Problem Chosen	2020 MCM/ICM Summary Sheet	Team Control Number
A		2014993

Moving North to Catch More

Summary

With the development of global industrialization and urbanization,climate change is becoming a significant ramification. In order to investigate the impact of climate change on herring and mackerel migration, we established a time series prediction model for the geographic migration of them.

In task 1, We established an ARIMA model of the sea surface temperatrue at 20 monitoring points in the North Atlantic (near the Scottish waters) for time series analysis and obtained forecast values for the next fifty years. Based upon the optimum temperature of the herring and mackerel, we track their migration trajectories and targets, and come to the conclusion that their most likely locations after 50 years will be Norway and Iceland.

In task 2, In order to predict the best case,worst case,and most likely elapsed time(s),we use outlier detection methods based on wavelet analysis and calculate the probability distribution of the sea surface temperature anomaly in the fifty years.We draw a conclusion that the good case lasts up to 54 months, the worst case lasts up to 3 months, and the best case lasts on average 6 months.

In task 3, we analyze the predictive model and concludes that small fishing companies should change their operations. They are supposed to gradually move the industry distribution in accordance with the predicted trajectory, and determine the optimal moving ratio by optimizing the investment portfolio.

In task 4, if some proportion of the fishery move into the territorial water(sea) of another country,from the macroscopic and microscopic perspectives, we explained the positive and negative impacts of our proposal in political, economic, cultural, and social aspects.

In task 5, we prepare an article for *Hook Line and Sinker* magazine.In the article, we analyze the severity of the current fishery production situation and put forward four suggestions for improving the dilemma and obtaining development: to move northward, innovate equipment, modify business strategies and implement integrated fishing.

Finally, we analyze the strengths and weaknesses of the methods we proposed in this paper. The research can also satisfy the need of the MCM. It will provide scientific and reasonable reference for small fishing companies affected by climate change along the North Atlantic coast to cope with global warming and achieve sustainable development of fishery resources development.

Keywords: Climate Change; Herring and Mackerel; Time series prediction; ARIMA; Wavelet analysis

Contents

1 Introduction

1.1 Background

In recent years, in the academic field of global climate, marine climate change has become a research focus of academic circles. Marine climate change, such as ocean warming, rising sea levels, and frequent occurrence of extreme weather events, will have impacts on marine fisheries in all aspects and dimensions. With the gradual intensification of global warming, global ocean temperatures will more profoundly affect the quality of habitats for certain ocean-dwelling species, and the abundance of marine fishery resources and the distribution of fishery productivity will also change and shift accordingly.[1][2]

Herring stock is densely populated, with large numbers of individuals, and is caught from June to September. Mackerel , which move in large group ,is captured from September to November in the next year. [3]As a country with a long history and highly profitable seafood industry, Scotland's market in ocean fishing is almost equally divided by herring and mackerel. The Scottish Fisheries Statistical Yearbook and related studies for the past forty years have shown that the sea areas where the two pelagic fishes gathered have deviated from their original latitudes.[4] Catches of both species in Scottish waters have also declined. Therefore, it is imperative to predict the geographic distribution and migration trajectory of herring and mackerel in the next few decades, and to find the optimal plan for fishery and fishery management under this premise. This has important meaning for small fisheries companies and even Scotland's overall national economy.

1.2 Our Work

To predict the possible geographic locations of North Atlantic herring and mackerel in the next 50 years, we need to build a time series model that can predict the migration location of fish swarms based on the ocean surface temperature. First, we establish a model of the surface temperature of the sea oxygen, and predict the future sea temperature based on the sea temperature data of fishing season from 1982 to 2019 . Second, we establish the corresponding relations between the intensive fishing areas of herring and mackerel and the sea temperature in the area. Finally, we search for ocean area whose temperature is in accordance of the target temperature several years later.

In Section 2, we state the basic assumptions of the ... Model and give detailed explanation and calculation for each indicator used in the model. In Section 3, we give a detailed solution process and comprehensive analysis of the prediction model We also solve tasks listed as follows

1 Predict the best case, worst case and most likely elapsed time (s) until these populations will be too far away for small fishing companies to harvest if these companies continue to the operate out of their current locations.

2 Determine whether small fishing companies should change their operations. Propose our plan accordingly.

3 If some proportion of the fishery move into the territorial water (sea) of another country, explain the impact to our proposal.

4 Prepare articles for Hook and sinker magazine to help fishermen understand the seriousness of the problem and propose countermeasures.

5 Evaluate the reliability of our model and do the sensitivity analysis. Then, we will discuss the strengths and weaknesses about our model.

2 Assumption

1 It is assumed that the water quality of the North Atlantic (the area within the fishing range of Scotland) will not change too much in the studied time range.

