Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
A		2013649

Scottish North Fishing Company Management Decision based on Changing of Sea Surface Temperature

Summary

Changes in ocean surface temperatures alter the growth patterns and distribution of Marine fish, posing challenges to the development of fishing companies. To protect the fishery industries in Scotland, our team studies the trends in Sea Surface Temperature (SST), the effects of SST on fish, and the influence on fish migration on fisheries companies' performance. Several models ~~were~~ constructed for quantitative analysis, and the results of the models were combined to provide strategic recommendations for local businesses.

According to question 1, in order to study the distribution of fish in 50 years, we propose the SST prediction model based on Long Short-Term Memory (LSTM) to preliminarily predict the water temperature in 50 years. Based on the existing literature on the distribution of herring and mackerel at different temperatures (species-specific normal probability distributions), we ~~then~~ predict the distribution of two fishes 50 years later. The quantity of two fishes are found to be gradually drop in the current fishing area, leading herring and mackerel resource to move to the Skagerrak.

For question 2, we reconstructed the SST history data since 1854 in multi-frequency. With the result of prediction in different time-series datasets, we get the SST interval of next 50 years. After that, we analyze the most optimistic and pessimistic and the most likely prediction result and find that the elapsed time is in 60 to 150 years and an average around 100. The existing fishing area fish stocks will be fell sharply, fishing companies will not be able to continue to operate in current position. Therefore, we suggest that small fishing companies should start to change their operating strategies.

To evaluate the profitability of fishery companies in different operating locations, different ship types and different Marine environments, we establish a Fleet Profitability Analysis model. We fully consider the influence factors such as SST, the rules of fish growth, actual fishing demand and the cost of fishing vessels, and determined that fishing companies should gradually relocate from the current location of Scottish ports to the vicinity of ports in southern Scotland where fish stocks are active.

To ensure that the fleet can maintain stable operation under different ocean resource conditions, we establish a Heuristic Fleet Allocation and Fishery Arrangement Strategy model. We analyzed the sensitivity of the proportion of fishing vessels of different sizes to the changes of fish resources and propose to set up 30% small vessels.

Finally, we revise and supplement our strategy for small fishing enterprises in the light of the current state of territorial waters.

Keywords: Sea Surface Temperature, Fishing, Scottish North, Operation Management Decision

1 Restatement of the Problem

Herrings and mackerels provide crucial economic beneficence to the Scottish fishing industry. However, potential migration of them may occur in the future due to global ocean temperature change. The possibility of fishing location changes will impair the economic performance of smaller Scottish-based fishing companies. We are required to better understand the migration process so as to offer practical suggestions for the industry.

As a result, we need to show the followings:

1. Indicate the most likely locations for these two fish species in the next 50 years by establishing a model.
2. Based on the analysis of ocean temperature changing process, predict the best case, worst case and most likely case of how long it would take for the small fishing companies to be quite far from the fish population in terms of their current operation locations.
3. Make judgements on whether these small fishing companies need to operate differently by the results of previous analysis.
4. Show the extent to what our proposal is influenced in case that some fishery moves to territorial seas of another country.
5. Create a short article for the magazine *Hook Line and Sink* to help fisherman understand the magnitude of fish migration problem and the positive effects of our proposal towards their future fishing business.

2 Modelling Preparation

2.1 Scotland's fishing grounds

Firstly, we obtain the map of Scotland's fishing grounds, as shown below:

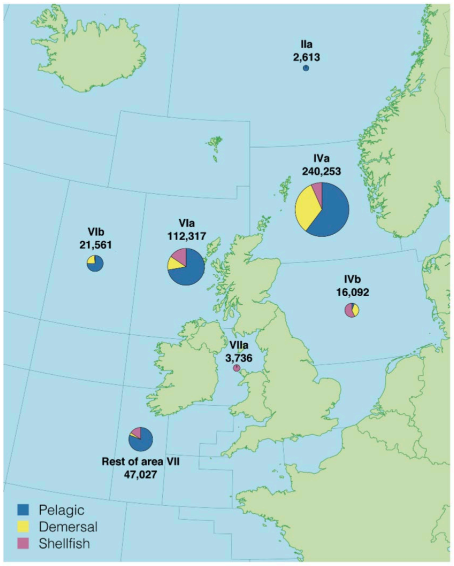


Figure 1 The map of Scotland's fishing grounds in 2018 (Scottish Gov News)

We only consider the Ⅳa region in our model as this area includes 75% of mackerel and herring production in Scotland.

2.2 Survey for Herring and Mackerel

Herring are a marine pelagic fish species living in groups. They generally live in areas ranging from 12 ° C to 15 ° C and have certain selection range for water temperature (Hakala et al. 27). In the suitable temperature range of herring, the effect of temperature on fish is firstly manifested in terms of growth and development, and secondly, they restrict their reproductive activities. The former manifests as the positive correlation between water temperature and their growth rate by an online aquatic encyclopedia. According to the Scottish government, the price of herring per ton in Scottish market was around £369 on average in 2018.

