Problem Chosen	2024 MCM/ICM Summary Sheet	Team Control Number
A		**2006402**

Away They Fleet: How Will the Fish Migration Impact Fishery?

Summary

Global warming is a cliché that always seems out of our reach. However, it is real and is closely related to every one of us. In fact, when we are talking about global warming freely at the dinner table, we may never realize that the fish on our plate is being affected by it. It is becoming an increasingly serious problem, which will cause the rise of sea surface temperature (SST) , and affect the distribution of fish. This will certainly bring some trouble to the fishery.

To give the small fishery companies in Scotland some solutions to this problem, we proposed a model to predict the temperature over the next 50 years, trace the fish habitats and offer economical attractive strategies in many aspects, such as relocating some of the assets,using vessels without land based support and so on. Considering some policy factors in reality, we also take the territorial sea into account.

Our model can be briefly divided into three parts: SST Prediction Model, Habitats Prediction Model and Revenue Estimation Model.

SST Prediction Model is based on the data of SST of the world in previous years. We use the **ARIMA model** to predict the sea surface temperature in next 50 years. Data of January and August respectively predict two extreme cases of temperature. We then depict a beautiful map to visually show the change of temperature.

Habitats Prediction Model derives the relationship between the SST and the metabolism. After that, we use the metabolism of fish and number of preys to predict the distribution of fish on the map. Based on our prediction of SST, we generate an easy-to-read **livability index map** to describe the distribution of fish in next fifty years.

Revenue Estimation Model is based on the livability index map and other data of the costs and profits of voyage and the company operation. We first chose **5 representative harbors of Scotland** and design an algorithm to search the place where fish is concentrated. Then we plug in other related data to derive the relationship between the radius of voyage and the revenue. We discussed the best case, worst case of revenue and the most elapsed time until these populations will be too far for companies to harvest.

Another section of our paper discusses strategies for making bigger profits, including relocating some of the assets,using vessels with freshness retaining system and so on. We weigh the **long term profit and cost** of both strategy, and **conclude relocation have better effectiveness**.

To make our model more realistic, we consider the territorial sea of England and discuss the situation when some of the fishery moves into territory of other countries. We evaluate the impact of territory by comparison, and give the direction of domestic relocation based on the result. We also make sensitivity analysis and discuss strengths and weaknesses of our model.

In the end, we write an exquisite and low-threshold **popular science article** to answer and solve the problems of those small fishery companies.

Keywords: Global warming; Small fishery company; ARIMA model; Fish habitats;

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December 13, 2024

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1 Introduction

1.1 Problem Background

1.1.1 Global Warming and migration of fish

As global warming rising the SST, marine habitants, who are sensitive to ambient temperature, have to migrate. In the north-east Atlantic, the temperature of sea water is rising at a high rate of 0.49°C per decade [2]. Species are moving to cooler seas for survival.

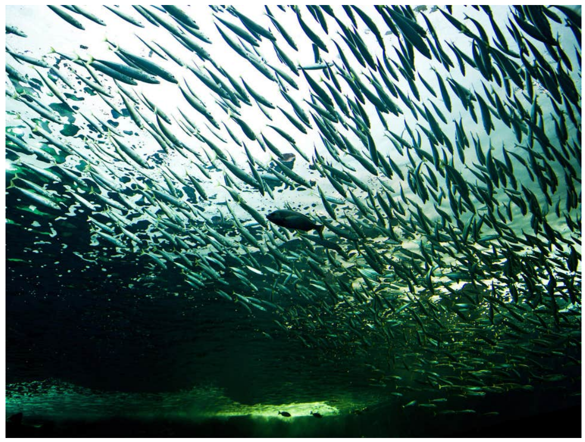

Figure 1: Thousands of fish are migrating to escape global warming [3]

Human economy is disturbed along with ecosystem. The migration of fish potentially increases the distance from harbor to fishing spot, which poses threats to small fishing company's productivity. Also, locating fish school will become more difficult, which decreases the average yield per departure. Therefore, it is important for those companies to trace and predict the migration behaviors of the fish and come up with corresponding strategies.

1.1.2 Scottish Fishing Industry, Herring and Mackerel

We now worked as a consultant team to provide advice for the Scottish North Atlantic fishery management. To be more specific, we investigate the two species: herring and mackerel. They are categorized as pelagic fish, found mainly in shoals, in mid-water or near the surface of the sea[4].

In 2018, Scottish vessels landed 446 thousand tonnes of sea fish and shellfish with a gross value of £574 million. In particular, mackerel remained the most valuable species landed by the Scottish fleet,representing 29 per cent of the value of all Scottish vessels' landings. Thus, we can conclude that the production of these two kinds of fish plays a vital role in the Scottish fishing industry.

1.2 Our Work

As is shown in summary page, we derive a model of fish migration under the influence of rising SST. We also analyze the situation of Scottish fishing industry and propose potential strategies to the companies.

In Section 2, we state our assumptions for this paper. Section 3 is a list of nomenclature used. Section 4 contains the discussion of our model. In Section 5 we carried out sensitivity test. Section 6 provides detailed strategies dealing with several conditions. At last, we further study our model in Section 7 and make some conclusions in Section 8.

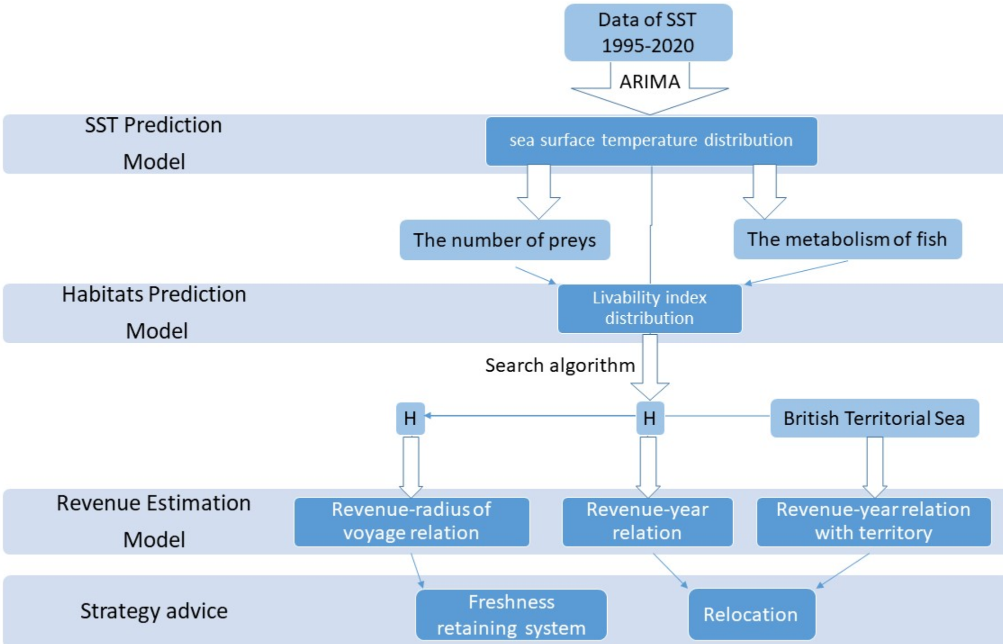

Figure 2: Flowchart of our SHR model

2 Assumptions

Following is the assumptions and justifications we made:

1. **Fish tend to migrate to a place more suitable for survival.**
   Driven by a natural instinct of survival, it is reasonable to assume the more suitable for survival the place is, the more likely fish migrate to there.

2. **Fish are free to migrate without block**
   Since the ocean is almost an open area, fish can go all directions as they want.

3. **During the process of migration, the loss of fish school is not considered**
   As fish school is of large quantity, the loss of predation during the migration can be ignored.

4. **Other environmental factors despite temperature are considered constant**
   Since change in temperature is most significant for fish migration, we ignore the changes in other factors.

5. **All kind of fishes have similar metabolism pattern**
   To simply the problem, we assume the effects of temperature on fish metabolism are the same.

6. **All the fishes are at the same depth below the sea surface**
   To simplify the model,we ignore the changes in depth.

7. **Temperature variation of sea water in depth is ignored**
   Since the variation is almost 1°C per 1000m, it is reasonable to ignore the change.

8. **The frequency of fish migration is once a year. For the rest of the time in a year, they stay in the same block**
   As the sea level temperature is sampled annually, and we only consider the annual change of fish's habitat.

