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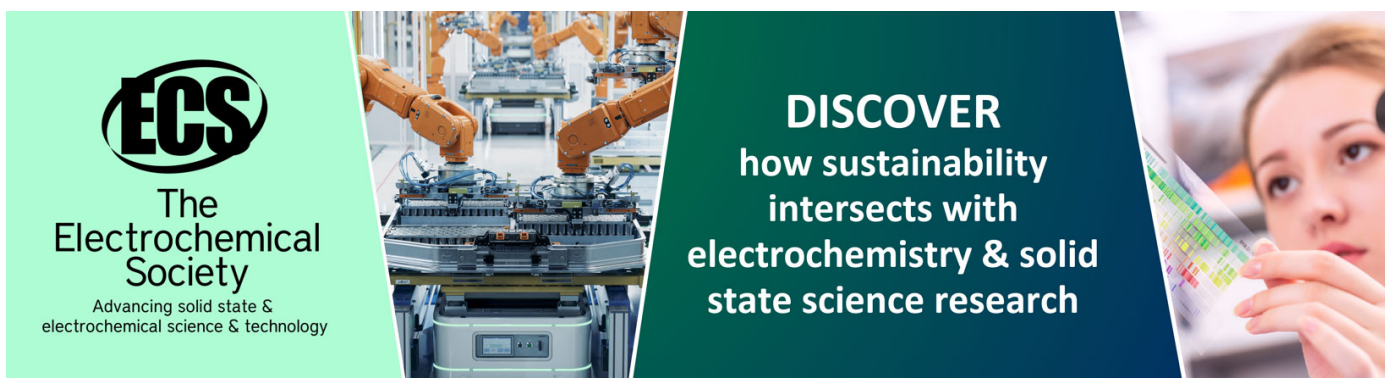
Fishery migration under the influence of global warming

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Fishery migration under the influence of global warming

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Abstract. With the pace of global warming getting faster and faster, the temperature of the sea is gradually rising. Meanwhile, Scotland, located on the east coast of the North Atlantic, is facing a serious problem: how to develop their fishing industry while fish are migrating. In this article, we will use a series of models to analyze the current situation and recommend some ways for the development of small Scottish fishing companies. In Task 1, based on the sufficient global ocean temperature data recorded by the Met Office Hadley Centre, we firstly used the convolutional neural network (CNN) model to learn the ocean temperature change in the waters around Scotland in the past 50 years, to find out the changing trend and make a reasonable prediction on the sea temperature (SST) change in the next 50 years. Then, by using the obtained data in ocean temperature, continental shelves, and ocean currents, the behavior of herring and mackerel was excavated and simulated. Besides, we build a double-objective Linear Programming (DLP) model to predict the location of these two fish species in the next 50 years, based on the distribution patterns of the Scottish fisheries over the past 50 years. What's more, we also performed the Process of Gridding on the map of Scotland, making all the models easier to calculate. In Task 2, we used the Logistic Growth Model (LGM) to establish a freshness model for captured fish, combined with the speed of a Scottish fishery boat to calculate the company's fishing range. Then we obtained the best and worst situations of the two fish habitats for the company's fishing business in the next 50 years through the fine-tuning of the parameters and sensitivity analysis. Also, we predicted the most likely future time for the company to be unable to continue fishing if maintaining a former strategy. In Task 3, we simulated the model in Task 2 to obtain a fish freshness model with refrigeration equipment, which provides basic elements needed for relocating a fishing port or updating fishing boats. Lastly, through the establishment of the Abstract Value-Estimated Model (AVEM), we roughly calculated the value of the two schemes to finally assure that the relocation of the fishing port was more economical. Although we did a lot of research to improve the accuracy of our work, the political decision of the government will change indefinitely, which means that our research still needs some innovational work before the actual adjustments of Scottish fishery.

Keywords: CNN; SST; DLP; Gridding; LGM; AVEM.



1. Introduction

1.1. Problem Statement and Analysis

Due to global warming, in addition to causing the shrink of Arctic and Antarctic ice circles and the rise of sea levels, the global ocean temperature will also rise to a certain extent, so that the habitat of marine fishes will move to the north. In order to ensure the rights and interests of the small Scottish fishing companies, it is very important to plan ahead. What we urgently need to determine is where herring and mackerel are most likely to migrate in the next 50 years. To this end, we need to consider the changes in seawater temperature around Scotland in the next 50 years and other factors affecting habitat. Once obtaining the position, we need to analyze the longest time that the small fishing company can continue to fish at the current position, and the most likely time for change. In addition, we need to advise the company: relocate all of the company's assets, or use a small percentage of small fishing vessels to catch fish, which can fishing without land support for a period of time, while ensuring the freshness and quality.

