Determine the impact on fisheries by predicting the migration of fish near Scotland

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Abstract. As global warming getting more severe in recent decades, the seawater temperature has also increased dramatically, which leads Atlantic fish heading north, so are two important economic fish species in Scotland, Scottish herring and mackerel. This paper discusses the impact of temperature change on the two species, and offer improvement methods for the small Scotland-based fishing companies. According the history temperature data in Scotland and the surrounding waters, we use a time series algorithm to predict the temperature range over next 50 years. Then establish a cost equation with parameters based on the relative distance and temperature. We obtain minimum cost from the predicted temperature and the relative distance from shoals. The result shows that in the next 50 years, a portion of the Scottish herring will move first northeast and then north, and the mackerel will move near the coast of Norway. The speed range of fish is obtained from previous model. Furthermore, maximum range of fishing time is obtained under different fish migration speed and fishing vessel speed. The best, worst and most likely case for fishing companies are defined and found. Which are they can fish before 2033 at lowest fish migration speed, they can not fish at the highest speed after 2051, and can not sell fresh fish anymore at 2040 respectively.

Keywords: Fish migration; Ocean temperature prediction; Time series algorithm.

1. Introduction
Both Scottish herring and mackerel are saltwater fish species, which cannot live in low-salinity waters, thus before building the connection between some factors and the possible habitats of the fish, we neglect those locations with insufficient salinity in following analysis.

Atlantic mackerel found in the north Atlantic, Norway, Iceland, Ireland and Scotland. Most of them mackerel live in coastal, near-coastal environments. However, herring is much more widespread than mackerel. Mackerel is much smaller than herring, herring is much cheaper than mackerel. They are social creatures, but companies prefer to catch mackerel when they are fishing. Fig. 1 shows the distribution of herring and mackerel, respectively.
Figure 1. The distribution of herring and mackerel. (a) Herring is much more widespread than mackerel and they are scattered all over the ocean. (b) Most of the mackerels live in coastal or near-coastal environments. Besides they usually gather together.

So we need to collect historical temperature data related to the vicinity of Scotland, then predict the future temperature. Next, find the optimum temperature for herring and mackerel. Therefore, we can use the future temperature data and the habits of fish to build the model and then get the migratory path. And according to the different temperature change rates, we can obtain the migration speed range. Therefore, we can get two time periods which indicate the best case that shoals migrate at the lowest speed, and the worst case that shoals migrate at the maximum speed, and the most likely elapsed time when fish is too far to be caught by fishing companies.

2. Proposed Model

In this chapter, we will deduce step by step how do the model predict the migration of fish near Scotland.

2.1. Temperature Prediction

First, since temperature is the leading driver for this two kinds of fish to migrate, we need to be aware of future temperature trend, without loss of generality, we divide the neighboring regions of Scotland into several $5^\circ$-longitudes $\times$ $5^\circ$-latitude areas, and assume the temperature in each small area is the same. The temperature change can be predicted by adapting the time series.

Figure 2. The partial autocorrelation and autocorrelation both show a tailing
The autocorrelation and partial correlation of the sample [1] are shown in Fig. 2. From the autocorrelation graphs above, we see tailing in both two graphs, thus we choose the Autoregressive moving average (ARMA) model [2] to improve the accuracy of temperature prediction:

\[ T_k = c + \epsilon_k + \sum_{i=1}^{p} \phi_i T_{k-i} + \sum_{j=1}^{q} \theta_j \epsilon_{k-j} \]  

(1)

Where \( T_k \) is the temperature we want to know at time \( k \), \( c, \phi, \theta \) that are parameters left to be estimated. \( p \) is the degree of nonseasonal autoregressive polynomial, \( q \) is the degree of nonseasonal average polynomial, these two degrees are left to be confirmed, which means we need to assume their values at first, then step up their values to generate a series of models, after that, find the model that has the highest prediction accuracy to be our final model.

Then, we divide the surrounding water of Scotland into several smaller regions and use ARMA model to obtain the predicted value of temperature in each region [3].

The prediction outcome of our final model is shown in Fig. 3, from the figure on the left, we see a high similarity between our model (red line) and the actual data (black line), which means the accuracy is guaranteed, the temperature prediction range over the next 50 years is displayed on the right.

Figure 3. Temperature Prediction. (a) represents the relationship between true and predicted values from 1850 to 2020. It shows that the true value is close to the predicted value. (b) adds the projections for the next 50 years. (c) denotes the 95% confidence interval for the next 50 years.

It is worth noticing that to make our prediction more appropriate, we use a 95% confidence interval to restrict our prediction, the lower and upper bound are shown in the figure above on the right [4].