9. **Other revenue sources of fishing companies are ignored**
   Since herrings and mackerels are two major revenue sources for Scottish fishing companies, we only take them into account.

3 Nomenclature

Table 1: Nomenclature

Symbol	Definition
SST	the sea surface temperature
H	livability index
σ	the concentration of fish
V	the value of unit mass of fish
C	cost
Re	revenue
e	the ability to catch fish

4 Statement of our Model

In this section, we will discuss about our model. This model is divided into three parts, an ARIMA Model, a fish migration model and a fishing company model. .

4.1 ARIMA Model [1] (Auto regressive Integrated Moving Average Model)

To predict the future change in SST, we first map the current and historical temperature[5].

Since we have made the assumption that SST is a stationary time series, we can apply the ARIMA Model (Autoregressive Integrated Moving Average Model) to predict the SST over the next 50 years In ARIMA (p, d, q), AR is "auto regressive", AR(p) is the number of auto regressive terms. This part indicates that the evolving variable is regressed on its own prior ones.

MA is "moving average", MA(q) is the number of moving average terms. This part indicates that the regression error is linearly combined of past error terms.

The number d is the times of difference. After preprocessing the data with difference for one time, the data values will be replaced with the difference between their values and the previous values. This process can repeat several times until the data become stationary so that the future data is able to be predicted with prior given data.

$$\left(1-\sum_{i=1}^{p}\phi_i L^i\right)(1-L)^d X_t=\left(1+\sum_{i=1}^{p}\theta_i L^i\right)\varepsilon_t$$

The model can be understood as: difference + stationary model. The data of non-stationary model is transformed into stationary data by difference processing, and then processed by stationary model

$$P-order \quad difference : \Delta^p x_t = \Delta^{p-1} x_t - \Delta^{p-1} x_{t-1}$$
$$K-step \quad difference : \Delta_k x_t = x_t - x_{t-k}$$

Lag operator L of difference represents:

$$\text{P-order} \quad \text{difference } \Delta^p x_t = (1-L)^p x_t = \sum_{i=0}^{p} (-1)^i C_p^i L^i x_t = \sum_{i=0}^{p} (-1)^i C_p^i x_{t-i}$$
$$K-step \quad difference\, \Delta_k x_t = x_t - x_{t-k} = \left(1-L^k\right) x_t$$

4.2 Fish Model: Evaluation of the map

As our assumption says, fish tend to migrate to a place more suitable for survival. The temperature's most effects on fish's survival are

- **The metabolism of fish**
  When the ambient temperature of fish is too high, the metabolism and growth rate of fish will decrease.
- **The number of preys**
  Plankton, the food of fish thrives in certain temperature range.

Therefore, we define the term the place "suitable for survival" as the place where fish can have maximum metabolism rate and most prey availability.

We use protein turnover rate K_g to represent the metabolism of fish. Protein turnover rate, the relation between protein synthesis process and protein degradation process, can reflect metabolism condition and growth possibility.From the research of Bar and Radde, K_g is highly related to the maximum weight of fish and can be seemed as a quadratic function of temperature T[6]. As we assume all fishes have the same metabolism pattern, we directly use the parameters in the article. The equation is

$$K_g = -0.01(T - T_{opt})^2 + 1.1 \tag{1}$$

where T is the ambient water temperature.

We know both herring and mackerel prey on plankton. Krill is a typical type of plankton, and the temperature's influence on its growth pattern is well-studied. According to the literature[7], the daily growth rate DGR (length increase rate) of krill can be characterized by

$$DGR = -0.066 + 0.002 - 0.000061L^2 + \frac{0.385CHL}{0.328 + CHL} + 0.0078SST - 0.0101SST^2 \tag{2}$$

where L means the length of the krill and CHL means chlorophyll-a concentration.

4.3 Evaluation of Fishing Companies' Condition

In this section, we evaluate how migration of fish affects the harvest of small fishing companies.

4.3.1 Model of fishing companies

To describe the operation of fishing companies, we build the business model with the following equations.

$$\begin{cases} Re = S - C & (3) \\ S = e\sigma V & (4) \\ C = \alpha d + \beta & (5) \end{cases}$$

Re is the revenue of the company per unit time. It is generally the difference between sales S and costs C.

For the sales part, as we are studying the impact of herring and mackerel specifically, We assume that all sales come from them. As fish tend to migrate to the place more suitable for survival, the concentration of the fish is inhomogeneous. σ represents the concentration of fish in the area of fishing spot. e stands for the fishing capacity, the kilograms of fish a boat can catch per sail with a fixed fish concentration. V stands for the value of fish per kilogram.

For the costs part, a boat has fixed costs and dynamic costs for each sail. The fixed costs, represented by β, involves the recruiting of crew and maintaining the boat's condition. The dynamic costs depends on how long the boat travels, represented by d. To simplify the problem, we assume dynamic costs all comes from the consumption of diesel, and α represents the costs of diesel per kilometer.

We estimate these coefficients using data from governmental annual statistics release. e is estimated by the overall kilograms of fish caught divided by the number of sails. k is estimated by the gross sales of each fish divided by the weight.α is the amount of diesel used per sail times diesel price. The values of parameters we determine is listed below.

Symbol	Parameter	Value
V_H	Unit Value of Herring	0.4£/kg
V_M	Unit Value of Mackerel	1£ /kg
e	Fishing Capacity	408 ton/sail
α	Costs of Unit Distance Sail	6.5£/km
σ	Concentration of fish	Represented by H
β	Fixed Cost	500£

Table 2: The Parameters for the Model of Fishing Companies

4.3.2 The Impact of fish migration on fishing companies near different harbors

As fish is moving away from some harbors, the dynamic costs of sailing increases. To analyze the impact, we discuss two cases: the best one and the worst one. Then we predict the most likely elapsed time that the fish school will be too far to reach. We will discuss it in section 5.

We can assume that our temperature prediction is correct, but the distribution of fish is random in reality. With our index map, fishing companies are able to find the best fishing spot in theory. In the best case, the fish concentration is exactly as we prediction, and therefore the yield can be maximized. In the worst case, the predicted best fishing spot is actually the worst in the region, and therefore the yield is minimized.

We create a program to find the best fishing(the distance between the harbour and the place where the fish production is maximized), the algorithm is as follows:

Algorithm 1: $find\_dist\_max(harbor\_position, H\_distribution, r)$

Input: $harbor, H\_distribution, r$
Output: $distance\_max, distance\_min$

```
for i = 1 to numberofharbors do
    for dx = −r to r do
        for dy = −r to r do
            if H(harbor(i).x + dx, harbor(i).y + dy) > H(max_x, max_y) then
                max_x = harbor(i).x + dx;
                max_y = harbor(i).x + dy;
                distance_max = √((dx)^2 + (dy)^2);
            end
            if H(harbour(i).x + dx, harbour.y + dy) < H(min_x, min_y) then
                min_x = harbour(i).x + dx;
                min_y = harbour(i).x + dy;
                distance_min = √((dx)^2 + (dy)^2);
            end
        end
    end
end
return distance_max, distance_min, min_x, min_y;
```

The reason why we let radius of voyage is within 30°latitude is as follows: As we all know, 1 °of latitude is about 111km.

$$r = 30^\circ \times 111km/^\circ = 3330km$$

We can estimate the average speed v of the ships is about 25km/h[8]. The longest duration of each voyage t is about 15 days per voyage, limited by the freshness retainment. [9]. We assume the vessel sails 18 hours/day.

Thus,We can derive the longest distance per voyage is about

$$s = 15days/voyage \times 18h/day \times 25km/h = 6750km/voyages \approx 2r$$

This implies that the largest radius of voyage we choose is consistent with the reality.If the largest radius is too large, our results will be meaningless.

4.3.3 The Territory Issue

United Nations Convention on the Law of the Sea defines the exclusive economic zone of each countries. The exploitation of natural resources from other countries in this region is forbidden. This restricts the Scottish vessels to the exclusive economic zone of UK and the high seas. To make our model more realistic, we adjust according to the territories.

To take territory issue into account, we map the exclusive economic zone of UK into a two dimension array as a constraint condition of our searching algorithm. Following diagram shows our simplification of exclusive economic zone contour[10].