Mackerel caught in Scotland is mainly Atlantic Mackerel. As a temperature hypersensitivity species with living temperature ranging from 3°C to 9°C (D'Amours and Martin 393), they generally live and move in large groups. The study conducted by Nguyen and Nguyena also indicates the linear correlation between ocean temperature and their population (4). According to the Scottish government, the price of mackerel per ton in Scottish market was around £1047 on average in 2018.

2.3 The data of SST

SST data is downloaded from the Improved Extended Constructed Sea Surface Temperature version 5 (ERSST V5) dataset created by the National Climatic Data Center (NCDC). This dataset contains monthly data from 1854 to 2019 in the form of spatial individual observations averaged into 2°, which means every data point represents a square space of 2° (longitude) × 2° (latitude) (Kug 3240).

3 Basic Definitions for the Modelling

3.1 General Assumptions

To make problems simple, we give the following justified assumptions to help establish the proper model:

- The single fishing point is large enough that one fishing vessel can only fish at the fishing point at a time and will not pass through two fishing points. Since a single fishing point in this case is in fact a 220 × 220 km^2 square region as shown in the model part, we only consider the situation where one fishing vessel moves within this region.
- Do not consider the competition of other fleets.
- The fishing cost is only related to the ship type and distance.
- When herring and mackerel coexist in the area, the proportion of fish caught shall be the same as that in the area.
- The model is analyzed independently on a monthly basis, assuming that the temperature of each month is constant. As we will show further below, the dataset we obtain consist of monthly temperature averages.

3.2 Notations and Symbol Descriptions

Notations	Description
x	fleet port location

Cap_S	fish capacity of small fishing vessels
Cap_L	fish capacity of large fishing vessels
M_S	number of small fishing vessels in the fleet
M_L	number of large fishing vessels in the fleet
MS_{ij}	number of the j^{th} small fishing vessels going to the i^{th} fishing point $(1 \le i \le N_L)\,(1 \le i \le NJ_i)$
ML_{ij}	number of the j^{th} large fishing vessels going to the i^{th} fishing point $(1 \le i \le N_L)\,(1 \le i \le NJ_i)$
$UCS_i(x)$	unit distance cost of the small vessel from position x to fishing point i
$UCL_i(x)$	unit distance cost of the large vessel from position x to fishing point i
$fS_i(x)$	single fishing income of the small vessel from the position x to fishing point i
$fL_i(x)$	single fishing income of the large vessel from the position x to fishing point i
H_p	price of herring
M_p	price of mackerel
$HVG(T)$	growth rate of herring at temperature
$MVG(T)$	growth rate of mackerel at temperature
NJ_i	maximum number of times a fishing vessel may go to the first fishing point during fishing period
NL	number of fishing sites
l_i	location of the i^{th} fishing point $(1 \le i \le N_L)$
T_i	temperature of the i^{th} fishing point $(1 \le i \le N_L)$
RM_i	proportion of mackerel in the i^{th} fishing spot
RH_i	proportion of herring in the i^{th} fishing spot
QM_i	number of mackerel in the i^{th} fishing site under natural conditions
QH_i	number of herring in the i^{th} fishing site under natural conditions
D_s	the longest allowable sailing distance to ensure that the fish caught on the return trip are still fresh
TM_{Δ}	standard deviation of relationship between mackerel temperature and catch
TM_{opt}	the best temperature for mackerel to survive

TH_{Δ}	standard deviation of relationship between herring temperature and catch
TH_{opt}	the best temperature for herring to survive
TM_{min}	the lower limit of temperature for mackerel to survive
TM_{max}	the upper limit of temperature for mackerel to survive
TH_{min}	the lower limit of temperature for herring to survive
TH_{max}	the upper limit of temperature for herring to survive
P	length of fishing period
l_i	optimal fishing interval length of the i^{th} fishing point based on the growth rate of fish groups
λ_{ij}	safety coefficient of going to the fishing point in batch j (compared with full load)
ϵ	fishing rate in sea area, i.e. ratio of actual fishing volume to actual fish population
$D(X,Y)$	navigation distance from position X to position Y

3.3 Definition of Fishing Point

i. It is a marine area to meet the fishing demand, each area is $220\times 220\,\text{km}^2$.

ii. The constraints to become a fishing point are to meet both conditions (1) and (2) or both conditions (1) and (3)

$$(1)\ D(x,l_i) < D_S \quad (2)\ TH_{\min} \le T_i \le TH_{\max} \quad (3)\ TM_{\min} \le T_i \le TM_{\max}$$

iii. The proportion of herring and mackerel at fishing point i is the same as their growth rate at the temperature of this fishing point. When the temperature at this location is only suitable for herring growth, $RH_i = 1$ and only herring will be produced; When the temperature at this location is only suitable for mackerel growth, $RM_i = 1$ and only mackerel will be produced.