2 There are no large-scale marine infectious diseases in this sea area

3 Assume Scottish herring and mackerel's survival and migration are unaffected by their predators and natural enemies

4 Assume that fishing catches for herring and mackerel has been kept within a reasonable range

5 The provided data is realistic and accurate.

3 Task 1

In order to monitor temperature changes in the sea area near Scottish herring and mackerel habitats, we focus on establishing observation points in and around the waters where fishing companies focus their fishing. By consulting the data, we know that the large-scale fishing areas of herring and mackerel in the 1980s and 1990s are $(53°30'N - 57°30'N, 7°E - 4°W)$ and $(52°N - 54°N, 3°W - 5°W)$. By 1995, the catch in this area had decreased significantly, and catches in $(58°N - 61°N, 5°E - 2°W)$ increased. In 2012, a large number of herring and mackerel were centralized in $(57°N - 62°N, 0°W - 4°W)$ and $(56°N - 59°N, 7°W - 9°W)$, and there are very few in $(53°30'N - 57°30'N, 7°E - 4°W)$. By 2017, the Scottish herring and mackerel centralized fishing area only exist two high latitude portion, and the proportion of catches of the two fishes in the lower latitudes $(53°30'N - 57°30'N)$ was almost zero. [5]Therefore, 20 monitoring points were selected (as shown in Figure 1), and a series of temperature-oriented mathematical models were established by analyzing the temperature series of sea surface temperatures in the historical years of these monitoring points to predict the likely survival places of the fish stock.[6]

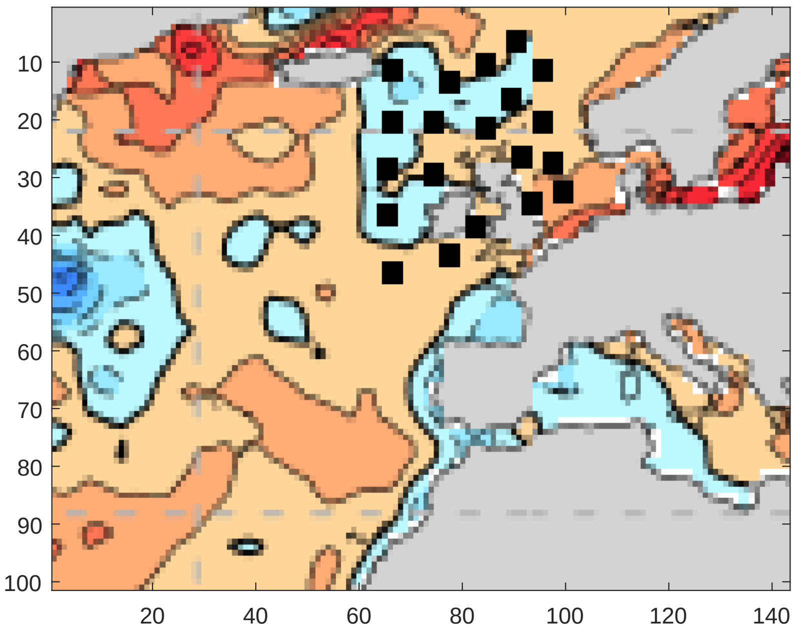

Figure 1: observation points

In data processing, we selected 20 monitoring points which are in size of 4*4 , and used stepwise regression method to establish a mapping model of the RGB value of the image to the temperature. The corresponding temperature scale is as shown in Figure 2.

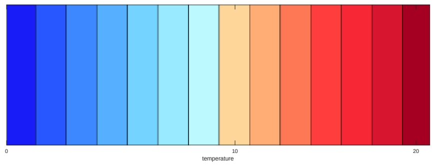

Figure 2: temperatrue scale

Through stepwise regression, the mapping relationship between the RGB value of the image and the temperature is obtained:

$$T = \theta^T RGB$$

The fitting results is shown in Figure 3.

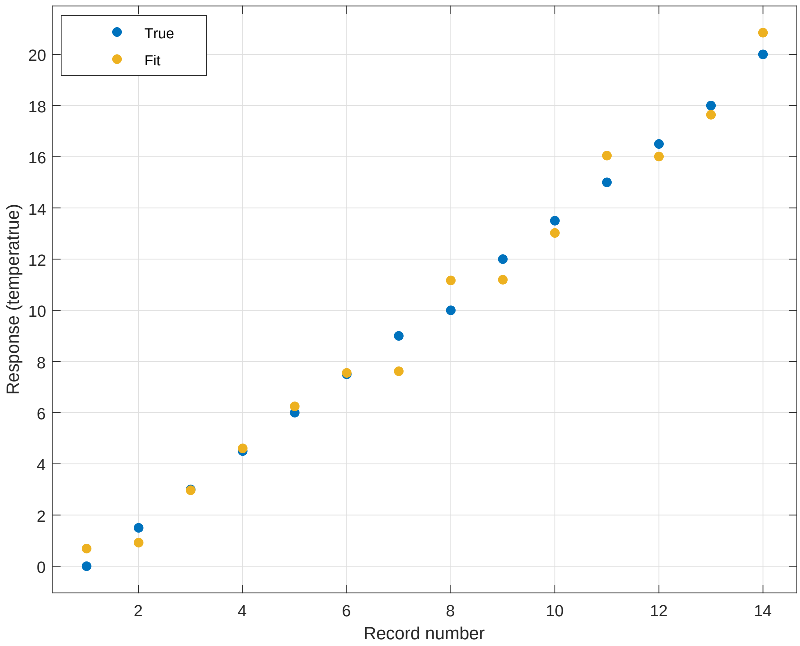

Figure 3: rgb-temperatrue fit

By mapping the RGB value of the image to the temperature, we obtained the temperature time series data from January, 1982 to January, 2020. By using historical data[7], we know that the centralized fishing time for herring and mackerel is from June to November of each year and January and February of the following year. Therefore, we set up a time series prediction model for the months of centralized fishing.

