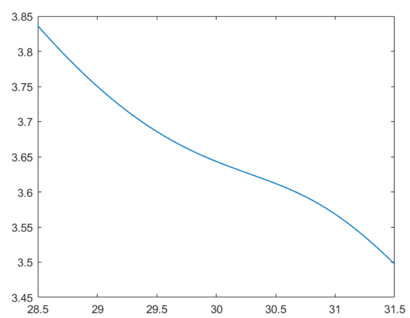
3.3 Port Changes

In question 4, it is expected to assess the feasibility and benefits of moving the port to another country. We also tackle this problem by using optimization model and solving it by the ergodic.

Table 3: The solution of the proposed model (15).

1 Question 3

input : Fish position P_{final}, map of Scotland, area Ω_G
Initialize positions (x_0, y_0)
$W_{max} = 0$
for $x = x_0 : x_{last}$
  for $y = y_0 : y_{last}$
    if $(x, y) \notin \Omega_G$
      continue
    end if
    for $m = 0 : 1$
      $d = \sqrt{(x - P_{final}(1))^2 + (y - P_{final}(2))^2}$
      Compute W via (14)
      if $W > W_{max}$
        $W_{max} = W$
        $P_{company} = (x, y)$
      end if
    end for
  end for
end for
output: $P_{company}$



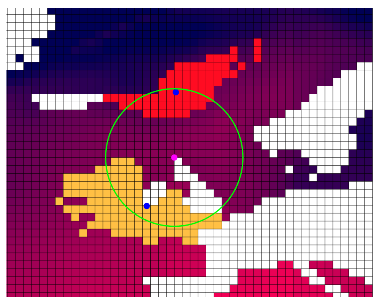
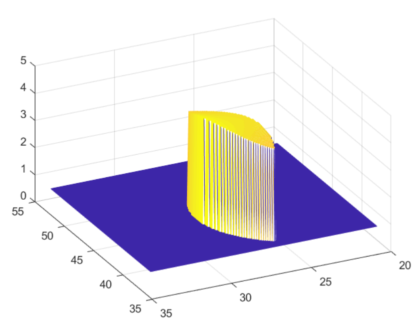


Figure 12: Left: the traversal process corresponding to the company's asset relocation of question 3. Right: the location of the relocated company (denoted by purple).



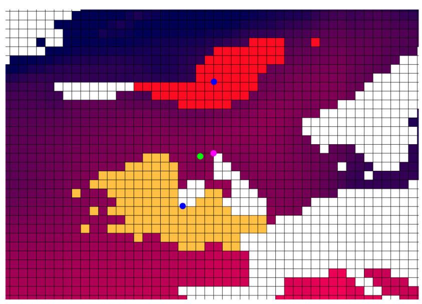


Figure 13: Left: the traversal process corresponding to the fishing boats without subgrade of question 3. Right: the location of the fishing boats (denoted by green).

3.3.1 Optimization Model

If some of the fisheries are relocated to other countries, then some characteristics will change. Specifically, the fishing company will have two ports. One of the ports is in Scotland and the other is chosen in Northern Ireland. Therefore, similar to the previous optimization model, we only need to set the traversal range on two pieces of land, i.e., the scotland Ω_G and the Northern Ireland $\Omega_{G_{out}}$. Specifically, the port in Scotland is fixed and we only need to determine the position of the port on Greenland.

For the position of the port outside the Scotland, we have the following optimization model

$$
\begin{aligned}
&P_{port}, m^* = \arg \max_{(x,y),m} \; m \times (\frac{a}{d_1} + \frac{b}{d_2}) + (1-m) \times (\frac{a}{d_3} + \frac{b}{d_4}) + \frac{\lambda}{d_l} \\
&\text{s.t.} \begin{cases} m \in [0,1] \\ (x,y) \in \mathbb{R}^2 \\ d = \sqrt{(x - P_{final}(1))^2 + (y - P_{final}(2))^2} \\ (x,y) \in \Omega_{G_{\text{out}}} \end{cases}
\end{aligned}
\tag{17}
$$

3.3.2 Model Solution

The algorithm to solve model (17) is shown in Table 4.