$$\frac{RH_i}{RM_i} = \frac{HVG(T_i)}{MVG(T_i)} \text{ and } RM_i + RH_i = 1$$

iv. Herring stocks at position i are independent of mackerel stocks. Therefore, under natural conditions, the number of herring and mackerel in this area are:

$$\text{Herring: } QH_i = e^{-\frac{T_i - TH_{opt}}{2TH_{\Delta}^2}} \text{ for } TH_{opt} - 2\delta \le T_i \le TH_{opt} + 2\delta$$

$$\text{Mackerel: } QM_i = e^{-\frac{T_i - TM_{opt}}{2TM_{\Delta}^2}} \text{ for } TM_{opt} - 2\delta \le T_i \le TM_{opt} + 2\delta$$

3.3 Definition of Fishing Cost

i. The cost of single fishing is the sailing distance of fishing vessel multiplied by the cost of unit sailing distance.

ii. The unit distance cost is related to the type of fishing vessel.

iii. The fishing costs for the small vessel and large vessel in the fishing area from position x

to position i are

$$\text{Small vessel: } 2\times UCS_i(x)\times D(x,l_i)$$

$$\text{Large Vessel: } 2\times UCL_i(x)\times D(x,l_i)$$

3.4 Definition of Fishing Income

i. Fishing income is the total price of herring and mackerel obtained by fishing vessels fishing in the sea.

ii. The maximum catch is the maximum capacity of the fishing vessel

iii. The maximum profit a single fishing vessel can obtain in an area is the volume of the vessel and the average unit price of the fish:

i. Small vessel: $Cap_S\times\left(RM_i\times M_p+RH_i\times H_p\right)$

ii. Large vessel: $Cap_L\times\left(RM_i\times M_p+RH_i\times H_p\right)$

iv. Under the influence of regional fish limit and multiple fishing vessels in the same area at the same time, the fishing vessel may return with full load, that is, it cannot exceed the maximum capacity of the fishing vessel. The ratio of the final catch to the maximum volume is λ_{ij}, which is related to the fish quantity at that time and the ships in the sea area at that time. Suppose there were big ships in the sea at that time

$$\left(QH_i+QM_i\right)\cdot\epsilon > ML_{ij}\times Cap_L+MS_{ij}\times Cap_S$$

which means that the fish quantity is enough for fishing vessel operation, then $\lambda_{ij}=1$,

otherwise $$\lambda_{ij}=\frac{(QH_i+QM_i)\times\epsilon}{ML_{ij}\times Cap_L+MS_{ij}\times Cap_S}$$

3.5 Interval between catch batches

The number of fish is related to their growth. Suppose that the regional ownership is the natural generation rate, then the initial quantity after fishing is

$$GH_i(t)\times(1-\epsilon)$$

According to the classical logistic fish growth model (占位符 10), taking herring as an example, the change of fish quantity is

$$\frac{dGH_i(t)}{dt}=HVG(T_i)\times GH_i(t)\times\left(1-\frac{GH_i(t)}{GH_i}\right)$$

If we integrate the above formula, we can get

$$GH_i(t)=\frac{GH_i\times GH_i(1-\epsilon)}{\left(GH_i-GH_i\left(1-\epsilon\right)\right)\times e^{-HVG(T_i)\times t}+GH_i(1-\epsilon)}$$

Simplify and get

$$GH_i(t)=\frac{GH_i\cdot(1-\epsilon)}{\epsilon\times e^{-HVG(T_i)\cdot t}+(1-\epsilon)}$$

According to the formula, we can calculate the fishing time from the end of fishing to the recovery of natural state.

4 Question 1: Distribution prediction based on SST data

4.1 SST prediction model based on Long Short-Term Memory (LSTM)

In this section, we establish a model to determine the most likely fish location with ocean temperature being the key factor. Basically, we first predict the ocean temperature over the next 50 years using the Long Short-Term Memory (LSTM) algorithm. Then by demonstrating the proportional relation between sea temperature and fish population, we successfully obtain the fish round up location. The LSTM model contains an input layer, a hidden layer with 50 neural units, and an output layer. The data of the SST from 1854 to 2019 is divided into the training set (80%) and the test set (20%). The Mean Squared Error (MSE) of forecasting is 0.03, so it has a good prediction performance.

4.2 The result of SST prediction

Taking the fishing season into consideration, we analyze the average temperature of May (Mackerel's fishing season) and August (Herring's fishing season) from 2020 to 2069. After processing the data, we finally obtain SST distribution in May and August (See Figure 2-5).