2. Symbol Explanation

In the section, we use some symbols for constructing the model as follows:

Table 1. Symbols for constructing the model

Symbol	Definition
T	The temperature at different observation locations in ocean($^{\circ}\text{C}$)
T_{hotm}	The optimum temperature for herring
T_{motm}	The optimum temperature for mackerel
T_{hL}/T_{hU}	The minimum/maximum survival temperature for herring
T_{mL}/T_{mU}	The minimum/maximum survival temperature for mackerel
D	The shortest distance from 200 meters deep of the continental shelf to different observation locations(km)
L_o	The longitude of different observation locations
L_a	The latitude of different observation locations
P_r	The normal distribution function value of different observation locations
t	Storage time from catch the fish (day)
R_o^*	The degree of fish decay
R_o	The degree of fish decay adjusted
F_r	The freshness of fish
Π	The total value of the decision
x_{11}/x_{12}	The number of locations of herring/mackerel in fishing range in the next 50 years (no refrigeration)
x_{21}/x_{22}	The number of locations of herring/mackerel in fishing range in the next 50 years (with refrigeration)

3. Task I:

3.1. Sea Surface Temperature (SST) Predicting Model

Researching has never been stopped in predicting ocean temperatures. In the traditional statistical method, YXue presented using markov model to predict the coastal temperature of the tropical Pacific Ocean. [2] Landman et al. used linear prediction techniques based on statistic to predict the temperature. In landman's study, some typical variables were used for abnormal prediction of monthly SST. These typical variables were composed of the previously changing of SST and some invariant features. [3] In the neural network method, LinsID proposed a method combining support vector machine (SVM) and particle swarm optimization (PSO) in the study of ocean temperature prediction. [4] Patil et al. trained the neural networks of four kind of architectures using the previous 49 years and tested the data for the remaining 12 years. [5]

The existing methods show that data-driven models are very popular and neural networks are effective in predicting ocean temperature. Therefore, we use neural networks to predict the SST.

First of all, we obtained the data of nearly 50 years (1969- 2019) on the Met Office Hadley Centre. [6] After screening and extracting carefully, we constructed the four-dimensional feature (year, longitude, latitude and temperature) data set, which is called the SST data set.

Having got the SST data set above, now we want to predict the SST in 50 years within our programming area. Such being the case, we divided the data set into two parts, one is the training set (75% of origin set), the other is the testing set (25% of origin set). By using neural network, the training set is used to train the model and the testing set is used to test how accurate the model is. Next, we tent to illustrate the basic steps of building the neural network model.

Step1. Data Pre-processing,

To build an effective and accurate neural network model, firstly we should normalize the SST data to ensure all the data are at the same scale. In general, we use linear transformation equation to achieve data normalization which is showed in the following. The variable scaled is within from 0 to 1.

$$T_{norm} = \frac{T_{org} - T_{min}}{T_{max} - T_{min}}$$

Where T_{norm} is the data which has been normalized, T_{org} is the origin data in the data set, T_{min} is the minimum data in the data set, T_{max} is the maximum data in the data set.

Step2. Convolutional neural network building

At first, the origin SST data set include some land temperate, the test result is not conform to the real result (Figure 3.1), then we remove these data and train the model again (Figure 3.1), from the graph we can see the points are close to the line. To get more accurate and effective model, we increase the training epoch to 1000 (Figure 3.2) where the points are almost uniform distributed closely to the line.

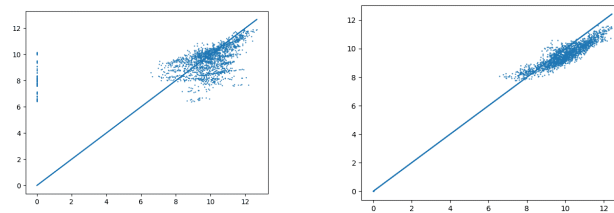


Figure 1. Data include land temperature and remove land temperature, training epoch=100

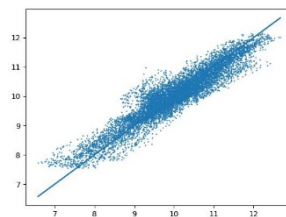


Figure 2. Remove land temperature, training epoch=1000

Having trained the model, we predict the SST data in the next 50 years. Apparently, the predicting SST data verify the validity of the SST predicting model. Now we get a map of the ocean temperature around Scotland between 2020 and 2069.