We perform ADF unit root test on the sequence data. Check Figure 4 for the sequence data whose results are not stable to the outcome, and use the difference operation to make it stable (shown in Figure 5).

Figure 4: time series

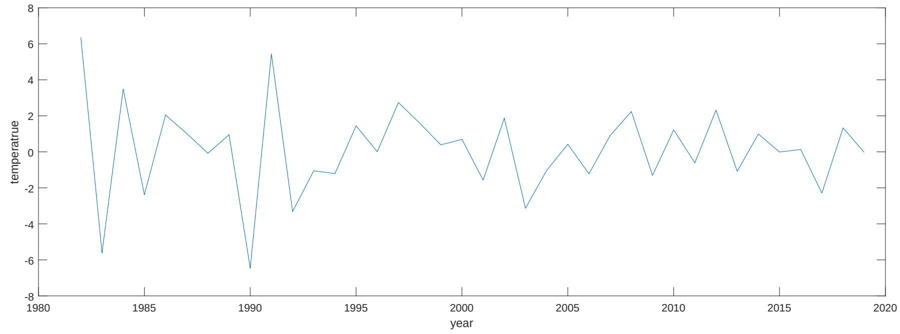

Figure 5: first difference

The monthly temperature series are obtained year by year, and then the ARIMA (p, d, q) model is established for all the series data to obtain the forecast series for the next 50 years. For example, the fit and prediction result for August is as shown in Figure 6.

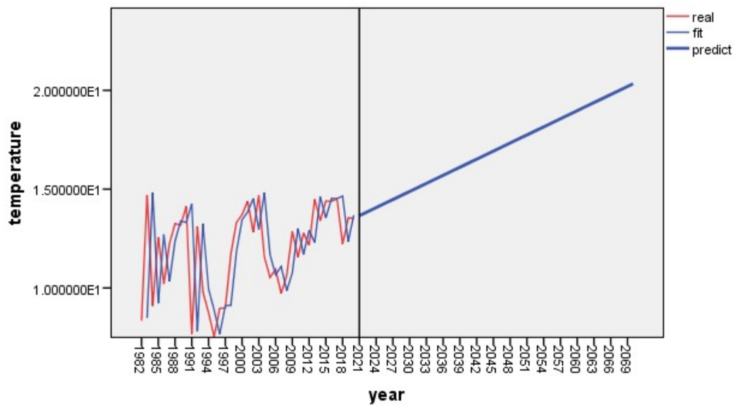

Figure 6: ARIMA predict

Then we tracked the temperatures suitable for the survival of mackerel and herring in the prediction data. After reviewing the corresponding data the optimal survival temperature for mackerel and herring is about 50 degrees Fahrenheit, so the tracking threshold is set to 49.1 to 52.7 degrees Fahrenheit. We tracked all the months of 20 monitoring points to get the optimal temperature duration matrix.

In addition, in accordance with the chronological sequence, we use the fish gathering place in former years as the starting point, and the optimal temperature movement trajectory was made in Figure 7.

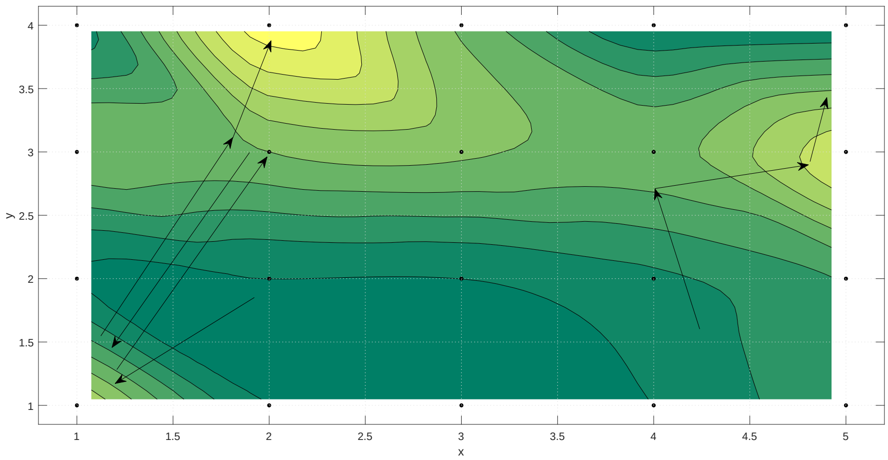

Figure 7: trace predict

We search the literature and learned the average migration speed of movement of fish habitat is 40 kilometers per decade. [8][9]Based on the water temperature prediction results, we speculate that cold water fingerlings will move in the direction to Norway or Iceland within the next 50 years, that is, the locations with bright colors in Figure 7.