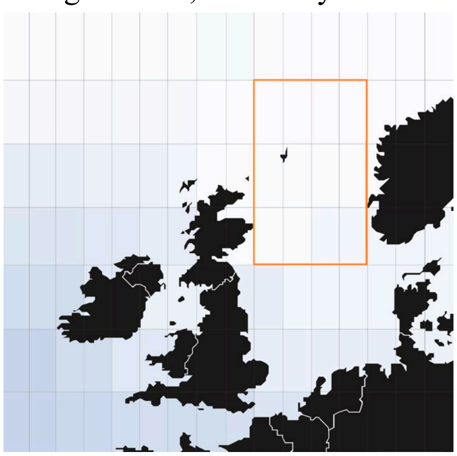


Figure 2 The SST in May 2019

Figure 3 The predicted SST in May 2070

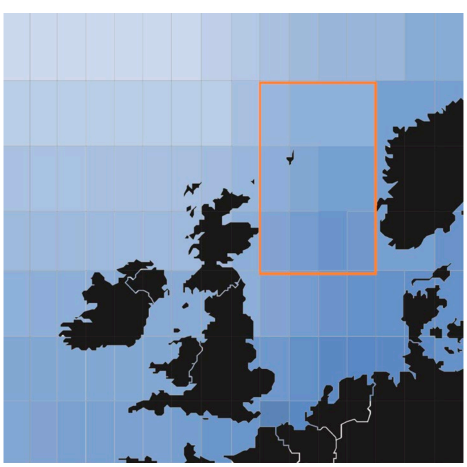


Figure 4 The SST in August 2019

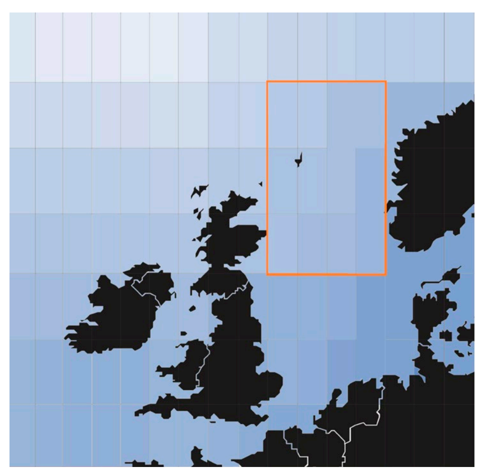


Figure 5 The predicted SST in August 2070

The dark blue parts represent the higher temperature regions and light blue parts represent the lower ones. The region in the orange rectangle is the current fishing location by fishing reports from Scotland government. These two pictures show the obvious differences of ocean temperature between the prediction result and the present. We will determine the most likely fish population from this prediction.

4.3 Distribution prediction of fishes

According to Serpetti's research, we can get the optimum temperature for mackerel growth is around 9 $\pm$ 1.5 ° C (5). Since mackerels are mainly caught in May, we will use the temperature prediction results for May to determine their location. The temperature field shifts will lead to the offset of fish group center. Therefore, under natural conditions, the number of mackerels in this area is:

$$QM_i = e^{-\frac{T_i - TM_{opt}}{2TM_\Delta^2}} \text{ for } TM_{opt} - 2\delta \le T_i \le TM_{opt} + 2\delta$$

Hence, as shown in Figure 6, the most likely mackerel location is

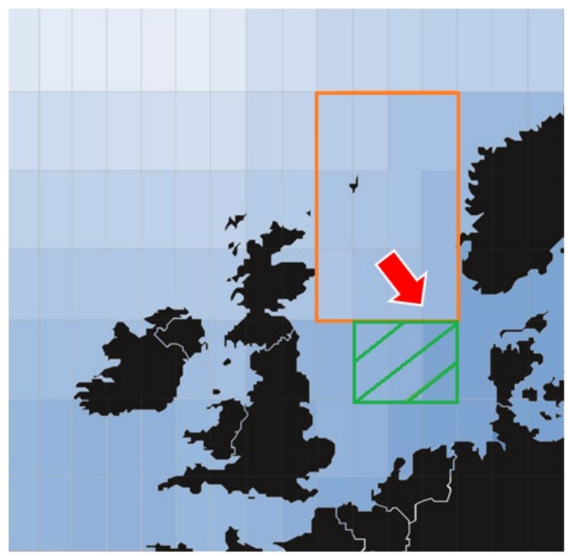


Figure 6 The most likely location for mackerel in May Figure 7 The most likely location for herring in August

where the green region is the most likely area for mackerel.

In fact, our model also indicates some of the mackerel stocks will move to the west coast of Scotland. Since we mainly discuss Ⅳa region (area within the orange rectangle) here, so we just manifest the green shadow area.

Similarly, the optimum temperature for mackerel growth is around 16 $\pm$ 1.5 ° C. The number of herring is given by:

$$QH_i = e^{-\frac{T_i - TH_{opt}}{2TH_\Delta^2}} \text{ for } TH_{opt} - 2\delta \le T_i \le TH_{opt} + 2\delta$$

plugging the temperature data in August 2070, we obtain the most likely herring location (see Figure 7).

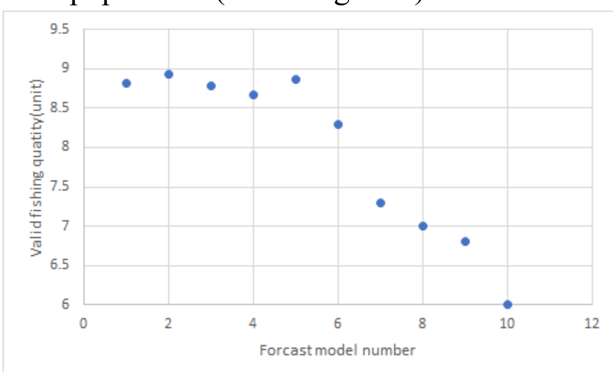
5 Question 2 The trend of fishery resources

5.1 Temperature prediction based on multi-frequency data

For this question, as we have shown above, we mainly discuss the change in the number of fish groups under the circumstance of temperature. In other words, it is the study on the number of center point drifts.