Besides, we have found surviving temperature maps of herring and mackerel: [7]

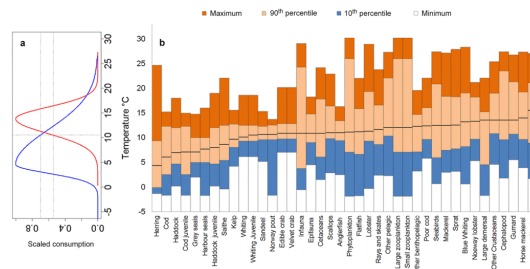


Figure 3. Some Temperature indexes of different fishes

From the figure we can know that the optimal surviving temperature for herring is 5°C, and the optimal surviving temperature for mackerel is 10°C. But herring and mackerel generally live at different depths, so we have to change the optimal temperature. Herring generally lives at a depth of 200 meters below the sea surface [9], so the temperature of the sea surface above should be increased by about 5°C, that is $T_{hotm} \approx 10^{\circ}C$. And Mackerel generally lives at a depth of 20 meters below the sea surface, so we ignore the deviation of temperature, that is $T_{motm} \approx 10^{\circ}C$

3.2. The process of gridding

We first analyzed the seawaters around Scotland, and finally selected the range that from 12.5°W to 5.5°E and 55.5°N to 64.5°N for research. Because the distance between adjacent latitudes is 111km, and since we are considering 60°N, the distance between adjacent longitudes is about 55.5km, so we converted the map into a 19 * 20 grid, each grid Corresponds to 1°longitude * 0.5°latitude. Then we establish a rectangular coordinate system, and gridding the observation points (L_o, L_a).

3.3. Prediction of habitat—double-objective Linear Programming Model

If we want to find the most suitable habitat, in addition to considering the influence of temperature, we should also consider the herring and mackerel spawning habits (herrings generally spawn at a depth of 200 meters on the continental shelf [9], mackerels spawn on the sea surface) [10], and whether the location facilitates spawning and the abundance of nutrients.

Since herrings generally spawn at a depth of 200 meters on the continental shelf [11], we find the ocean depth map of the sea near Scotland, and fine-tune the areas less than 200 meters into polygon to simplify calculation. Based on the shortest distance from each observation point in the grid to this polygon, the distance that herrings need to migrate during the spawning period is obtained to determine the possibility of living at that observation point.

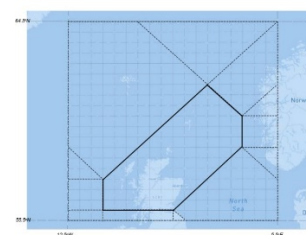
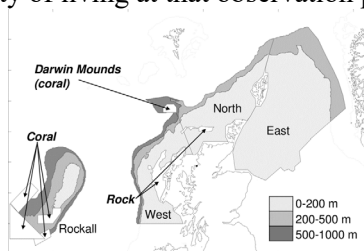


Figure 4. The ocean depth map of the sea near Scotland

While mackerel is not mandatory for spawning, so we do not consider the location requirements for spawning. Instead, we consider the impact of nutrient richness on the location of mackerel. A strong North Atlantic warm current passes through the waters of western Scotland, intersects with the cold water from the Arctic Ocean, causing the deep seawater to surge and form an ascending compensating flow. At the same time, it brings a lot of nutrients which is suitable for the growth of plankton (food for juvenile mackerel). Since the nutrients brought by the North Atlantic warm current will decrease from the central area to both sides, we naturally fit its distribution law with a normal distribution(ND).

According to the 3σ principle in ND, and the historical fishing area of the mackerel we found[8], the standard deviation($\sigma = 2\sqrt{2}$) was determined, and considering the nutrition-rich position will come with greater pressure of homospecies competition and natural enemy predation, so A competition-predator correction factor $C = 0.1$ was added to the ND function.