4 Task 2

We select the monitoring points on the trajectory of the school of fish moving in the direction of Norway, and perform wavelet anomaly analysis of historical data throughout the year. We will use the analysis results to predict the probability of future anomalies. The understanding of the anomaly here is that the water temperature exceeds the optimal survival temperature of herring and mackerel in a short period of time, which is not propitious to fish survival. After reviewing, we chose an anomaly detection algorithm based on wavelet decomposition and implemented it in Matlab.[10] First, the first-order difference operation is performed on an unstable temperature (Figure 8) sequence, and autocorrelation tests and partial autocorrelation tests are performed.

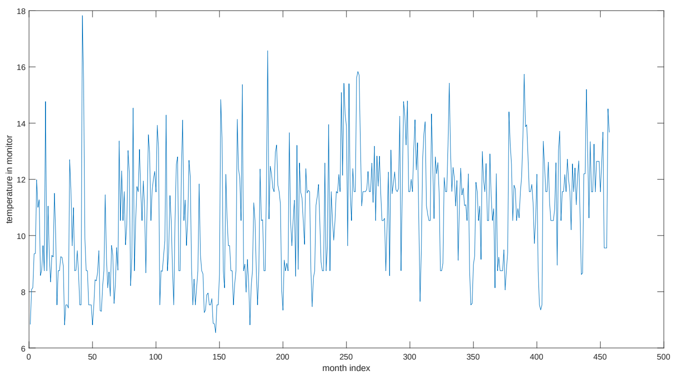

Figure 8: temperatrue series

It can be seen from Figure 8 that the sequence is not stable, and there are some outliers. After the first-order difference, the overall fluctuation of the series is stable, and the auto-correlation tests and partial correlation tests can be seen in Figure 9.

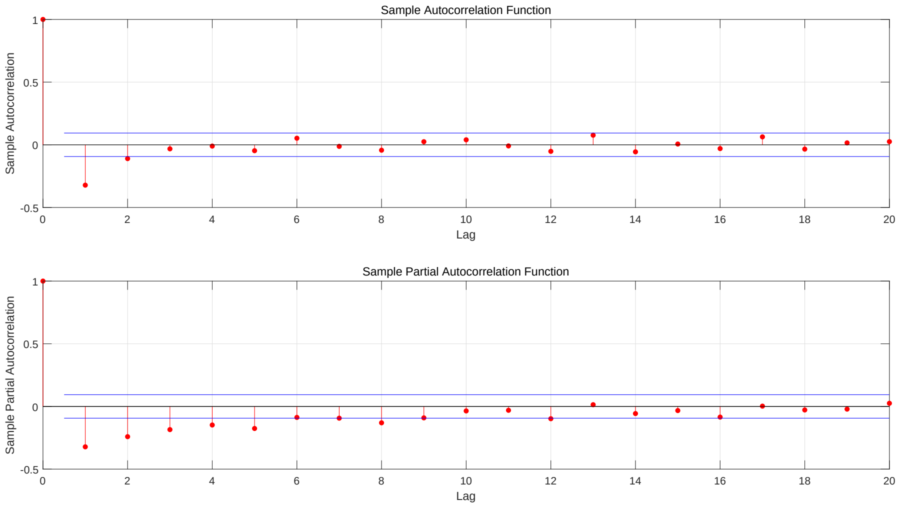

Figure 9: ACF and PACF

A GARCH (1,1) model is established for the temperature series. The results are shown in Table 1.

GARCH (1,1) Conditional Variance Model (Gaussian Distribution)				
	Value	StandardError	TStatistic	PValue
Constant	3.2942	0.62139	5.3013	1.15E-07
GARCH{1}	0.095363	0.15239	0.62578	0.53146
ARCH{1}	0.15782	0.053429	2.9538	0.003139

Table 1: GARCH (1,1) Conditional Variance Model (Gaussian Distribution)

Acquire the residual sequence obtained from the model in Figure 10.

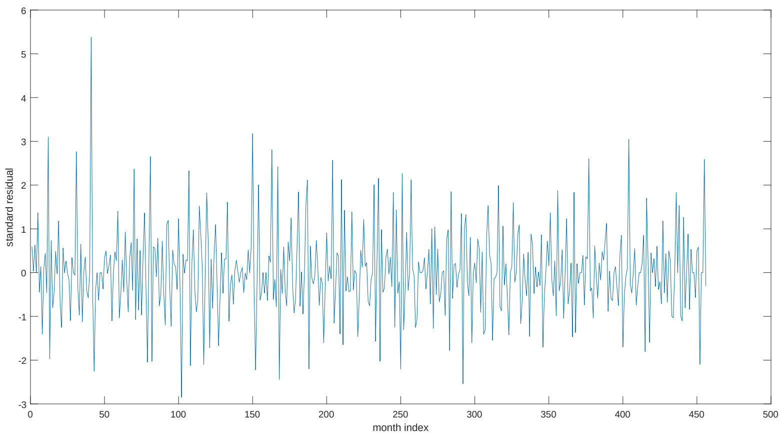

Figure 10: residual series

Anomaly detection algorithm steps demonstration:

1. Use the Monte Carlo algorithm to simulate the approximate normal distribution of the residual sequence. Run 10,000 times, take the maximum value of each result, and use the average value of all results as the threshold for screening anomalies.