Since the two kinds of fish are different, we need to discuss them separately. We discuss the mackerel first and apply the analogous approach to study herring.

In terms of the mackerel, we use the temperature data in May to do the prediction. We select different time intervals for our LSTM model, which includes 1 year to 10 years. Then we get different temperature prediction results based on different time interval choices (See Figure 8). For each temperature prediction result, we apply the normal distribution to calculate the predicted mackerel population (see in Figure 9).



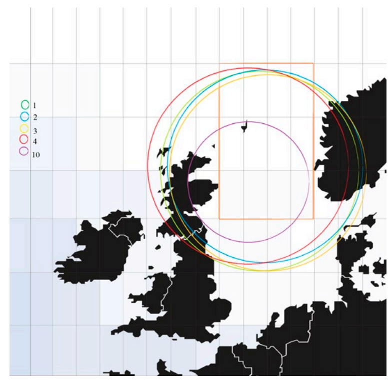


Figure 8 Predicted mackerel population on multi-frequency data Figure 9 Mackerel population distribution

The area of circles in Figure 9 represents the predicted mackerel population amount. It is obvious that time intervals in short terms have almost identical evolution speed of fish population, while the time interval of long terms has a relatively higher speed.

The future fish population of the current fishing region is estimated to decline. Results based on short intervals manifest the slow decline trend of the mackerel population, while the long intervals lead to a faster decline.

5.2 The Best case

Based on Figure 8, we can see the maximum quantity of the fish is about 9 units, and the color of the corresponding circle in Figure 9 is blue. We find that the center location of the circle is far away from the current population center. The shift distance of the center is about 200km. Based on the velocity of temperature declining in this situation, the elapsed time is about 150 years, which means that there will be no sufficient fishery resource to support the operation of the fishing company.

5.3 The Worst case

Based on Figure 8, we can see the maximum quantity of the fish is about 6 units, and the color of the corresponding circle in Figure 9 is purple. We find that the center location of the circle is close to the current population center. The shift distance of the center is about 300km. Based on the velocity of temperature declining in this situation, the elapsed time is about 60 years.

5.4 The Most Likely Elapsed Time

Based on Figure 8, we can see the medium quantity of the fish is about 8 units. Based on the velocity of temperature declining in this situation, the elapsed time is about 100 years.

6 Question 3 The Suggestion of operational decision for fishing companies

Based on the previous analysis, we find that the center of the fishery is drifting continuously due to the change of temperature, and the fish quantity at the current fishing site is decreasing, which leads to the failure of fishing companies to obtain sufficient fishery resources. The following is an account of the changes in two operating locations and the adjustment of the proportion of fishing vessel types.

6.1 Relocating the asset of small fishing companies

6.1.1 Fleet yield model

The fishing companies' income mainly sources from fishing, and their fishing location is closely related to where they operate. Since the freshness of the fish can only be guaranteed if the vessel returns within a specified time. Based on the description in the third part of this paper, the income formula of fishery companies is determined as follows:

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\lambda_{ij}\left(\left(ML_{ij}\times Cap_L+MS_{ij}\times Cap_S\right)\times\left(QM_i\times M_p+QH_i\times H_p\right)-\left(2\times UCS_i(x)\times D(x,l_i)+2\times UCL_i(x)\times D(x,l_i)\right)\right)\right]$$

As it can be seen from the formula, the yield is positively correlated with the number of catch points and fish quantity that can be reached, and negatively correlated with the distance.

6.1.2 The adjusted strategy of the operational location

Based on the prediction model in Part 4 and 5, the amount of the herring and mackerel in the original fishing point will drop sharply. According to Figure 6 and 7, we can find the movement the fish is to the mostly south east direction. The population of herring and mackerel will gather to Skagerrak in fifty years. Therefore, we suggest the small fishing companies move to the ports in the South of Scotland, which can be ports in Anstruther and Eyemouth. Besides, since what we are analyzing are small companies, so the best choice for them is to move all their assets to target port to run their business smoothly and economically.

Figure 10 Districts and ports in Scotland, 2018 (Scottish Gov News)

6.2 Adjusting fishing vessels types and arrangements

6.2.1 Heuristic Fleet Allocation and Fishery Arrangement Strategy model

Under the circumstance that the fishery resources and the catch ability of fish is constant, different types of vessels and catching arrangements have a great influence on the finally profits. Therefore, we design the Heuristic Fleet Allocation and Fishery Arrangement Strategy model to find the proper solution.