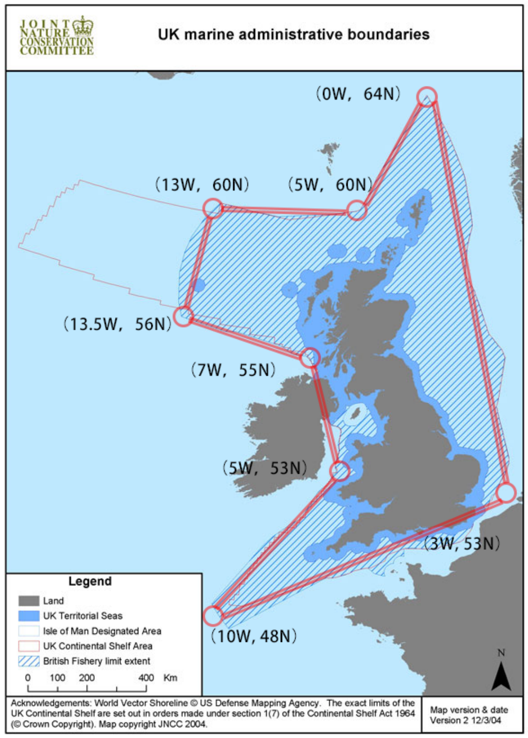

Figure 3: Simplification of exclusive economic zone contour

5 Implementation

5.1 Predicting SST with ARIMA Model

ARIMA model is a perfect model to predict a sequence with prior data. Here, we use ARIMA model to predict SST in next 50 years.

5.1.1 Calculate the parameters of ARIMA model

In order to use ARIMA model to predict SST in next 50 years, we should first calculate the appropriate parameters (i.e., p, d, q) to adapt the model to the data we have. Auto-correlation function (**ACF**) will give us values of auto-correlation of any series with its lagged values hence we can get a proper value of p. Partial auto-correlation function (**PACF**) finds correlation of the residuals with the next lag value so that we can learn the relevant features and the value of q. After preprocessing the data with difference for one time, the data have a relatively stationary mean and variance. Since the origin data is not stationary enough, while preprocessing the data with difference for too many times will lead to loss of precision, the value of d is set to 1. We feed these two functions with the difference of prior data and get the results shown in Figure 4 and Figure 5.

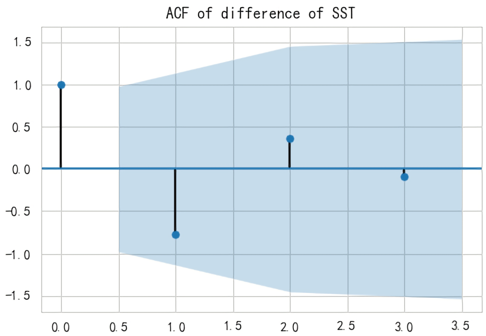

Figure 4: ACF of difference of SST

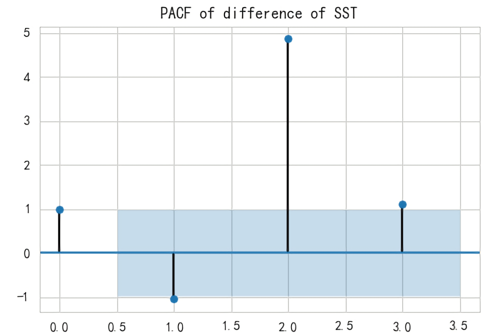

Figure 5: PACF of difference of SST

We can see the results with different input values of p and q clearly in these pictures, where the blue area represents confidence interval. All points that fall within the confidence interval are acceptable. In view of the complexity of the calculation, we choose the simplest parameters for the model within an allowable range. Hence, the value of p and q are both set to 1. As a conclusion of the calculation of parameters, our ARIMA model is ARIMA(1, 1, 1) .

5.1.2 Predict SST in Next 50 Years

We use ARIMA(1, 1, 1) model on the data we have. The data come from HadSST[5], which provides data of each month. By using the data in august from 1870 to 2019, the code tell us the predicted SST in next 50 years.

The results of SST in future years are shown in contour maps. Our predictions account for the SST on 16 August every year, in accordance with the history data we chose.