2.2. Connection Between Two Factors
Consider water temperature and the distance from the most suitable location as two factors that influence the migration directions of Scottish herring and mackerel, to find the potential migration path over the next 50 years, we first define a cost function to find the weight parameters of these two factors:

\[ Cost = k_1 \sqrt{(t_i - T)^2} + k_2 \sqrt{[(x - x_i)^2 + (y - y_i)^2]} \]  

(2)

Since \( k_1 \) and \( k_2 \) are only parameters that stand for the weight between two factors, as long as we find the ratio between \( k_1 \) and \( k_2 \), the weight of these two factors is obtained, thus the cost function can be rewritten as:

\[ Cost = \frac{k_1 \sqrt{(t_i - T)^2}}{k_2} + \sqrt{[(x - x_i)^2 + (y - y_i)^2]} \]  

(3)
\(x_i, y_i\) stand for the coordinates of other locations that have temperature records, \(t_i\) stands for record temperature at the location, \(T\) denotes the most suitable temperature, \(x, y\) represents the coordinates of the most possible position of the fish at the moment, \(k_1, k_2\) are two parameters.

We adopt the Likelihood function [5] to obtain the ratio \(k_1/k_2\). More specifically, this function is defined in Eq. (4).

\[
L(\theta|x) = 0
\]

(4)

Where \(\theta = k_1/k_2\), \(x\) represents previous data (i.e., \(x_i, y_i\) and \(t_i\)). Thus, we combine the cost function and the Likelihood function to obtain the value of \(k_1/k_2\).

\[
(i.e., \sum_{i=1}^{N} \left( k_1/k_2 \sqrt{(t_i - T)^2 + \sqrt{(x_i - X)^2 + (y_i - Y)^2}} \right) = 0).
\]

2.3. Predict Migration Route

Finally, we put the temperature prediction we obtained from ARMA model into Eq. 4 and search for the lowest value, the corresponding \(x_i, y_i\) represents: at certain temperature in the next 50 years, the coordinates of the biggest possibility of migrating shoals reach that location, after combing all the coordinates, we can find the potential migration path of most shoals.

We adopt several restrictions to make our model more helpful:

- Considering the fact that the suitable temperature range for spawning and living is different for both Scottish herring and mackerel, we choose the area that overlaps as our general most livable location.

- The spawning behavior of the two species is flexible, they can lay eggs both in the center of the ocean or near the shore, in our prediction, the majority of shoals tends to move to the north, getting further and further from dry land, thus we do not consider the situation when they moving back to the south to spawn.

Our prediction of the the major locations of fish in certain years is shown in Fig. 4.

**Figure 4.** The migration route of herring and mackerel, they both experience a journey first toward northeast then straight north

We number the regions that most shoals will pass as region1, region2, and region3. The general moving trend of the shoals is towards the northeast and then to the north, but may experience little fluctuations in several years.
As for the time when the majority of fish moves to our second sea region and the third sea region, under the 95% confidence interval of temperature prediction, the estimated time will be in a fluctuation range instead of an extract value.

For herring widely distributed in Scottish around 55 − 60°N [6], we can conclude that herring moves to the second grid in 2031 and it moves to the third grid in 2060. This conclusion is obtained by the ARIMA model [7]. With a 95% confidence interval, there are two strategies:

- One is herring moves to the second grid in 2035 and it moves to the third grid in 2066 at the slowest temperature change.
- The other is herring moves to the second grid in 2029 and it moves to the third grid in 2055 at the fastest temperature change. Meanwhile, mackerel widely distributed in Scottish around 55 − 60°N and 0 − 5°W longitude.

- We use the ARIMA model to predict mackerel moves to the second grid in 2033. With a 95% confidence interval, there are two tactics. One is mackerel moves to the second grid in 2038 at the slowest temperature change. The other is mackerel moves to the second grid in 2031 at the fastest temperature change.

3. Situations Small Companies Will Face

Through the fish migration route in Fig. 4, the general direction of fish movement can be obtained (i.e., from the northeast to the north). It shows that the fish are mainly in the North Sea for 10 years, in the Thorshavn for the subsequent 29 years and in the Norwegian Sea for the subsequent 11 years. Then this information from the first problem, as the previous information, is adopted to solve the second problem.

3.1. Evaluating Standard

The information of longitude, latitude and other areas in north Scottish is regarded as the previous information [8] [9]. Firstly, we adopt the Uniform Distribution to set the fishing companies to a fixed location. Then we apply the Kmeans algorithm to cluster the similar fishery.