We define the capacity of a large vessel (Cap_L) is 1800 ton and the capacity of a small vessel (Cap_S) is 300 ton. Then we suppose that the ratio of small vessels to large vessels can be adjusted and the scale adjustment range of small vessels and large vessels is 0.2-0.5. The searching steps of the heuristic model is following:

1. Arrange the fleet by the size of fish groups in the fishing area, the area with more fish groups should be put in first.
2. Launch according to the priority principle of large ships.
3. Calculate the regional fishing point safety coefficient λ_{ij}, and determine the number of large ships and vessels based on the principle of safety factor is larger than 1 (See the formula in Part 3).
4. After traversing all fishing areas, if there are fishing vessels, calculate the safety factor of all fishing areas according to the distribution of large ships and vessels according to the remaining fish in the fishing areas.

5. For areas with large safety factors, priority is given to launching vessels of the corresponding size until all vessels have been launched.

6.2.2 The proportion of small vessel and large vessel

According to the most likely ocean temperature and port location determined above, we can calculate the total profit after the fishing vessel is launched by formula in Part 6.1.1. Then we can select the ratio which leads to the biggest profit and it is the proportion small vessels. Hence, we finally obtain which shows the proportion of the small vessel should be 0.3 and that of the large vessel should be 0.7 (see Figure 11).

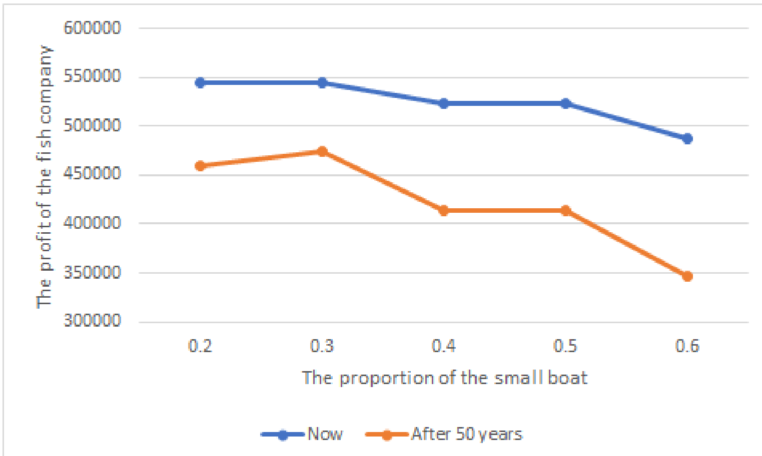


Figure 11 The relationship between the proportion of the small vessels and the profit of the fishing company

7 Question 4 The changing proposal due to the territorial sea

Based on the conclusion of our prediction model, the herring and Atlantic mackerel are moving in the same direction, swimming towards the Skagerrak sea uniformly. Although Skagerrak is an international high sea (Wikipedia), Skagerrak fishing is jointly negotiated and managed by Norway and the European Union (EU). Whether Scotland can conduct fishing in Skagerrak waters is subject to the trilateral agreement agreed upon by them. However, since the United Kingdom left the European Union, and under Agreement of 15 January 2015 between the Kingdom of Norway and the European Union on Reciprocal Access to Fishing in the Skagerrak for Vessels Flying the Flag of Denmark, Norway and Sweden (European Union and Norway for 2020 - Skagerrak and Kattegat), Scottish fishing vessels do not fly the flags of Denmark, Norway or Sweden for fishing operations, so Scotland's fishing operations in Skagerrak are illegal and will be prohibited by the relevant Norwegian maritime authorities.

With the SST interval of next 50 years resulted from prediction in different time-series datasets, the herring and Atlantic mackerel will gradually migrate to the Skagerrak sea over the next 50 years because of temperature changes (see Figure 1, 6, 7). Based on the result of question 2, we believe that the speed at which herring and Atlantic mackerel migrate to Skagerrak will have small impact on the fishing performance of Scottish fishermen and Scotland's fisheries in the next 50 years. However, as the times goes on, fish will gradually migrate towards Skagerrak waters, the number of herring and Atlantic mackerel caught by Scottish fishermen will drop a lot which will seriously affect the survival and development of Scottish fisheries and related industries.

Hence, when herring and Atlantic mackerel migrate from the North Sea to Skagerrak, Scotland's small fishing companies' interests will be affected. Therefore, the proposal should be changed more based on the model,

i. In the next 50 years, we suggest that Scotland's small fishing companies should transfer to Anstruther, Eyemouth and other ports in south coast of Scotland from their original ports to obtain the maximum benefits.

ii. As the herring and mackerel may not be able to be captured in the area IVa and IVb. In this case, we suggest that Scotland's fishing industry, together with related industries, put more focus on for the sea area at the west of Scotland, namely to VIb, VIa and VIIa for fishing herring and Atlantic mackerel. Although the ports in the west, right now, are mainly focus on the shells. Based on the fishery resources distribution prediction, the SST may sooner or later be the proper temperature for the growth of mackerel, which means that it would be easy for the fisherman to catch fish inshore. At this time, small fishing companies are advised to move to the ports at the west coast of Scotland such as Stornoway, Portree, Mallaig, Oban, Campbeltown and Ayr from their original ports for the maximum benefit.

iii. No matter how the small fishing companies move, if they move to the ports on the south coast of Scotland, they can try to find fish processing plants in Germany and Denmark adjacent to area IVb to deal with the caught fish nearby. If they move to the ports on the west coast of Scotland, accordingly, they can try to find the corresponding fish processing plants in Ireland adjacent to area VIa and VIIa. If such small fishing companies can find multinational cooperative fish processing plants, fishing efficiency will be greatly improved, which will help improve the small fishing company's profits.

iv. When all herring and Atlantic mackerel migrate from areas IVa to the Skagerrak sea area, there is another plan to maintain the survival of small fishing companies, that is, it is recommended that small fishing companies use loans and other means to purchase vessels and equipment related to long distance fishing operations. The increase in the distance of fishing operations will allow small fishing companies to maintain steady or small increases in revenue.