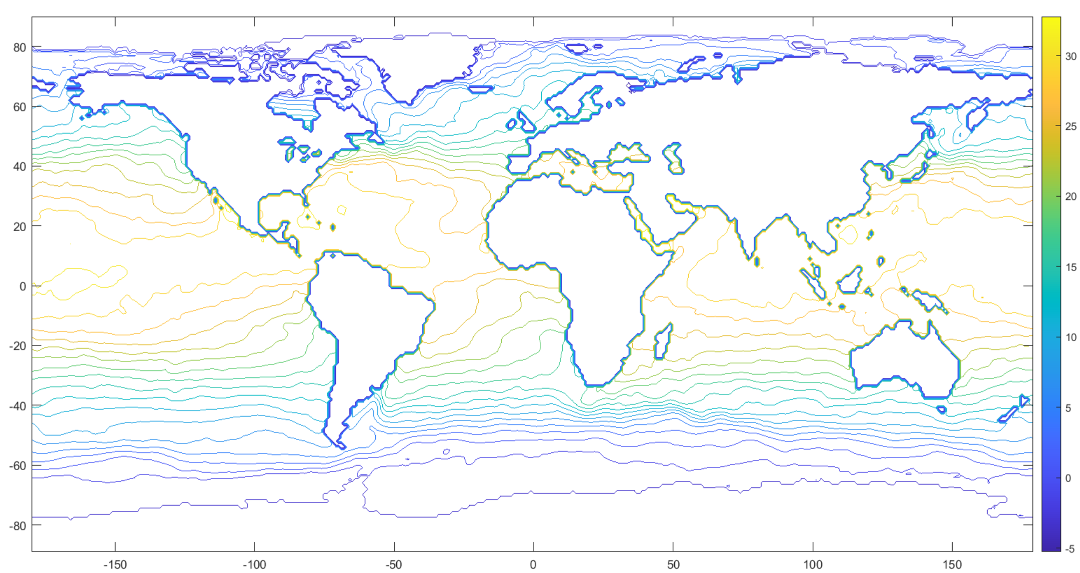

Figure 6: SST Prediction in 2025

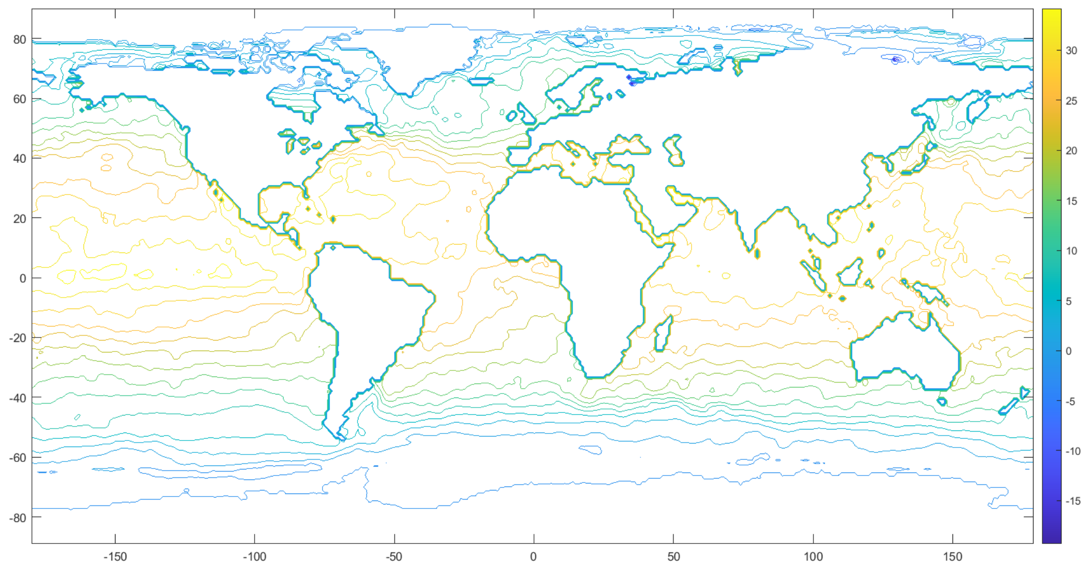

Figure 7: SST Prediction in 2050

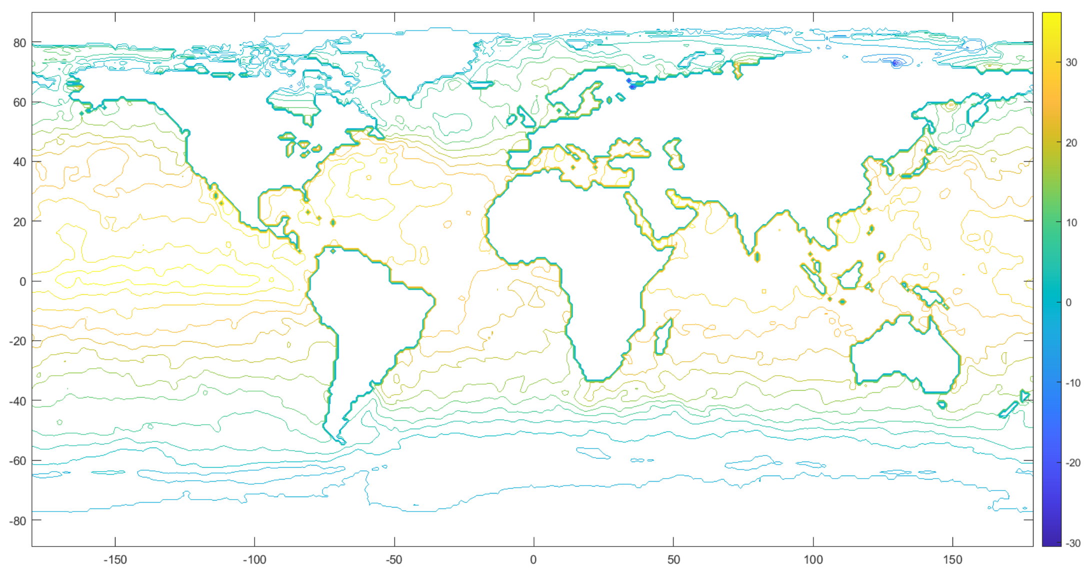

Figure 8: SST Prediction in 2070

The results show that global SST is on steady rise in the following fifty years, which causes the migration of fish.

5.1.3 The migration of fish

As is mentioned above, we have an equation of protein turnover rate.

$$K_g = -0.01(T - T_{opt})^2 + 1.1 \tag{6}$$

We also have an equation of the daily growth rate(DGR).

$$DGR = -0.066 + 0.002 - 0.000061L^2 + \frac{0.385CHL}{0.328 + CHL} + 0.0078SST - 0.0101SST^2 \tag{7}$$

Both functions are quadratic functions. We apply the functions to the temperature map. Then we make linear combination of them to form a final indice. The indice is used to evaluate the extent to which each partition suits the survival of herrings and mackerels. To make the equation more realistic, we adjust the weight of two factors and times the indice of prey with 0.3. We adjust the model with the data of the optimal temperature for herring and mackerel[11]. Figure 9 shows the curve of two indices and their combination. The optimal temperature of herring and mackerel is around 11 °C and maximum living temperature is about 15 °C, which are in accordance with the result.

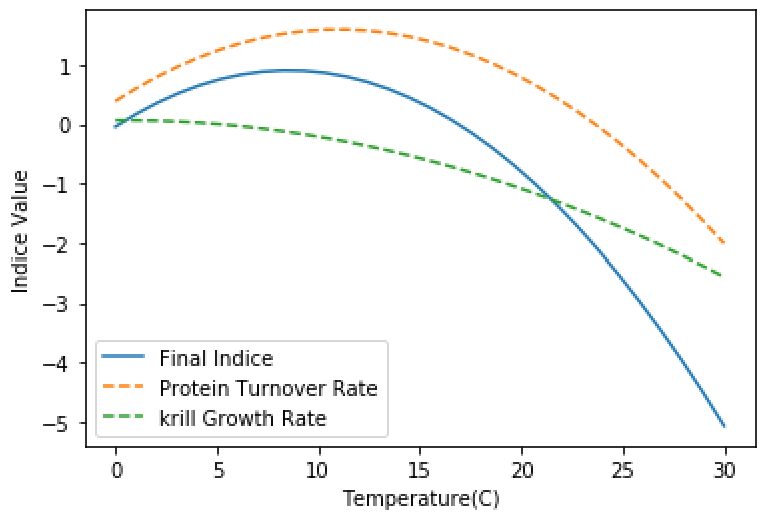

Figure 9: Two Indices Curve and Their Combination of Final Indice

5.1.4 Generation of Livability pa Map

We now plug SST into the indice formula and get the result. The graph shows the extent to which each partition is suitable for the survival of herrings and mackerels.

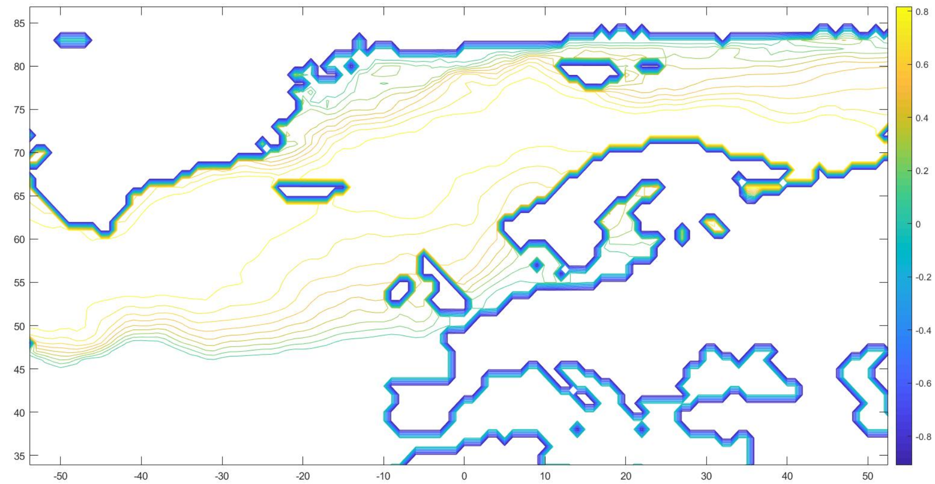

Figure 10: Livability Index of 2025

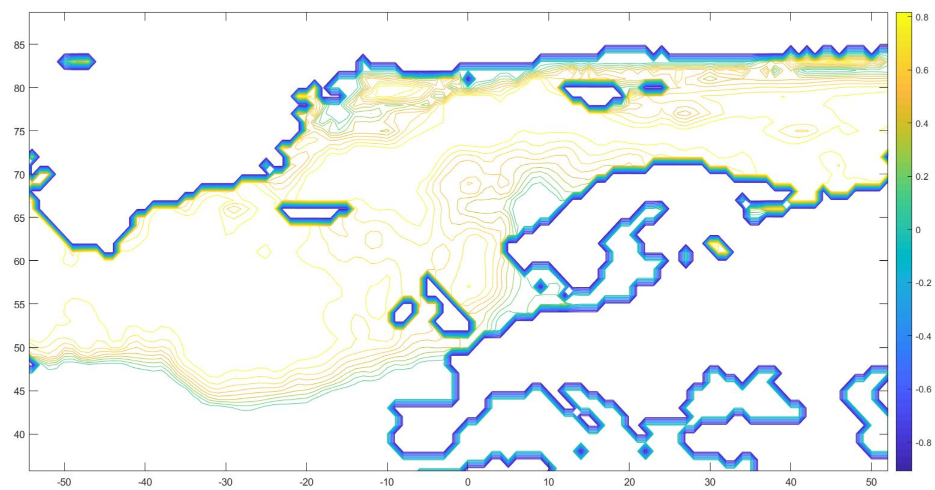

Figure 11: livability index of 2070

The graph shows the degradation of fish habitat around Scotland. The mild yellow curve, which represents the contour of the most suitable habitat area, is retreating to the north.

5.2 Impact of Fish Migration on Fishing Companies Near Different Harbors

To get a more accurate estimation, we discuss the best and worst situation for the fishing companies. The temperature data have huge difference between seasons. In winter, the temperature is more mild and temperate near UK, so fish habitat near the harbor. In summer, the temperature is high and fish are driven to the north west.

We choose some typical harbors to find the difference the influence location. The harbors we choose is shown by Figure12.