2. The DWT discrete wavelet decomposition is performed on the residual sequence, and the haar wavelet is selected as the wavelet base to obtain the wavelet approximation coefficient and wavelet detail coefficient of the first layer.

3. Find out the position that exceeds the threshold, record it, and modify the corresponding position of the detail coefficient to 0, and then use IDWT to reconstruct the time series.

4. Repeat the above process until all the sequence values are smaller than the threshold.

After correcting the outliers, the abnormality of the residual sequence was significantly improved (Figure 11).

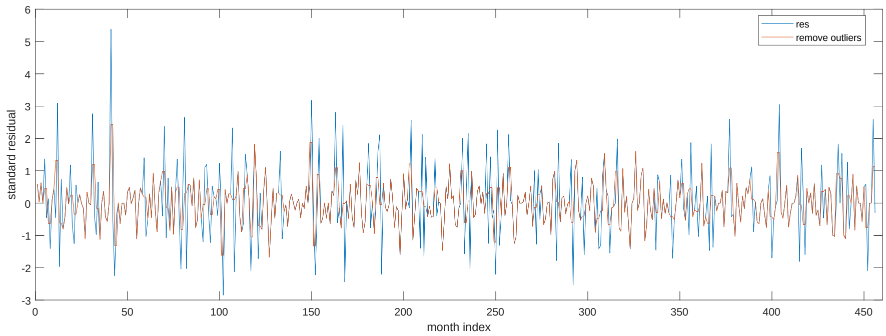

Figure 11: outliers check

So we got a series of anomalous positions. For example, the anomaly statistics of a monitoring point are shown in Table 2.

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
frequency	6	0	1	6	8	8	13	8	7	6	6	0

Table 2: monitoring point

Based on all the anomalous positions, we get the probability distribution of anomalies on the moving trajectory in the direction of Norway.

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
frequency	5	6	0	1	6	8	8	13	8	7	6	6
	6	4	3	1	9	9	9	8	9	11	4	8
	7	4	6	6	6	7	14	4	5	7	8	8
	7	5	5	9	11	9	7	10	8	4	8	6
probability	0.076687	0.058282	0.042945	0.052147	0.09816	0.101227	0.116564	0.107362	0.092025	0.088957	0.079755	0.08589

Table 3: probability

After a series of analyses, we found that the longest interval between abnormalities was 54 months and the shortest was 1 month. And the abnormality has certain continuity in the short-term, the longest abnormal period is 4 months. In other words, on this trajectory, the stable period is at most 54 months and the longest abnormal period is 4 months. Then the best case lasts up to 54 months, and the worst case lasts up to 3 months.

5 Task 3

Through the previous analysis, we learned that the best case lasts up to 54 months, the worst case lasts up to 3 months, and the best case lasts on average 6 months. After reviewing, we know that the migration speed of fish habitats is an average of 40 kilometers per decade.In the best case, the water temperature changes steadily, and the fish migration lags behind, the speed will be lower than the average value; in the worst case, the water temperature change will tremble, the fish group will be in a disordered state, and the speed may be higher than the average value. No matter what kind of situation occurs, according to the previous forecast situation, the fish school will inevitably undergo a certain migration, and the migration distance can affect the production and operation of the fishery company. In addition, since the distribution of future outliers is difficult to predict, we recommend that small-scale fisheries companies improve their existing business models to resist fish migration caused by global warming.

As for how to improve, we have proposed a decision-making scheme for reference (Figure 12). This decision plan hopes that the fishery companies will gradually move the industry distribution according to the predicted trajectory. The industry movement can be divided into three processes. In each process, the fishery company determines the proportion of industry movement according to its own condition and in the form of investment portfolio. When the fish migration direction is found to change, it can be judged to enter the next process.