Conclusively, if some proportion of the herring and Atlantic mackerel migrant to the Skagerrak sea predicted by our models, our proposal will suggest small fishing companies leave their original ports for the ports at the south or west coast of the Scotland to change to the fishing sites with more herring and Atlantic mackerel. Hence, the two variables, the fleet port location and the number of fishing sites, in the Fleet Profitability Analysis model established by us are most affected.

Question 5 The report for fisherman in Scotland

With global warming accelerating, the biosphere is suffering its worst disaster since the dawn of human ingenuity. Herring and Atlantic mackerel, the main targets of Scottish fishing, are also being affected. This is mainly reflected in the fact that during the May-June and July-August fishing season, the favorable conditions for herring and Atlantic mackerel near the British Isles are gradually moving southeastwards towards the Skagerrak sea and the territorial waters of Germany and Denmark.

This means that the two kinds of fish that account for three-quarters of Scotland's annual catch are moving away from the Scotland. Herring and Atlantic mackerel catches are set to fall in the next 50 to 100 years because Skagerrak sea are not open to fish-related fishing from Britain, which has left the European Union. Worse, extrapolations and projections based on available data suggest that the migration of herring and Atlantic mackerel to the Skagerrak sea is continuing and irreversible. The worst case scenario would be a century or so in which there would be little herring or Atlantic mackerel in the north-east offshore of Scotland, or where Scotland would be able to fish; The best case scenario is that there will be no fish to catch until the next two centuries or so. No matter how fast or slow the process, the lack of fish would be devastating to most of Scotland's small fishing companies. Therefore, the entire fishing industry and related industries in Scotland need to be highly concerned and vigilant.

Given the current forecast, although herring and Atlantic mackerel are expected to move towards Skagerrak from the north-east offshore of Scotland, a number of herring and Atlantic mackerel will remain in the south-east sea of Scotland for a long time to come. Meanwhile, herring and Atlantic mackerel are still plentiful in the north Atlantic, west of Scotland. Hence, we recommend that small fishing companies, which are in the north or north-east coast of Scotland, with the ability to leave for the ports in the south-east, can start going to ports for adaptive fishing. Similarly, small fishing companies with long distance fishing capabilities can go to the ports in the west coast of Scotland and start exploiting north Atlantic fishing sites and fish stocks westward.

While advising small fishing companies to move ports, we also suggest that the small fishing companies, those with the ability to establishing partnership with Denmark and Germany’s fish processing plants eastward and Ireland's westward, directly send their caught fish to abroad for processing in order to improve the efficiency of the fishing and to improve the company's profits.

Finally, we suggest that small fishing companies increase their long-distance fishing capacity through, for example, loans. At the same time, we also recommend that the vessels in fishing operation should be separated by at least 22 nautical miles in order to ensure the efficiency of fishing, according to our data and model. Moreover, the small tonnage vessels should be separated from the large tonnage vessels by a certain distance to ensure the maximum profit from a single voyage.