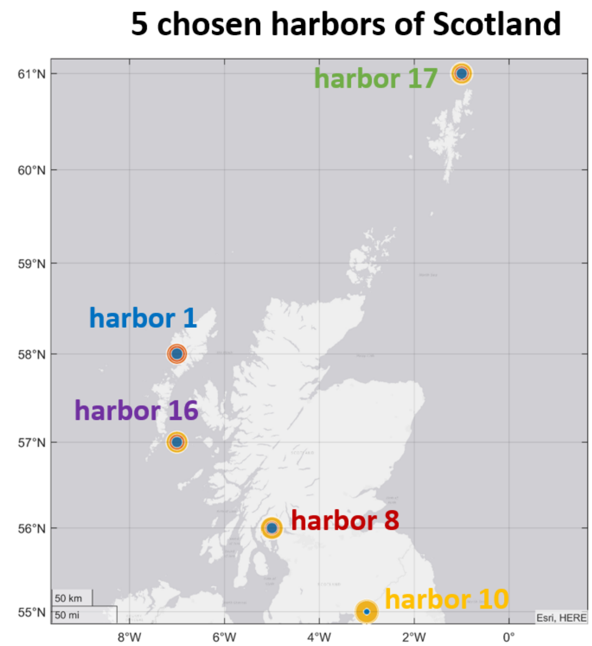

Figure 12: The location of chosen harbors

5.2.1 Best Case

We estimate the best case by assuming the distribution of fish throughout the whole year is the same as that in winter.

The vertical axis is the ratio of 2070 revenue and 2025 revenue. The horizontal one is the radius of voyage. Colored curves stand for different harbors.

Since in winter the temperature around harbor is almost the same, the fish distribution is even. The fish concentration σ is almost a constant. Therefore, the revenue is a linear function of distance d. The difference between harbors are negligible. In this case, the more close to the harbor, the more revenue can be generated. The maximal revenue is about 102%.

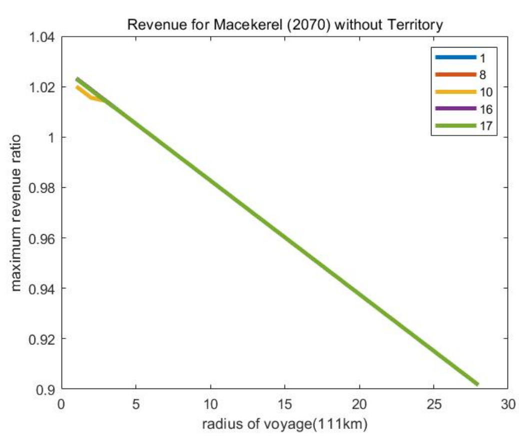

Figure 13: Revenue ratio without the constraint of territory (best case)

5.2.2 Worst Case

The worst case is that the distribution of fish throughout the whole year is the same as that in summer.

In summer, the temperature distribution is nonuniform. Noticeable deviation appears between different harbors. Although most peak values appear closely to each other, the greatest difference is almost 3 percent. If time factor is considered, as harbor 17 is closer to the fishing spot, the vessels can sail more times and generate even more revenue.

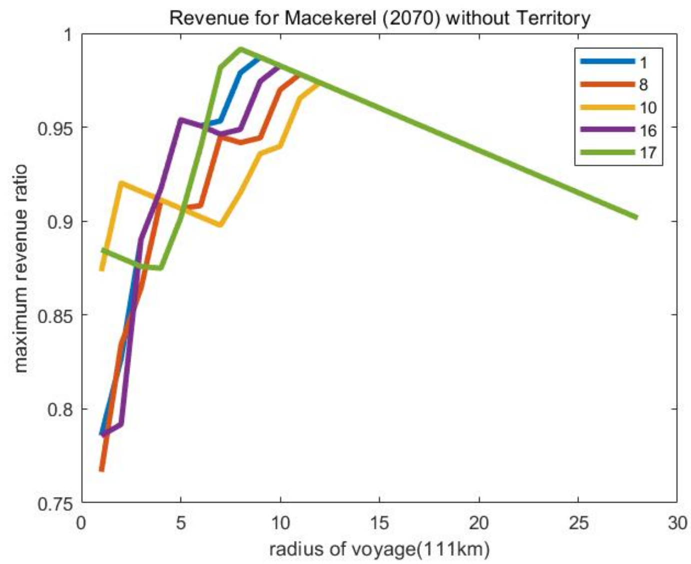

Figure 14: Revenue ratio without the constraint of territory(worst case)

5.2.3 The Most Likely Elapsed Time

To see how soon will the fish migration affect the operation of business, we collect the change of maximal revenue ratio with time. The result is shown below.

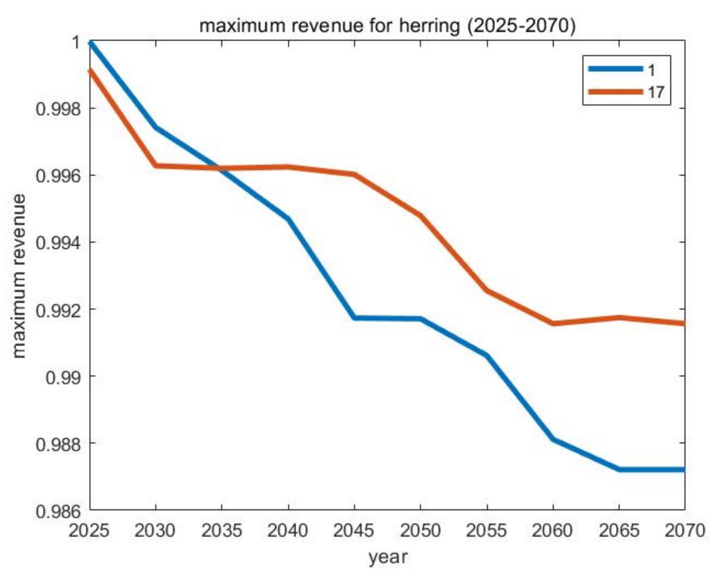

Figure 15: The change of maximal revenue ratio with time

The result shows that in near fifty years, there will be little change (about 1.4%) in the revenue. As a result, it will not be too far away for small fishing companies to harvest. That is to say, there will not be a most likely elapsed time.

5.2.4 The Territory Issue

To make our model more realistic, we add territory boundary constraints to our algorithm. The simulation results for 2070 as the worst case senario are as follows.

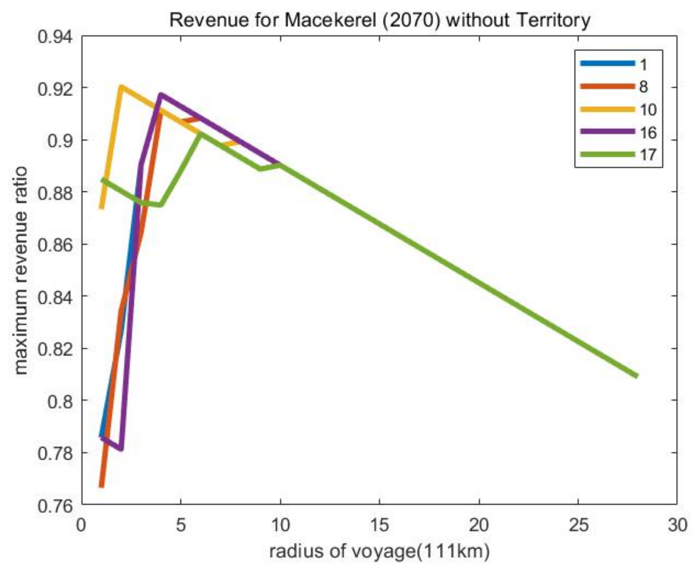

Figure 16: The revenue ratio with the constraint of territory

The territory decreases the revenue by 8 to 10%. It is against our intuition that the order is completely reversed if territories are taken into consideration, and southern harbors make the most revenues. This is due to the shape of UK territory. As there is little space for Scottish vessels to explore northward, the harbors in the north is score less in revenue, as they have to sail way longer than southern harbors.

Thus, our proposal should change. When we take territory into consideration, we can see that the harbor in the southern reach the maximum in the smallest radius. Besides, the maximum revenue rate is also the highest among all the harbors. Therefore, we can come to a conclusion that, if we discuss the restriction of territorial sea, the company should moves to south to get higher profits.

On the contrary, when we don't have the restriction of territorial water, the fish companies should go northward.