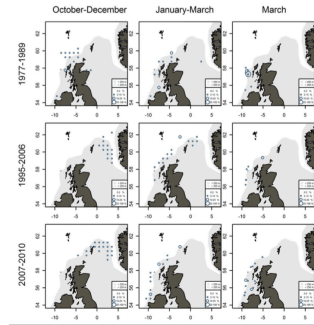


Figure 6. The historical fishing spot of mackerel

Based on the work we have done, we use these variables and data to establish DLP models for herring and mackerel positions, respectively.

3.3.1. The model of position of herring. Step I: Construct the mapping between the temperature of each observation point and its latitude and longitude coordinates

$$T = f(L_o, L_a)$$

Step II: Map the shortest distance between each observation point in the grid and the polygon to its latitude and longitude coordinates

$$D = g(L_o, L_a)$$

Step III: Construct the objective function P

$$\min P = \alpha_1 \left| \frac{T - T_{hotm}}{T_{hotm}} \right| + \alpha_2 \frac{D}{D_{max}}$$

$$s. t. \begin{cases} T_{hl} \leq T = f(L_o, L_a) \leq T_{hu} \\ D = g(L_o, L_a) \\ -12.5 \leq L_o \leq 5.5 \\ -55.5 \leq L_a \leq 64.5 \\ \alpha_1 + \alpha_2 = 1 \end{cases}$$

Among them, α_1 and α_2 are the parameters to be determined, $D_{max} = \max\{g(L_o, L_a)\}$

After Matlab's program simulation trials and the verification of actual fishing areas from 1970 to 2019, we got the best parameters $\alpha_1 = 0.7$, $\alpha_2 = 0.3$, $T_{hotm} = 10.2^\circ\text{C}$

And the location of herring habitat from 1970 to 2069.

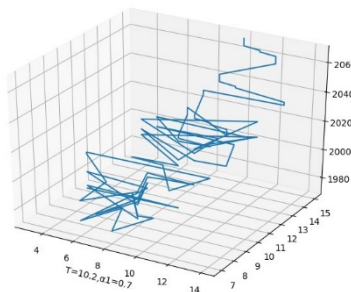


Figure 7. The location of herring habitat in 1970-2069

3.3.2. The Model of Position of Mackerel. Step I: Inherit the mapping of temperature and latitude and longitude coordinates constructed in 3.3.1

$$T = f(L_o, L_a)$$

Step II: Construct a mapping of ND function and latitude and longitude coordinates

$$\begin{cases} d = \frac{|x - y|}{\sqrt{2}} \\ P_r = 2\Phi\left(\frac{d}{\alpha}\right) - 1 \end{cases}$$

Where d is the distance from any point (x, y) to the centerline of the North Atlantic warm current, $\Phi(x)$ is the distribution function of the standard normal distribution.

By the inverse transformation above, you can get

$$P_r = h(L_o, L_a)$$

Step III: Construct the objective function P

$$\begin{aligned} \min P &= \beta_1 \left| \frac{T - T_{motm}}{T_{motm}} \right| + \beta_2 C P_r \\ \text{s.t.} \quad &\begin{cases} T_{ml} \leq T = f(L_o, L_a) \leq T_{mU} \\ P_r = h(L_o, L_a) \\ -12.5 \leq L_o \leq 5.5 \\ -55.5 \leq L_a \leq 64.5 \\ \beta_1 + \beta_2 = 1 \end{cases} \end{aligned}$$

Where β_1 and β_2 are the parameters to be determined.

After Matlab's program simulation trials and the verification of actual fishing areas from 1970 to 2019, we get the best parameters

$$\beta_1 = 0.9, \beta_2 = 0.1, T_{motm} = 10.3^\circ\text{C}$$

And the location of the mackerel habitat from 1970 to 2069.