References

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Appendix

 # The code for LSTM prediction

```
from keras.datasets import mnist,boston_housing
from keras.layers import Dense, LSTM
from keras.utils import to_categorical
from keras.models import Sequential
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import re
from sklearn.model_selection import train_test_split
from keras import metrics
from sklearn.preprocessing import MinMaxScaler
from sklearn.metrics import mean_squared_error
#Jan
def R2(y_pred,y_test):
    SStot=np.sum((y_test-np.mean(y_test))**2)
    SSres=np.sum((y_pred-np.mean(y_test))**2)
    r2=SSres/SStot
    return r2
month = list()
for i in range(1854,2021):
    data = pd.read_csv("monthly data/"+str(i)+"-7.csv").set_index("Unnamed: 0")
    # L -4/356(356/2=178 171-180) W 51(51/2=25 25+44=69 65-74)
    data = np.vstack((np.array(data)[174:180,70:76],np.array(data)[0:7,70:76]))
    month.append(data)
month = np.array(month[:-1])
result = list()
all_process = np.zeros([50,13,6])
process_acc = list()
for i in range(13):
    process = list()
    for j in range(6):
        process_x = month[:,i,j]
        scaler = MinMaxScaler(feature_range=(0, 1))
        process_x = scaler.fit_transform(process_x.reshape(len(process_x),1))
        x_train, x_test = process_x[:134],process_x[134:]
        y_train = np.append(x_train[1:len(x_train)],0).reshape(len(x_train),1)[:-1]
        y_test = np.append(x_test[1:len(x_test)],0).reshape(len(x_test),1)[:-1]
        x_train = x_train.reshape(len(x_train),1)[:-1]
        x_test = x_test.reshape(len(x_test),1)[:-1]
        x_train = x_train.reshape((x_train.shape[0], 1, x_train.shape[1]))
        x_test = x_test.reshape((x_test.shape[0], 1, x_test.shape[1]))
        model = Sequential()
        model.add(LSTM(50,input_shape=(x_train.shape[1],
x_train.shape[2]),kernel_initializer='random_uniform'))
```

```
        model.add(Dense(1,kernel_initializer='random_uniform'))
        model.compile(loss='mae', optimizer='adam')
        history = model.fit(x_train, y_train, epochs=50, batch_size=10,verbose=0)
        y_predict = model.predict(x_test)

process_acc.append(mean_squared_error(y_predict.reshape(1,len(y_predict)),y_test.reshape(1,le
n(y_test))))
        circle = np.array([process_x[-1]])
        circle = circle.reshape((circle.shape[0], 1, circle.shape[1]))
        circle = model.predict(circle)
        all_process[0,i,j]=scaler.inverse_transform(circle)[0][0]
        print("Start prediction!")
        for a in range(1,50):
            circle = circle.reshape((circle.shape[0], 1, circle.shape[1]))
            circle = model.predict(circle)
            all_process[a,i,j]=scaler.inverse_transform(circle)[0][0]
        process.append(scaler.inverse_transform(circle)[0][0])

print(mean_squared_error(y_predict.reshape(1,len(y_predict)),y_test.reshape(1,len(y_test))))
    result.append(process)
    print(result)
    print("Done!",i)
print(result)
```

 # The code for heuristic algorithm for analysis the proportion of the small boat

```
small_boat_p = 0.4
small_boat = np.zeros(12)
big_boat_p = 1 - small_boat_p
big_boat = np.zeros(12)
small_boat_a = small_boat_p*10
big_boat_a = big_boat_p*10

def norm_proba(x,opt,delta):
    if x>=opt-delta*2 and x<=opt+delta*2:
        return np.exp(-((x - opt)**2)/(2*delta**2))
    else:
        return 0
def Distance_calculation(location_1,location_2):
    return np.sqrt((location_1[0]-location_2[0])**2+(location_1[1]-location_2[1])**2)

small_boat_cap = 300
big_boat_cap = 1800

location=[(7,2),(7,3),(7,4),(7,5),(8,2),(8,3),(8,4),(8,5),(9,2),(9,3),(9,4),(9,5)]
x = (6,2)

data = np.array(pd.read_csv("Aug_2.csv").set_index("Unnamed: 0"))
temperature =[]
for i in location:
    temperature.append(data[i[0],i[1]])

distance = list()
for i in location:
    distance.append(Distance_calculation(x,i))

s_price = 200
l_price = 1200
def cost_s(small_boat):
    cost_s = (distance*small_boat)*s_price*2
    return cost_s
def cost_l(big_boat):
    cost_l = (distance*big_boat)*l_price*2
    return cost_l

total_cost = np.sum(cost_s(small_boat)+cost_l(big_boat))

qm_max = 120
qh_max = 300
qm = list()
qh = list()
```

```
for i in temperature:
    qm.append(norm_proba(i,800,150))
    qh.append(norm_proba(i,1600,150))

qm = np.array(qm)*qm_max
qh = np.array(qh)*qh_max

qh_1 = list(zip(qh,np.arange(12)))
qh_1.sort()
qh_1 = qh_1[::-1]

# Put the big boat in the sea
for i in qh_1:
    big_boat[i[1]]+=1
    big_boat_a -= 1
    if big_boat_a == 0:
        break

# Put the small boat in the sea
for i in qh_1:
    if big_boat[i[1]]>0:
        continue
    else:
        if small_boat_a == 1:
            small_boat_a -= 1
            small_boat[i[1]]+=1
        else:
            small_boat_a -= 2
            small_boat[i[1]]+=2
        if small_boat_a == 0:
            break
print(small_boat)
print(big_boat)
ability = 0.3
def lambda_calculation(qm,qh,ability=0.3):
    result = (qm+qh)*ability/(small_boat*small_boat_cap+big_boat*big_boat_cap)
    for i in range(len(result)):
        if result[i] >1 and result[i]!=np.inf:
            result[i]=1
        if result[i]==np.inf or np.isnan(result[i]):
            result[i]=0
    return result


m_price = 1000
h_price = 333
```

```
rm = qm/(qm+qh)
rh = 1-rm
for i in range(len(rm)):
    if np.isnan(rm[i]):
        rh[i]=0
        rm[i]=0

def income(small_boat,big_boat,rm,rh,qm,qh):
    return
sum((small_boat*small_boat_cap+big_boat*big_boat_cap)*(rm*m_price+rh*m_price)*lambda_
calculation(qm,qh))

target = income(small_boat,big_boat,rm,rh,qm,qh)-total_cost
print(target)
```