6 Strategies

6.1 Relocating the Company

The simulation result of our model shows that the fish are moving to the north, and fishing companies in the northern region profit most. Therefore, a potential strategies to deal with the fish migration is migrating together.

To evaluate the feasibility of relocation the companies, we propose the following model.

The most prominent costs of relocation for fishing companies are hiring new employees and interruption of revenues [12]. The fishing company has to transport its equipment to the new place, the process of which takes up to 4 weeks[13]. The transportation and interruption of revenues take about 4 week's revenue, roughly eight percent of annual revenue. According to statistics[13], the expense of hiring new employees is 72627 dollars per person. Assume small fishing companies has the same size of other conventional small companies, which is defined to have 30 to 250 employees[14]. The average is about 140 employees. Then, the cost of average hiring new employees are about ten million dollars.For companies with such size, the average revenue is estimated as 20 million[15]. Therefore, the refreshment of employees takes up to almost fifty percent of annual revenue. The annual revenue will drop about 58% of the whole annual revenue.

The revenue of domestic harbors are close to each other. Therefore, we consider international harbor this time.

We choose a new harbor according to the livability index map and do the simulation. The following graph shows the revenue ratio of different harbors as time goes on.

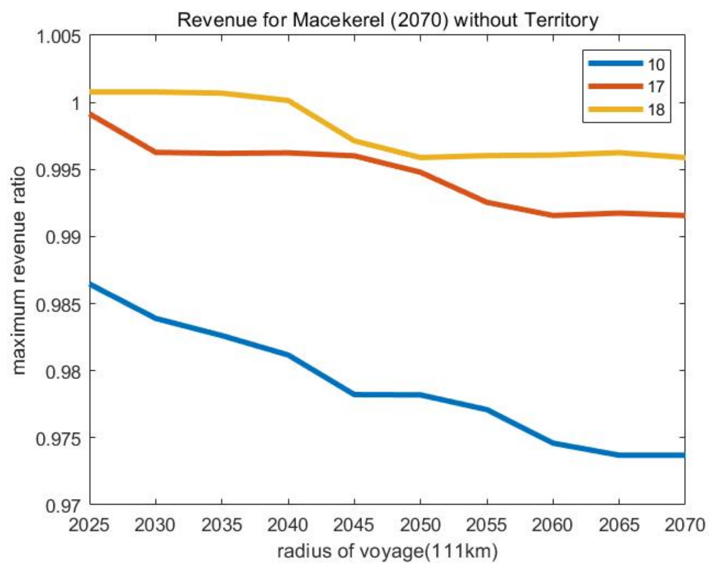

Figure 17: The revenue ratio of newly selected harbor and harbor 10

The figure shows that there is a steady gap between harbor 18 and harbor 10 of 2% of revenue. Therefore, it takes about 10 years to recover from the cost of relocation, which is an acceptable choice.

6.2 Introducing New Freshness Retaining Equipment

The distance of each voyage is largely limited by the requirement of freshness retainment. If the boat is away from harbor for too long, herring and mackerel can die without life maintaining system. There exists a technology called partial freezing that can retain the freshness of fish from the 15 days to 26 days on average. Hence, by equipping the freshness retaining system, fishing boat can have larger coverage.

If the price of fish depends on the freshness, then the system matters. We add the factor of freshness to our model.

We modify Equation4, Equation5 to be the following ones.

$$\begin{cases} S = nC_a\rho V + (e\sigma - nC_a)Ve^{(-\gamma d)}\rho & (8) \\ C = \alpha d + \beta + nP & (9) \end{cases}$$

Considering the company may not be able to buy enough sets of system for all fish, we assume that they support a portion of fish while not supporting the rest.Suppose they buy n set of system, each has a capacitance of C_a. Then, nC_a amount of fish can retain its value, while the rest is subjected to a value loss. To simplify the problem, we assume the loss of value is a linear function of sailing distance d. The cost should include the price of all systems bought. Below are the value of parameters.

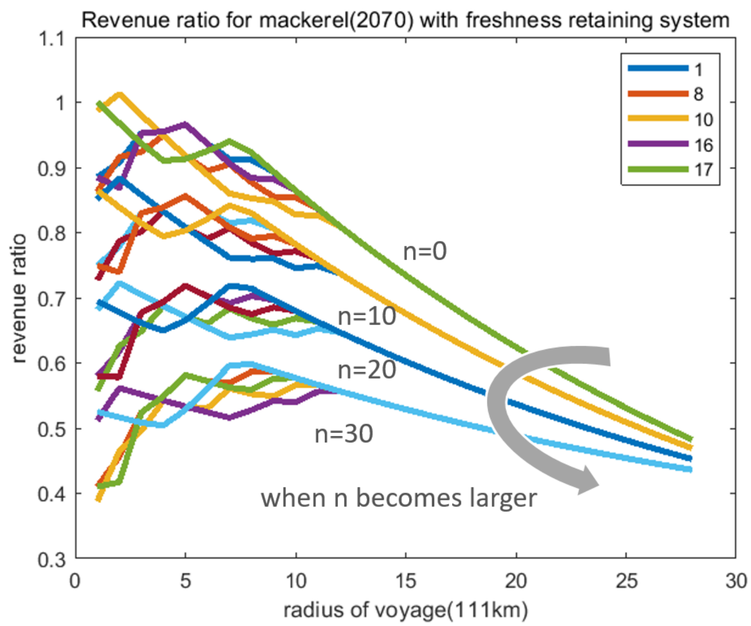

Figure 18: Recenue when we buy n freshness retaining system

From the figure shown above, we can know that when we buy n set of system. Generally speaking, as we extend our radius of voyage, the revenue ratio first becomes lager and then slowly decreases. This implies, for a certain radius around 5 * 111 km, we can reach maximum of our revenue. When we fix our radius of voyage and change n, which is the number of freshness retaining system we purchase,we can find that as n becomes larger, the revenue becomes less. Thus, the more freshness retaining system we bought, the less revenue we will get. Therefore, to maximize our revenue,we should not buy the freshness containing system.

Symbol	Parameter	Value
ρ	Density of fish	$1000kg/m^3$
C_a	Capacity of freezer	$8m^3$
P	Price	$2700£perset$
γ	The value degradation rate	900£/m

Table 3: Parameters of freshness considered model

7 Model Analysis

7.1 Sensitivity Analysis

Our model contains several parameters. We determine some of the parameters by surveying the literature. We would provide a sensitivity test to some important parameters. We will study the impact of two important parameters in our model.

7.1.1 Impact of combination coefficient in livability index

When deriving the livability index, we use the linear combination of two indice, the protein turnover rate Kg and the growth rate of prey, DGR. The coefficient is determined to be 0.3 when to fit the information of herring and mackerel. We change the coefficient to 0.25 and 0.35, each varying 16.6%. The following graph shows the result.

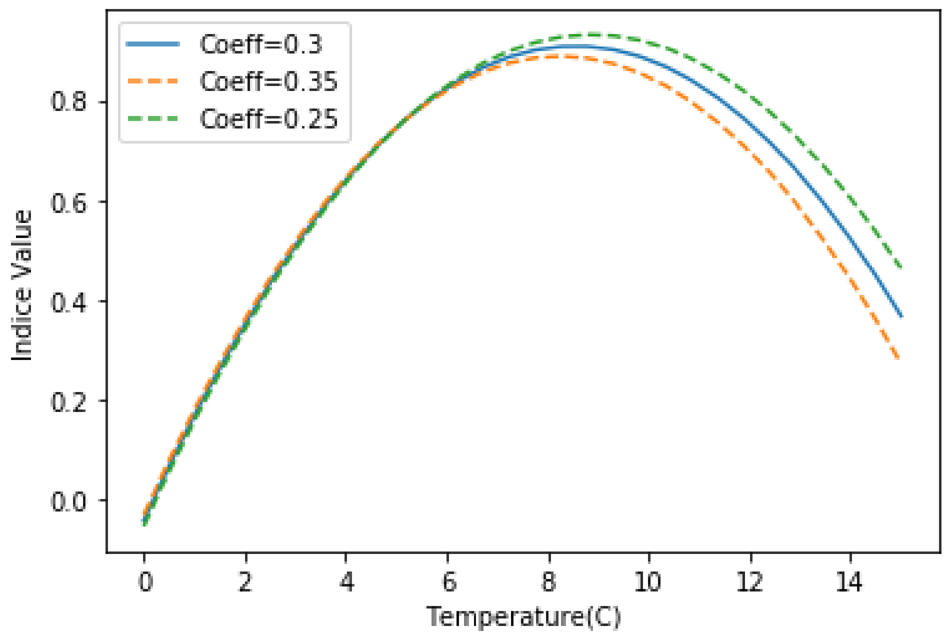

Figure 19: The sensitivity test of coefficient in livability index

The result shows that around the optimal temperature, 11 °C for herrings and mackerels, the deviation is little. The apparant change happens after 14°C, where the deviation exceeds 15%. Therefore, this coefficient is stable given that the the optimal temperature is around 11 °C.