Table 4: The solution of the proposed model (17).

1 Question 4

input : Fish position P_{final}, map of Scotland, area $\Omega_{G_{out}}$
Initialize positions (x_0, y_0)
$W_{max} = 0$
for $x = x_0 : x_{last}$
  for $y = y_0 : y_{last}$
    if $(x,y) \notin \Omega_G \cup \Omega_{G_{out}}$
      continue
    end if
    for $m = 0 : 1$
      $d = \sqrt{(x - P_{final}(1))^2 + (y - P_{final}(2))^2}$
      Compute W via (14)
      if $W > W_{max}$
        $W_{max} = W$
        $P_{company} = (x,y)$
      end if
    end for
  end for
end for
output: $P_{company}$

For the port on the other country, we have the best position of the port northeast of Northern Ireland and $m = 1$. The position of the result is shown in Fig. 14. It needs to be clarified that $m = 1$is unrealistic in this issue. Therefore, if we consider the cost (λ is very large), we would better send less assets to the other country. However, in order to get more fish and profits (λ is very small), more assets can be changed to the other country.

3.4 Summary and Suggestions

In total, by establishing Arima prediction model, the temperature change in the North Atlantic is analyzed, and the annual temperature change rate in the next 50 years is predicted. In the worst case, it is predicted that there will be no herring and mackerel around Scotland in 2023 at this rate of change; in the best case, it is predicted that there will be no herring and mackerel around Scotland in 2069 at this rate of change. In order to improve the future business prospects of fishermen, we put forward a variety of new management methods, and quantified the economic benefits of these methods by establishing interest models.

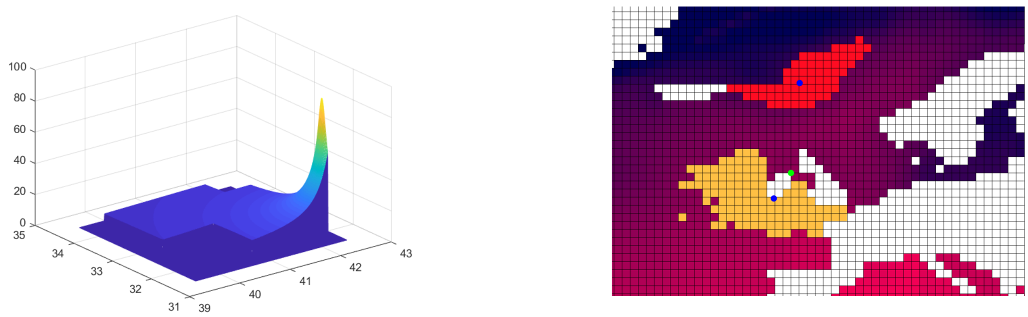


Figure 14: Left: the traversal process corresponding to question 4. Right: the location of the relocated company outside the Scotland (denoted by green).

In order to cope with the expected revenue loss, we propose the following four strategies:

- Move northward to a better fishing port (e.g., Northern Ireland). The financial model predicts that according to the current method, fishery companies in the north will generate much profit and revenue in revenue in the next 50 years, while fishery companies in the South will only generate much less.
- Concentrate on mackerel rather than herring. Although not immune, mackerel is expected to be more resistant to temperature changes in the next few years, and its price is more preferable.
- Move the original port to another position in Scotland or other country. Meanwhile, employ the small boats that do not need the land as basis.
- Upgrade existing fishing vessel assets. If the company have not filled your ship's capacity yet, upgrading to onboard refrigeration or faster engines (which menas faster speed and less cost on the wey) can increase your net revenue from small to large.