Kmeans algorithm randomly selects k objects as the initial clustering center, and then calculate the distance between every object and every clustering center [10]. It assigns each object to the nearest cluster center. The combination of the cluster center and the objects assigned to it represents a cluster.

After that, we use two conditions to estimate whether fishers can go fishing or not [11]:

- Retained profits of the company is greater than 0.
- The time from fishery to companies should been ought to keep the fish fresh.

3.1.1. Navigation cost. The first condition can be met if revenue is greater than the cost. Revenue represents the weight (in kilogram) of the fish multiplied by the price (in pound per kilogram) of the fish. The weight of the fish is determined by the maximum amount of fish each boat can carry, and the number of boats. Cost consists of the land cost and the ocean cost. Because the cost is higher at sea than on the land, the position of the fishery is perpendicular to the shore. Thus, this point on the shore is regarded as a Cut-off point denoted as C. The straight-line distance from the company to C is called the departure land distance, the vertical distance from the fishery to C is called the departure ocean distance. Because fish need to be transported to Scotland fishing ports, the return ocean distance must arrive at Scotland fishing ports. The Scotland fishing port is denoted as S. The straight-line distance from fishery to S is called the return ocean distance and the straight-line distance from S to the company is called the return land distance [12]. The total cost is defined in Eq. (5).

\[
Cost = (L_d_1 + L_d_2) * L_{cost} + (O_d_1 + O_d_2) * O_{cost}
\]

Where the L_d_1 and L_d_2 represent the departure land distance and the return land distance respectively. The O_d_1 and O_d_2 denote the departure ocean distance and the return ocean distance, severally. L_cost is the expense of the land and O_cost denotes the cost of the ocean.
3.1.2. Sale Profits. We use the migration distance of fish divided by the interval time to obtain the average speed. This speed is the speed of the fish in the northeast. The Pythagorean theorem defined in Eq. (6) is adopted to compute the north distance by the northeast distance. According to Sec 3.1, we can get the distance of fish in the company every year.

\[ N_d = \sqrt{2} \times \frac{N_E_d}{2} \]  

(6)

Where \( N_d \) denotes the northern distance of the fish eastward migration. \( N_E_d \) represents the distance of the fish eastward migration. We assume that eastern and northern are the same distance.

We assume that companies use a kind of fish vessel called Nordic Tugs 26 to catch fish. Its fuel consumption is 30 gallons per 100 sea miles, cruising speed is 8 sea miles per hour, the minimum speed is 5 sea miles per hour and top speed is 14 sea miles per hour. The price of oil is set as 6.36 dollar per gallon.

3.2. Special Cases

The fresh time of fish is set as 24 hours [13]. Thus, if the return time is less than 24 hours, the company can go fishing. This ship has three speed levels (i.e., 5, 8, 14 sea miles per hour). Besides, the fish migrate at three cases, which is based on the 95% confidence interval for upper, lower and average temperatures. The lower limit of temperature is when the fish migrate the slowest, the upper limit is when the fish migrate the fastest, and the average is the general case [14]. Thus we define the best case, worst case and general case as follows:

1. The best case. The time range where fish migrate the slowest and can catch at all three speeds.
2. The worst case. The time range in which fish migrate fastest and can not be fished at any of the three speeds.
3. The general case. The time range can not be fished in average temperature and average speed.

Figure 5. The conclusion about the best case, worst case and most likely elapsed time(s). The best case is the slowest migration of fish and can catch fish for 13 years at the lowest speed. The worst case is the fastest migration of fish and can catch fish for 31 years at the fastest speed.

Under different fish speed and vessel speed, the period that the fish is accessible for fishers varies, if the companies stay at their original locations, the best case is the fish vessels can operate at lowest speed.
(5 sea miles per hour) for 13 years, the most likely case is the vessels can fish at their average speed (8 sea miles per hour) for 20 years, and the worst case is after 31 years, even if the vessel is traveling at the highest speed (14 sea miles per hour), the shoals will be too far to catch.

### 4. Conclusion

This paper discusses the effects of temperature changes on these two fish species and provides improved methods for small fishing companies in Scotland. Based on historical temperature data in Scotland and surrounding waters, we use a time series algorithm to predict the temperature range in the next 50 years and establish an equation model to solve it. The results show that in the next 50 years, part of the Scottish herring will move northeast and then north, and mackerel will move near the Norwegian coast. That is to predict the best, worst and most likely fishing situation of the fishing company. Respectively, they can fish at the lowest fish migration rate before 2033, they cannot fish at the highest rate after 2051, and they cannot sell fresh fish after 2040.

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