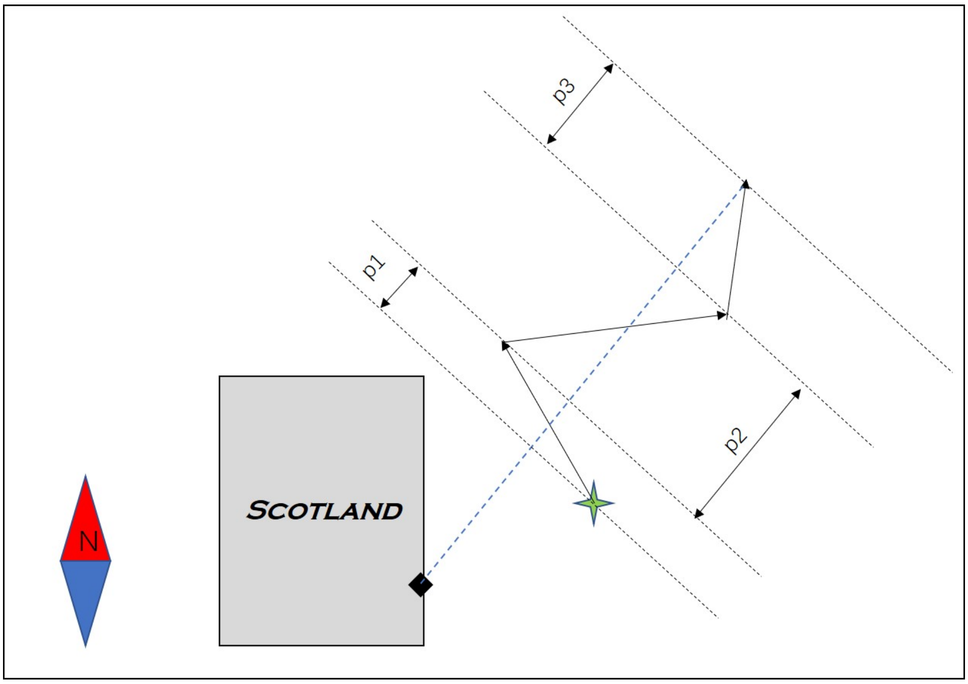

Figure 12: decision model

6 Task 4

Impact of fishery relocation on this proposal

In the previous model, we have obtained a large amount of data and empirical analysis and reached a conclusion that in order to cope with the impact of global climate change Scottish small fishing companies should properly migrate to high-latitude fishing area while balancing costs and benefits for greater economic benefits. And at the same time, if some proportion of the fishery move into the territorial water (sea) of another country, our proposal is bound to be affected by various aspects.

With the global warming, the mackerel and herring fishing grounds move northward.Assuming that the relocation of fishing grounds into high latitudes meets the legality, as a symbol of national sovereignty, the territorial sea is bound to be restrained by the policies, laws, languages, and cultures of the country. Fisheries companies will be subject to many restrictions due to different regulations on no-fishing season, protection for marine life and other various control measures. In addition, fisheries in the North Atlantic have specific limited catch shares all the time. Once a fishery company relocates to the territorial sea of another country, the contradiction between the nationality of the fishermen and fishing vessels and the identity of fishermen in the sovereign state of the territorial sea and which quota is occupied by the fishing volume will lead to disputes over fishing quotas. Various uncertainties is going to push the existing quota dispute more confusing,.The battle for fishery resources, which is directly induced by global climate change, will become more intense.

Economically, as Scottish fishery companies enter the territorial sea, the competition among fisheries companies in the sovereign countries of the original territorial sea has increased, their fishery markets will be affected. If the country introduces trade protection policies, the operations of these fishing companies and even the regional economy will be affected. Furthermore, the migration of fishing grounds has increased the distance from the domestic market, increasing transportation costs, and will make the market of Scottish fishing grounds more competitive. In addition, the migration of fishing grounds will add increasing safety hazards to fishermen and fishing boats. The average waiting time for rescue when encountering dangers will extend, and personal and property safety is inferior to domestic protection.

Territorial waters is under the sovereign jurisdiction of coastal states. If they enter other countries for illegal fishing, it will lead to disputes between the sovereignty of the two countries, which will probably lead to further intensification of the situation and affect social stability and regional peace.

At the same time, we do not deny the positive impact of the move, as the relocation of fishing grounds means the expansion of the availability of fishery resources and the reduction of partial cost, and the profits of fishery companies may increase, which is beneficial to achieving profitability.

In summary, if some proportion of the fishery move into the territorial water (sea) of another country, our proposal will be affected both positively and negatively, but because territorial sea is closely related to national sovereignty, this measure will trigger regional sovereignty in the integrated game between countries, the effect of negative influence is greater than that of positive influence. Therefore, we propose that, when relocating to the north, fishery companies should try to choose the international waters or legally enter the territorial waters of other countries to carry out fishing activities.

7 Task 5

With the serial release of the Intergovernmental Panel on Climate Change (IPCC) assessment report and the signing of a series of climate agreements in various countries, the issue of climate change has become the focus of international research on global environmental issues. It is not difficult to find that the impact of climate change on marine fisheries has become more profound and obvious along with the keep-going investment by countries.

The study shows that the warming speed of the Atlantic cold wind extending from Scandinavia to the United Kingdom is four times faster than the global average. Over the past three decades, its annual average temperature has increased by about 2 degrees Fahrenheit, which has significantly influenced the survival and migration of fish, the maturation of fish eggs, and the food chain and commercial fishing that plankton has participated as a supporting link.[11] As global warming intensifies, future temperature changes in this region will further increase. Therefore, the impact of climate on marine fisheries is wide and profound, and fishermen are also facing severe tests from natural ecology and socioeconomics.

Global warming is the primary and most important manifestation of climate change, and the ocean is the main carrier of energy stored in the climate system. Global warming causes increasing seawater temperatures and decreasing mass concentrations of dissolved oxygen in seawater, which leads to changes in marine biological, chemical, and physical balances. Most marine organisms, including herring and mackerel, are sensitive to seawater temperature. Under the influence of rising sea temperature, their inadaptability to the former environment prompts them to deviate and migrate from their original latitudes and water layers to higher latitudes or deeper sea. This also leads to the reduction and extinction of native species and the invasion of alien marine species to a certain extent, which severely affects regional marine biodiversity.[12]For the people who live on fisheries, the modify of the spatial pattern of marine life leads to the reduction in catches in low-latitude fishing area, local fishery companies and fishermen is going to suffer great operating pressures and economic losses, which causes their fishing potential being weakened, fishery resources declining, and the development and employment of the fishery industry will be restricted in many ways. In addition, the stability of the ecosystem's functional structure in low-latitude waters is disrupted, and continued fishing is likely to destroy fishery resources and deepen their vulnerability. The development of fisheries and fishermen will be more restricted if the state introduces relevant protective measures against fishing.