7.1.2 Impact of optimal temperature of fish

We estimated the optimal temperature of fish with a range given in literature. Here we change the optimal temperature for about 10%. The impact on livability index is shown below.

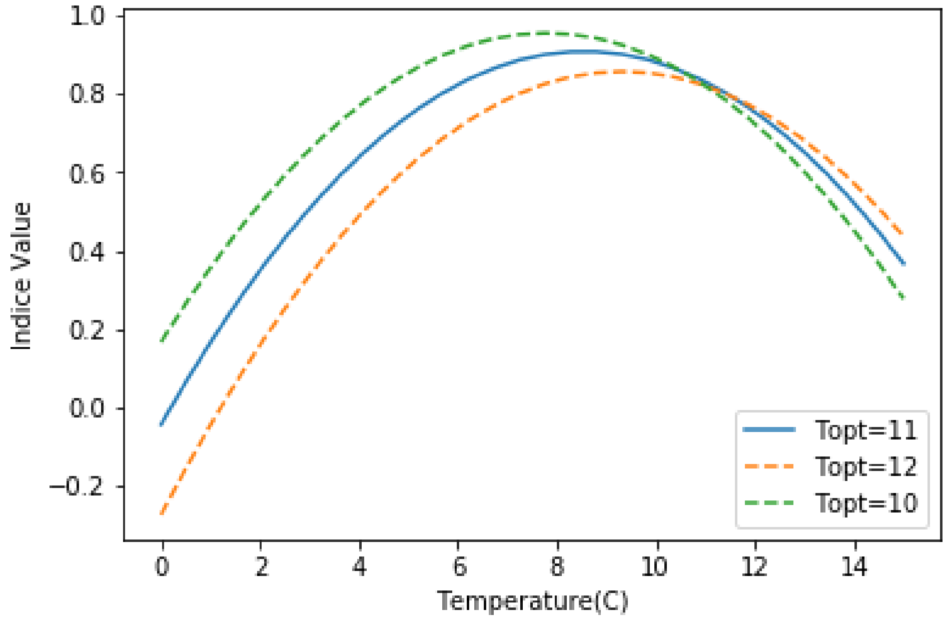

Figure 20: The sensitivity test of optimal temperature in livability index

Similar to the previous one, although there is considerable deviation on two sides, the model is rather stable around optimal temperature. Therefore, the model is still effective at distinguishing the livability of fish.

7.2 Strengths and Weaknesses

7.2.1 Strengths

1. Use accurate data of global SST from a credible data base. Since the change of SST is the root of all consequences, it lays solid foundation for our simulation and prediction.
2. Our model has a great extensibility. Although we only display our result about Scotland and Scottish herring and mackerel, just change some of the data and we can adapt our model to any place and any fish on earth.
3. Use fancy visualization to display our model.

7.2.2 Weaknesses

1. The ecosystem is huge and contains a wide range of species. It is impossible to reconstruct the ecosystem completely and to collect data of all species accurately. Considering that krill is one of the common species that Scottish herring and mackerel prey on, we regard krill instead of all plankton as food for Scottish herring and mackerel.
2. The geographical environment may change a lot in next 50 years such as sea level rise, geomorphological changes, etc. This will impose a certain impact on the distribution of fish shoals and ports, resulting in incorrect predictions. These random and chaotic factors may cause the prediction of the model to deviate significantly from the reality after a long period of time.

8 Conclusion

Q: Where is the most likely locations for these two fish species over the next 50 years?

A: North West of North Atlantic Ocean.

Q: What is the best case and worst case if the ocean water temperature change occurs?

A: In the best case, where temperature remain high as summer throughout whole year, the minimal revenue of fishing companies in 2070 will be from 97% to 99%. In the worst case, where temperature remain low as winter, the maximal revenue in 2070 will be 102%.

Q: When is the most likely elapsed time until these populations will be too far away for small fishing companies to harvest?

A: The low decreasing rate of revenue shows that it will not happen in near future.

Q: Should these small fishing companies make changes to their operations?

A: Yes. Companies can have about 2% increase in revenue by relocation. The cost of relocation can be recovered in ten years.

Q: How is the proposal affected, if some proportion of the fishery moves into the territorial waters (sea) of another country?

A: The constraint of territory will decrease the revenue to about 90%.

9 Article for *Hook Line and Sinker*

How will Fish Migration Affect Fishery Industry?

Research Need

Fishing always means a lot of fun to us, and we believe it is an industry we care. However, the future situation is not optimistic. There have been truth and rumor about global warming and its effect on fishing. Large temperature panels on fishery websites are ticking like a clock. The researchers start to wonder how much global warming will affect the fishing industry, and what corresponding measurements we should take to cope with it. Since the fishery industry has already revealed evidence of declining, it's better to take actions before its too late.

What Did They Study?

The researcher specifically research the impact of rising sea surface temperature and the fishing of herrings and mackerels in Scotland. Regarding sea surface temperature as the primary factor that varies the system, they make predictions of sea surface temperature in the following years. Then they transform the temperature map to an easy-to-read livability index map according to the relation between the physiology of fish and ambient temperature. Based on these information, they build a brief business model that describes operation of fishing companies to find out how they suffer from fish migration.

What Did They Find?

In the simplest of terms, researchers find that global warming is gradually harming the fishery industry in a slow manner, as an increment of 2 °C is due in the next fifty years. The livability index map reveals a retreat of fish schools to South-West corner of North Atlantic Ocean. With the constraint of territory of other countries, the Scottish fishery company's revenue will notably drop by about ten percent in the next fifty years, and is open to further decline.

Figure 21: Copyright: Team 2006402

So What?

Based on the business model, the researchers made simulations to see how things will be going if different measures should be taken. Changing the location to where fish is more concentrated is a good idea. They estimated that it would take only ten years to recover the cost, and the rest is pure increasing profit. Another proposal, sailing farther with ship with freshness retaining system, is rejected. The equipments cost much, let alone the oil cost for oceangoing voyage. However, those efforts can only slow down the dropping speed of revenue. The ultimate way to save the industry is to save our planet.

Anything else?

The research only covers two kind of pelagic fish. The impact temperature change on demersal fish and shell fish, which are the other two revenue sources of fishery companies, are not studied. In the end of the research, the researchers noted that there has been a long history that herring and mackerel live with human together. It is unethical and malicious to expel them out of their habitat.