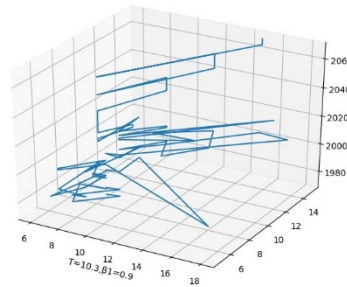


Figure 8. The location of mackerel habitat in 1970-2069

4. Task II:

4.1. Fish Freshness Model Based on Logistic Growth Model(LGM)

We notice that the Decline of the freshness of fish will go through slow, then fast, and finally slow by looking up information. If the fish is covered in brine (juice in the bottle), it can usually last between 10 to 15 days in a well working refrigerator. If not, it can last between 5 to 7 days.[12] In addition, mackerel can easily cause food poisoning once it is spoiled.[10] So we must pay attention to the freshness of the fish we catch. Now considering the situation of the fishing vessels we have, there is no refrigeration equipment on the fishing vessels. Suppose the degree of decay of the fish increases at the rate of

$$\frac{dR_o^*}{dt_s} = r_L R_o^* \left(1 - \frac{R_o^*}{K} \right)$$

And we give the initial value as $R_o^*(0) = 1$. Where r_L , K is the normal number to be determined. Solving the above initial value problem can get a model of the degree of decay over time

$$R_o^* = \frac{K}{1 + (K - 1)e^{-r_L t}}$$

In order to limit the degree of decay to the range of $[0, 1]$, we value $R_o = \frac{R_o^* - 1}{K - 1}$, Let the equation for freshness be $F_r = 1 - R_o$, which is

$$F_r = \frac{K}{e^{-rLt} + K - 1}$$

The final freshness model after fitting according to the data is $F_r = \frac{73.2475}{e^{0.8751t} + 72.2475}$ [13]

Give $F_r \geq 95\%$ as the minimum standard for freshness so that $t \leq 1.8$ days, the fish is fresh.

4.2. Determine Fishing Range

According to the fishing area in Scotland (3°W, 59°N), we chose Orkney Islands as the location of our company. Besides, we know that fishing bottom trawlers generally travel no faster than 4 knots. [14] We assume trawlers can sail at full speed for 16 hours per day after having considered uncertain conditions of sea surface and crew sleep, etc. Therefore, on the premise of ensuring freshness $F_r \geq 95\%$, the furthest sailing distance of the trawlers is $d = 213.4$. By making a circle with base location as the center and d as radius, our fishing range can be obtained.

4.3. Sensitivity Analysis

Since the optimum SST we got for herring and mackerel is not accurate, we conducted Matlab experiments with other temperature parameters and coefficient parameters around $T_{hotm} = 10.2^\circ\text{C}$ and $T_{motm} = 10.3^\circ\text{C}$. Ultimately, the best case we end up with is this:

$$\alpha_1 = 0.7, \alpha_2 = 0.3, T_{hotm} = 10.5^\circ\text{C}$$

$$\beta_1 = 0.9, \beta_2 = 0.1, T_{motm} = 10.5^\circ\text{C}$$

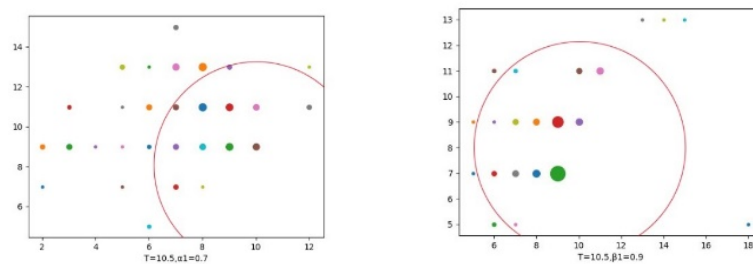


Fig. 9 Scatter chart

At this time, most of the fish passed location are in the current fishing ranges between 1970 and 2069. The worst case is this:

$$\alpha_1 = 0.7, \alpha_2 = 0.3, T_{hotm} = 10^\circ\text{C}$$

$$\beta_1 = 0.9, \beta_2 = 0.1, T_{motm} = 10^\circ\text{C}$$

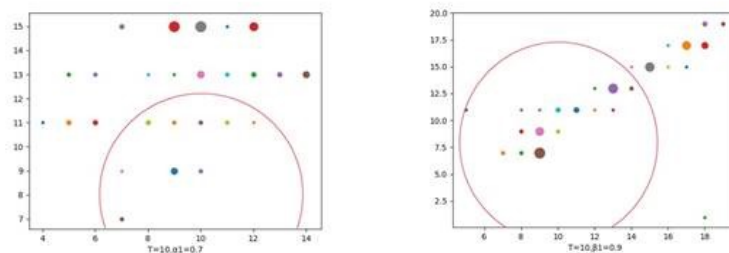


Fig. 10 Scatter chart (1970-2069)