In response to the above situation, we proposed four measures in order to improve the future business prospects of fishermen. First, move the fishing ground northward. Fisheries companies in lower latitudes do need to correctly understand the seriousness of the impact of climate change on marine fisheries. After correctly assessing the costs and benefits, they should relocate fishing grounds to northern cities, and focus their fishing efforts on fishing areas in the high seas of the North Sea to acquire more fish catches. In particular, it is necessary to act according to its own ability and capacity. The relocation of the site beyond the reach greatly enhances the transportation and preservation costs, which brings economic pressure to the company. At the same time, the impact of policies, regulations, language and culture of the place of relocation must also be taken into account. Second, innovate ships and fresh-keeping equipment, and improve fresh-keeping technologies and methods. In order to cope with the northward migration of shoals of fish, small-scale fisheries companies can purchase new large-capacity fishing vessels to expand the catch on a single voyage, reduce unit costs, and enhance their ability to withstand risks. Because herring and mackerel have a very short fresh-keeping period, fisheries companies can also add and innovate fresh-keeping equipment on board to extend the fresh-keeping time of fish. In addition, some people can be set up on the ship to directly perform preliminary processing such as slaughtering and salting the fish caught, to solve the predicament of freshness preservation.

Third, modify business strategies and expand market share. Compared with the original simple management method and management strategy when the fishing ground and the company base are relatively close, under the current situation, it is possible to develop processing lines for various fish by-products, extend the industrial chain, and increase the added value of products. Fishery companies can appropriately develop tourism experience projects such as recreational fishing and sightseeing fishery, which not only meet the spiritual enjoyment needs of modern people, but also can increase income and profit. Finally, implement an integrated marine life fishing model. In view of the change in the geographical distribution of marine organisms caused by climate change, a new distribution pattern can be established. Fishery companies can change the original single herring and mackerel fishing, increase the fishing and management of other marine organisms in the sea area, and increase the company's overall benefits.

According to the The State of World Fisheries and Aquaculture issued by the Food and Agriculture Organization of the United Nations (FAO), marine fisheries play an increasingly important role in ensuring food security, meeting nutritional demands, and promoting employment. The problem to solve the balance among the climate ,ocean and the fishery is particularly urgent. Only by correctly understanding the impact of climate change on marine fisheries and exploring countermeasures can we achieve sustainable development of marine fisheries.

8 Sensitivity Analysis

The accuracy of our prediction model is mainly affected by the following factors 1. Accuracy of rgb to temperature mapping 2. Sparseness of the monitoring point matrixThe structure of the time series data extracted from the monitoring point matrix is shown in (Figure 13). The low accuracy of the rgb-to-temperature mapping model will affect the authenticity of the underlying time series data as well as the trend and accuracy of the predicted data of the upper layer.

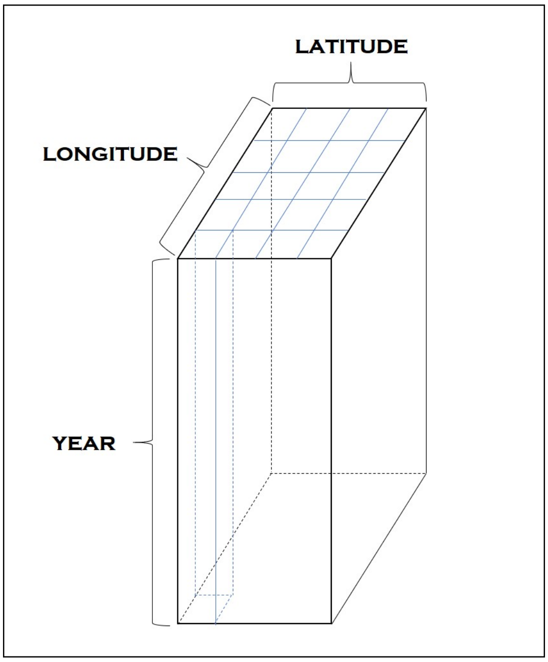

Figure 13: data structrue

In the model, the sparseness of the monitoring point matrix (see Figure 14) determines the observation accuracy and observation range of the model. When the number of monitoring points is constant, overly sparse monitoring points will cause key features to be missed and even cause observation failure; too dense monitoring points will result in sparse or duplicate feature acquisition. In addition, too many observation points will affect the smoothness of subsequent calculations.