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Appendices

Appendix A Algorithm for task2,3 and 4

```
load data_indice2
load map

    for year=1:1
            %temp=360*(y+89)+x+181
            z=zeros(180,360);
            habitat_restriction=0;

            for i= 1:180
                for j=1:360
                    if data(360*(i-1)+j,year)==9999
                         z(181-i,j)=-5;

                    else
                        z(181-i,j)=data(360*(i-1)+j,year);


                    end
                end
            end

            if (habitat_restriction==1)
                    for i= 1:180
                        for j=1:360
                                if (i<90+58 || j<180-21) &&z(i,j)>0
                                    z(i,j)=z(i,j)*0.5;
                                end
                        end
                    end
            end

    end

max_year=10;

            harbour=struct('x',{},'y',{},'n',{});
            %we simulate the edge of the scotland, due to precision, latitude and
            %logtitude difference is within 1 degree
            p=[-7 -6 -6 -5  -5   -5 -5  -5    -4   -3   -4   -2  -2  -2   -3   -7   -1  6 10;
                58 58 57 55  59   58 57  56    56   55   58   58  57  56    59  57   61 60 66];
            harbour(1).n=size(p,2);

            dist_map_max=zeros(180,360);
            dist_map_min=zeros(180,360);


            VH=0.4;
            VM=1;
            e=408;
            k=10;
            ka=1;
            alp=6.5*ka;
            terr=0;
            worst=0.8;
            for o=1:28
                for i=1 : harbour(1).n
                    harbour(i).distance_max_set=zeros(1,o);
                    harbour(i).distance_min_set=zeros(1,o);
                   harbour(i).ReH_set=zeros(1,o);
                   harbour(i).ReM_set=zeros(1,o);
                   harbour(i).ReM_max=zeros(1,max_year);
                   harbour(i).ReH_max=zeros(1,max_year);
                end
            end


            da=1;
            for a=1:da:o

                b=a;
                    for i=1 : harbour(1).n
                    harbour(i).n=size(p,2);
                    harbour(i).a=a;
                    harbour(i).x=p(1,i);
                    harbour(i).y=p(2,i);
```

```
                harbour(i).distance_max=0;
                harbour(i).distance_min=0;
                harbour(i).maxx=mod(harbour(1).x+181,360)+1;
                harbour(i).maxy=mod(harbour(1).y+91,180)+1;

                harbour(i).minx=mod(harbour(1).x+181,360)+1;
                harbour(i).miny=mod(harbour(1).y+91,180)+1;

                harbour(i).minx1=mod(harbour(1).x+181,360)+1;
                harbour(i).miny1=mod(harbour(1).y+91,180)+1;

                harbour(i).beta=0;
    for year=1:max_year
        %temp=360*(y+89)+x+181
        z=zeros(180,360);
        habitat_restriction=0;

        for ii= 1:180
            for j=1:360
                if data(360*(ii-1)+j,year)==9999
                     z(181-ii,j)=-5;

                else
                    z(181-ii,j)=data(360*(ii-1)+j,year);


                end
            end
        end

        if (habitat_restriction==1)
                for ii= 1:180
                    for j=1:360
                        if (ii<90+58 || j<180-21) &&z(ii,j)>0
                            z(ii,j)=z(ii,j)*0.5;
                        end
                    end
                end
        end



                    for dx=-a:a
                        for dy=-b:b
                            zx=mod((harbour(i).x+round(dx)+181),360)+1;%index for z
                            zy=mod(harbour(i).y+round(dy)+91,180)+1;

                            %the territory
                            if(terr==1)
                                            xx=harbour(i).x+round(dx);
                                            yy=harbour(i).y+round(dy);
                                            if(map2(90-yy,xx+38)==0)
                                                continue
                                            end
                            end

                            if(z(zy,zx)>z(harbour(i).maxy,harbour(i).maxx))%if scanned point larger
                                 harbour(i).maxx=zx;
                                 harbour(i).maxy=zy;
                                 harbour(i).distance_max=dist([mod(harbour(i).y+91,180)+1,mod((harbo
                                 harbour(i).distance_max_set(round(a/da))=harbour(i).distance_max;
                            end
                            if(z(zy,zx)<z(harbour(i).miny1,harbour(i).minx1)) && z(zy,zx)>=0
                                 harbour(i).minx1=zx;
                                 harbour(i).miny1=zy;
                                 harbour(i).distance_min=dist([mod(harbour(i).y+91,180)+1,mod((harbo
                                 harbour(i).distance_min_set(round(a/da))=harbour(i).distance_min;
                            end
                        end
                        %take the max of (last min and present min)
%                         if(z(harbour(i).miny1,harbour(i).minx1)>z(harbour(i).miny,harbour(i).minx
                                 harbour(i).minx=round((harbour(i).minx1+harbour(i).maxx)/2);
                                 harbour(i).miny=round((harbour(i).miny1+harbour(i).maxy)/2);

                                 harbour(i).distance_min=dist([mod(harbour(i).y+91,180)+1,mod((harbo
                                 harbour(i).distance_min_set(round(a/da))=harbour(i).distance_min;
%                         end
                    end
                dist_map_max(harbour(i).y+90,harbour(i).x+180)=harbour(i).distance_max;
                dist_map_min(harbour(i).y+90,harbour(i).x+180)=harbour(i).distance_min;

        %best case
        harbour(i).ReH=k*e*z(harbour(i).maxy,harbour(i).maxx)*VH-(alp*harbour(i).a+harbour(i).beta)
        harbour(i).ReM=k*e*z(harbour(i).maxy,harbour(i).maxx)*VM-(alp*harbour(i).a+harbour(i).beta)
```

```
            harbour(i).ReH_set(round(a/da))=harbour(i).ReH;
            harbour(i).ReM_set(round(a/da))=harbour(i).ReM;

                    %record the max revenue of each year
                    for jj=1:round(a/da)
                       if( harbour(i).ReH_set(jj)>harbour(i).ReH_max(year))
                           harbour(i).ReH_max(year)=harbour(i).ReH_set(jj);
                       end
                       if( harbour(i).ReM_set(jj)>harbour(i).ReM_max(year))
                           harbour(i).ReM_max(year)=harbour(i).ReM_set(jj);
                       end
                    end

            %worst case
            harbour(i).ReH2=k*e*z(harbour(i).maxy,harbour(i).maxx)*VH-(alp*harbour(i).a+harbour(i).beta
            harbour(i).ReM2=k*e*z(harbour(i).maxy,harbour(i).maxx)*VM-(alp*harbour(i).a+harbour(i).beta

            harbour(i).ReH_set2(round(a/da))=harbour(i).ReH2;
            harbour(i).ReM_set2(round(a/da))=harbour(i).ReM2;
    end
                    end


            end











% for i=1 : harbour(1).n
%     if()
% harbour(i).ReH_max_point=[a,]
% end




ratio=1442.5;
for k=1:harbour(1).n
   if (k==harbour(1).n)||(k==10)||(k==17)
        %figx=[1:o/da];
        figx=[2025:5:2070]
        figy=harbour(k).ReH_max./ratio;
        display(k);
        display(figy);
        plot(figx,figy,'LineWidth',3);
xlabel('radius of voyage(111km)');
ylabel('maximum revenue ratio');
%figurename=['Revenue for herring('+num2str(2020+2*year)+')'];
%title('maximum revenue for herring (2025-2070)');
title('Revenue for Macekerel (2070) without Territory')

        hold on
        %axis([1 30  540/ratio 700/ratio])
        hold on
   end

end



legend('10','17','18')




% for o=1:30
%     for i=1 : harbour(1).n
%        harbour(i).ReH_set(o)=e*z(harbour(i).maxy,harbour(i).maxx)*VH-(alp*harbour(i).distance_max+harb
%        harbour(i).ReM_set(o)=e*z(harbour(i).maxy,harbour(i).maxx)*VM-(alp*harbour(i).distance_max+harb
%     end
% end
```

```
%  harbourdata = readtable('harbourdata.xlsx');
% gb = geobubble(harbourdata,'y','x', 'SizeVariable','distance_max');
% gb.SourceTable.radius_of_voyage = discretize(harbourdata.distance_max,[0:6:18],...
%                                    'categorical', {'2', '4', '8'});
% gb.ColorVariable = 'radius_of_voyage';
% name=['dis',num2str(a),'.png'];
% saveas(gb,name);




%[x,y]=meshgrid(-180:1:179,-89:1:90);
% [C,h] = contour(x,y,dist_map_max,20);
% set(h,'ShowText','off','TextStep',get(h,'LevelStep')*3)




%bar3([x,y,dist_map_max])
[x,y]=meshgrid(-20:1:20,40:1:80);
dist_map_max2=zeros(40:40);
for i=-20:20
        for j=40:80
            dist_map_max2(j-39,i+21)=dist_map_max(j+90,i+180);
        end
end

 maxx=zeros(harbour(1).n);
 minn=zeros(harbour(1).n);
for i=1 : harbour(1).n
    maxx(i)= harbour(i).distance_max;
    minn(i)=harbour(i).distance_min;
end




%
% gb.SourceTable.Severity = discretize(harbourdata.distance_max,[0:2:10],...
%                                   'categorical', {'Low', 'Medium', 'High'});
%gb.ColorVariable = 'Severity';


% [C,h] = contour(x,y,dist_map_max2,20);

%[C2,h2] = contour(x,y,dist_map_min,20);
% set(h2,'ShowText','off','TextStep',get(h2,'LevelStep')*3)


function d=dist(aa,bb)
    d=sqrt((aa(1)-bb(1))^2+(aa(2)-bb(2))^2);
end
```