4 Strengths and Weaknesses

In this paper, we peopose to use the cellular automata to simulate the movements of the fish group. In the second and third questions, we suggest to build optimization models to determine the best position of the port and the company. The strengths of the proposed model are:

4.1 Strengths

- Our K-mean algorithm can well estimate the position of fish after 50 years. In this way, the location of fish can provide essential basis for port and company strategy.
- Our cellular automata can well simulate the range and direction of fish. According to the seawater temperature predicted by ARIMA model, cellular automata can flexibly and effectively predict the position of fish swarm.
- Our optimization model well describes where fishing vessels and companies can have the greatest interests. In this way, they can change and transfer their positions according to the results of our model.
- In the third problem, we add a regularization term based on migration cost to describe the relationship between migration cost and migration benefit. In this way, our optimization model is more robust and interpretable.

However, there are weaknesses of the proposed model:

4.2 Weaknesses

- Our cellular automata has shortcomings in step size selection. Our step size is fixed and artificially designed. This setting lacks flexibility.
- Our port recommended relocation location is not specific. Further analysis is needed to determine the specific migration location and scheme.
- Our optimization model is difficult to find an analytical solution. Therefore, more computationally friendly models need to be studied.

5 Sensitivity Analysis

We test the sensitivity by adjusting different parameters in the model. First, our K-means algorithm gets the same result when selecting different initial centers, which shows that K-means algorithm is not sensitive to the initial centers using our selected features. Second, we reduce the coefficient of the cellular automata, so that we can consider different situations of the movements of the fish. The results show that different step size and initial point would considerably change the final position of the fish. Finally, we apply different values to the trade-off parameters in our potimization model and find that our model is sensitive to the trade-off parameters. This is quite reasonable since the parameter in the objective function is critical to balance the fidelity and regularization. Also, the intrinsic parameters such as the price of the fish and the cost of the oil are sensitive parameters to the proposed models.

6 Memorandum

To: Hook Line and Sinker Magazine
From: Team 1234567
Date: January 31, 2021

Subject: The impact of human activities on the earth's climate is intensifying. The combustion of a large number of fossil fuels produces greenhouse gases, which wrap the earth in the hot mantle and make the earth's surface warm gradually. In the past decades, we have seen the impact of global warming on the environment: the redistribution of global rainfall, the melting of glaciers and permafrost, the rise of sea level and so on. These changes endanger the balance of natural ecosystems and change the habitats of animals.

Lobsters originally living in Maine are slowly moving north to Canada due to rising ocean temperatures, according to marine scientists. This phenomenon has attracted our attention. We know that this kind of geographical migration may have a huge impact on fishing companies, especially small and medium-sized companies. Fishing companies may be forced to go further to keep up with the migration, which will require more labor and capital investment. Therefore, fisheries will face severe economic challenges.

In order to further understand this problem, we use cellular automata and optimization method to solve the problem of fishery management strategy design under species migration.

First, we collected sea surface temperature changes in the Northeast Atlantic and North Sea over the past 40 years. According to the development trend of sea surface temperature, the periodic variation of sea surface temperature is systematically described, and the prediction model of sea surface temperature in the next 50 years is established. In order to identify the location of herring and mackerel, we established cellular automata. The rule of cellular automata is that if there is no suitable temperature around the fish, the fish (cells) move one step randomly. If the fish is at the right temperature, move a device in the right direction. Combined with the predicted temperature data, the model accurately reflects the migration direction and location of herring and mackerel in 2070.

Secondly, the relationship between speed and ship design parameters is studied, and the relationship model between range and fuel consumption is established. At the same time, we consider the capture value of these two kinds of fish. Then, the interest rate calculation model is established. A large number of results accurately estimate the average uptime of each port under the best and worst conditions.

Based on the above analysis, we believe that small fishery enterprises should change their business model. We believe that port location and small fishing boats are necessary. According to the change of port location, an optimization model is designed to maximize the profit, and the optimization model is solved by direct traversal method. Reasonable results show the effectiveness of the model.

Finally, we make a sensitivity analysis and discuss the factors that affect the yield. Help fishermen analyze the severity of current problems and provide solutions to improve their business in a simple way.

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