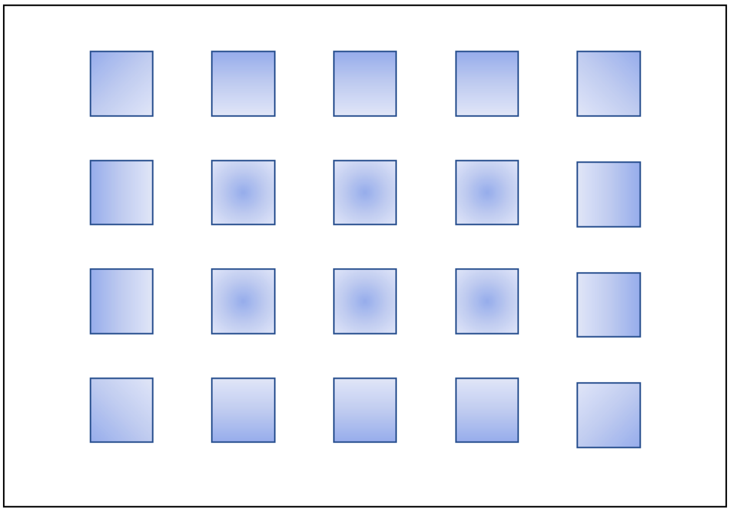

Figure 14: observation matrix

9 Strengths and Weaknesses

9.1 Strengths

- The mapping model of the images RGB value to temperature is very accurate, which can ensure that the difference between the time series obtained in the constant is very small.It is directly related to the tracking of the optimal temperature.
- The structural framework of the model is flexible and changeable. The monitoring point method is adopted to make the model capable of reading data from any areas . In addition, the data read by the structured model is neat and standardized, which is convenient for the general development of software and the establishment of large databases.
- Wavelet decomposition can perform multi-angle analysis on time series. SST changes occur under the general trend of global warming, and wavelet analysis has natural advantages. Also, the use of wavelet outlier detection algorithm based on GARCH (1,1) model improves the model's recognition of outliers, which is conducive to more micro-scale data mining.
- Using diagram reflects the model-establishment process. The results are displayed more vividly.

9.2 Weaknesses

- The changes in Sea Surface Temperature are concealed and complicated by natural factors. There are certain restrictions on the analysis of Sea Surface Temperature sequences by wavelet analysis.
- Although we have try our best. Time is finite, and some data are missed. As a result, the missing data can still bring the errors in evaluation.

References

[1] Simon Jennings,Keith Brander.Predicting the effects of climate change on marine communities and the consequences for fisheries[DB].Journal of Marine Systems Volume 79, Issues 34, 10 February 2010, Pages 418-426.https://doi.org/10.1016/j.jmarsys.2008.12.016

[2] Harald Loeng.The Influence of Temperature on Some Fish Population Parameters in the Barents Sea[DB]. J.North.Atl.Fish.Sci.Vol.9:103-113

[3] Morrongiello John R,Sweetman Philip C,Thresher Ronald E. Fishing constrains phenotypic responses of marine fish to climate variability.[J]. The Journal of animal ecology,2019,88(11).

[4] Scottish Executive[J].Journal of the Scottish Fisheries Statistics.2016.https://www.gov.scot/publications/scottish-sea-fisheries-statistics-2016-9781788512169/pages/3/

[5] R. Ian Perry,and Stephen J. Smith[DB].Identifying Habitat Associations of Marine Fishes Using Survey Data: An Application to the Northwest Atlantic.Can. J. Fish. Aqursr. Sci., VQI. 51, I994

[6] National Climate Center:https://cmdp.ncc-cma.net/cn/index.htm

[7] Teunis Jansen, Andrew Campbell, Ciarán Kelly, Hjálmar Hátún, and Mark R. Payne.Migration and Fisheries of North East Atlantic Mackerel (Scomber scombrus) in Autumn and Winter[DB].Progress in Oceanography.2012.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3519697/

[8] V.M. Trenkel , G. Huse , B.R. MacKenzie , P. Alvarez H. Arrizabalaga , M. Castonguay, N. Goñi ,F. Grégoire , H. Hátún , T. Jansen , J.A. Jacobsen , P. Lehodey , M. Lutcavage , P. Mariani , G.D. Melvin ,J.D. Neilson , L. Nøttestad , G.J. Óskarsson , M.R. Payne , D.E. Richardson , I. Senina , D.C. Speirs.Comparative ecology of widely distributed pelagic fish species in the North Atlantic: Implications for modelling climate and fisheries impacts[DB]Progress in Oceanography 129 (2014) 219243

[9] Teunis Jansen , Henrik Gislason.Temperature affects the timing of spawning and migration of North Sea mackerel[DB]Continental Shelf Research 31 (2011) 6472

[10] LiHong Zhang.Detection of Outliers Based on Wavelet Analysis in Time Series[D].Xiangtan University,2017

[11] Winter Anna-Marie,Richter Andries,Eikeset Anne Maria. Implications of Allee effects for fisheries management in a changing climate: evidence from Atlantic cod.[J]. Ecological applications : a publication of the Ecological Society of America,2020,30(1).

[12] SYLVAINLENOIR , GREGORYBEAUGRAND and Eť RICLECUYER.Modelled spatial distribution of marine fish and projected modifications in the North Atlantic Ocean.[DB].Global Change Biology (2011) 17, 115129.