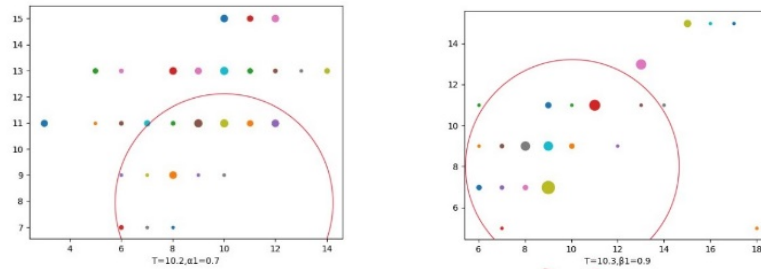
At this time, most of the fish passed location are out of the current fishing ranges between 1970 and 2069. Hence, we are sure that the solution obtained in Task 1 are the most likely case indeed.

The size of the points represents the intuitive number of years in which the points coincide in all the above scatter plots.

The partial locations of the two kind of fish in the next 50 years are showed in the following table. The most likely elapsed time that the company will not be able to catch any fish is 33 years (2053 year)

Table 2. The position of the two fish in the next 50 years

mackerel	longitude	latitude	herring	longitude	latitude
2020	2.5W	58.5N	2020	2.5W	60.5N
2030	2.5W	58.5N	2030	0.5E	60.5N
2040	0.5W	60.5N	2040	2.5W	61.5N
2050	1.5E	61.5N	2050	1.5W	61.5N
2060	3.5E	62.5N	herring	0.5E	62.5N

**Fig. 11** Scatter chart (NEXT 50)

5. Task III:

5.1. Abstract Value Evaluation Model(AVEM)

Based on the previous model and results, we know that there will be a period in the next 50 years that the companies will not be able to continue fishing at the current fishing port with fishing vessels that currently do not have refrigeration equipment. Therefore, the companies need to take specific measures for long-term interests to deal with this problem.

Due to limited time and difficulty in finding economic data, we have established an abstract value assessment model to serve as a reference for company decisions. We take the points that may appear in the next 50 years as the object of value assessment and assign value for them. Since the market prices of herring and mackerel are 0.46 \$/kg and 1.50 \$/kg respectively, the ratio is 1:3, so assuming the value of a herring fish point is 1, and the value of a mackerel fish point is 3, the following model is obtained :

$$\Pi = x_1 + 3x_2$$

Where x_1/x_2 refers to herring/mackerel habitat point numbers within the next 50 years.

5.2. Calculation of the Value of Efferent Decisions

Since what we are considering is a small fishery company with limited funds, the complexity of the decision is not high. We simplify it to the following two decisions.

a. The company was relocated to the Shetland Islands (1.5°W,60.5°N) , but fishing vessels without refrigeration equipment were still used. Its value model is

$$\Pi_a = x_{11} + 3x_{12}$$

Based on Task1, we can count the values of x_{11} and x_{12} , and then calculate to get $\Pi_a = 162$

b. Do not relocate and use fishing boats with refrigeration equipment with the ratio of ($0 < \alpha \leq 1$) in the old port (3°W,59°N). First, we need to model the freshness model without refrigeration equipment in Task2 to build a freshness model with refrigeration equipment.

$$F_r = \frac{60.0414}{e^{0.590t} + 59.0414}$$

Also, given the minimum standard $F_r \geq 95\%$ of freshness, it can get when $t \leq 2.5$ days, the fish is fresh in the daytime, so the longest sailing distance of a new fishing boat is $d=296.3\text{km}$. Its value model is

$$\Pi_b = (x_{11} + 3x_{12})(1 - \alpha) + (x_{11} + 3x_{12})\alpha$$

Based on Task1, we can get $\Pi_b = 115 + 12\alpha$

5.3. Analysis of Results and Proposals

From the results, we can know that even if we replace all the old fishing boats with new fishing boats, which means $\alpha = 1$, the final value is far less than the benefits of relocating to the new port. Although in the short term, the cost of relocating to the new port is higher and has no noticeable effect. However, in the future, there will be more opportunities to catch fish, and the long-term profit will be higher. Therefore, we propose to relocate the company to the Shetland Islands(1.5°W,60.5°N).

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