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Abstract

This paper establishes the grey prediction model to predict the potential migration of Scottish herring and mackerel from their current habitats near Scotland when global ocean temperatures increase. Base on the migration track we predict, we establishes the fuzzy evaluation model to give some practical proposals to small fishing companies.

Firstly, we build the grey first-order differential equation model. Applying annual mean observed sea temperature near Shetland Islands in the North Atlantic from 1950 to 2011, we can get the trend of sea temperature in 50 years. Then, according to the temperature range suitable for these two fish species living, we can predict their most likely locations over the next 50 years. Since 2021, the annual average sea temperature is more than 10 Celsius degree, which is not suitable for the spawning and survival of mackerel, and the spawning of herring is also inhibited. They gradually migrated from the Shetland Islands to the north along the continental shelf edge.

Secondly, in order to effectively reduce the impact of fish migration on small fishing companies, some alternative measures should be taken into account. For this reason, we build the fuzzy evaluation model. Then we use analytic hierarchy process(AHP) to identify the weight of three factor consisting of temperature change, exploitation level and bait concentration. According to the principle of fuzzy distribution, the subordinate degree of high efficiency of various measures is $0.4690 > 0.4535 > 0.4432$, representing Planned classified fishing, using small fishing vessels and Migrating all assets respectively.

Finally, we prepare a one-page non-technical explanation to help fishermen understand the seriousness of the problem and how our proposals will improve their future business prospects.

Keywords: migration, grey prediction model, fuzzy evaluation model, analytic hierarchy process

Contents

1 Introduction

1.1 Background

Global climate change will lead to an increase in global ocean temperature and will affect the quality of certain marine lifes habitat. We take the North Atlantic herring and mackerel as an example here. The mackerel and herring begin to find other habitats that are more suitable for their current and future life and reproduction when the temperature changes too much and they can not continue to grow and spawn. For small fishing companies, this geographical migration of fish stocks will lead to a decline in fishing and greatly affect the company's income, and the income of fishermen will also be affected because herring and mackerel are important economic sources of Scottish fisheries.

In order to effectively reduce the impact of fish migration on fisheries, it is necessary to study issues related to the migration of Scottish herring and mackerel from their current habitats near Scotland. However, there is no model to predict the migration of herring and mackerel currently. Therefore, our task is to establish a prediction model and to give the migration status of the fish species in the future and corresponding measures.

1.2 Herring and mackerel

In order to study the effect of seawater temperature on the migration of herring and mackerel, we first understand the external factors, especially temperature requirements, of the two fish species:

1) Herring: Herring is a cold-temperate marine upper-layer fish whose ability to adapt to water temperature is between warm-water and cold-water. It Generally lives in the areas with a water temperature of $6-11°C$ and spawns in high-salinity sea areas below $10°C$.

2) Mackerel: It lives with a water temperature of about $5-10°C$ suitably and spawns in the high-salinity sea areas below $10°C$.

3) In addition, fish species dynamics are affected by a variety of ecosystem drivers, such as:food-web interactions, exploitation, density-dependence, and the wider environment.

1.3 Our work

Our work starts with a Gray prediction model and we make the annual average sea temperature value as a series.

First, we calculate the extreme ratio of the data. If the data test is satisfied, then we can establish a GM (1,1) first order differential equation model to construct the gray model which predicts the trend of the North Atlantic sea temperature change over the next 50 years.

So we can judge the migration direction and speed of the two fish species by the need to water temperature requirements of herring and mackerel.

We adopt a Fuzzy evaluation model and give measures to cope with fish migration to decrease the influences of the fishery effectively, based on the migration of two kinds of fish.

2 Problem restatement

1) Build a mathematical model to identify the most likely locations for these two fish species over the next 50 years.

2) Based upon how rapidly the ocean water temperature change occurs, use model to predict 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 the small fishing companies continue to operate out of their current locations.

3) In light of the predictive analysis, should these small fishing companies make changes to their operations?

4) Use model to address how the proposal is affected if some proportion of the fishery moves into the territorial waters (sea) of another country.

5) In addition to technical report, prepare a one- to two-page article for Hook Line and Sinker magazine to help fishermen understand the seriousness of the problem and how the proposed solution(s) will improve their future business prospects.

3 Terminology

3.1 Terms

1) Gray prediction: The prediction made on the gray system. The Gray system is a transition system between the white system and the black box system. The specific meaning is if all the information of a system is known as a white system, all the unknown information is a black box system, some information is known, and some information is unknown, then this system is a Gray system.

2) Fuzzy evaluation: A comprehensive evaluation method based on fuzzy mathematics. This comprehensive evaluation method converts qualitative evaluation to quantitative evaluation according to the membership theory of fuzzy mathematics, which is using fuzzy

mathematics to make an overall evaluation of things or objects restricted by multiple factors.

3) Hierarchical analysis: A qualitative and quantitative analysis decision-making method based on breaking decision-related factors into goals, guidelines, and solutions.

3.2 Symbols

Symbol	Descriptions
$X^{\circ}(i)(i=1,2,3\cdots)$	The known raw temperature data
$Z^{\circ}(i)(i=1,2,3\cdots)$	The adjacent temperature generation
$GM(1,1)$	The first order differential equation model
$u=\begin{bmatrix} a \\ b \end{bmatrix}$	a call The Development Coefficient and b call The Gray Effect Value
$B_i^{(3)}(i=1,2,3\cdots)$	The judgment matrix of 3 factors on the i-th plan

4 General Assumptions

1) The water temperatures are going to change enough to cause the populations to move.
2) No major natural disaster leads to significant reduction of fish species.
3) The population moving is not affected by density-dependence.

5 The Grey prediction model

We make the annual average sea temperature value as a series and calculate the extreme ratio of the data. If the data test is satisfied, then we can establish a GM (1,1) first order differential equation model to construct the gray model which predicts the trend of the North Atlantic sea temperature change over the next 50 years. So we can judge the migration direction and speed of the two fish species by the need to water temperature requirements of herring and mackerel.

5.1 Local Assumption

1) The water temperature data at observation points is absolutely accurate.
2) Once the water temperature changes to be unsuitable for herring and mackerel, they migrate immediately.

5.2 Basic model

In order to use the model to predict the trend of water temperature change in the North Atlantic over the next 50 years, we first obtain the average observed sea temperature of each of the seven observation points of the North Scottish Atlantic from 1950 to 2011.

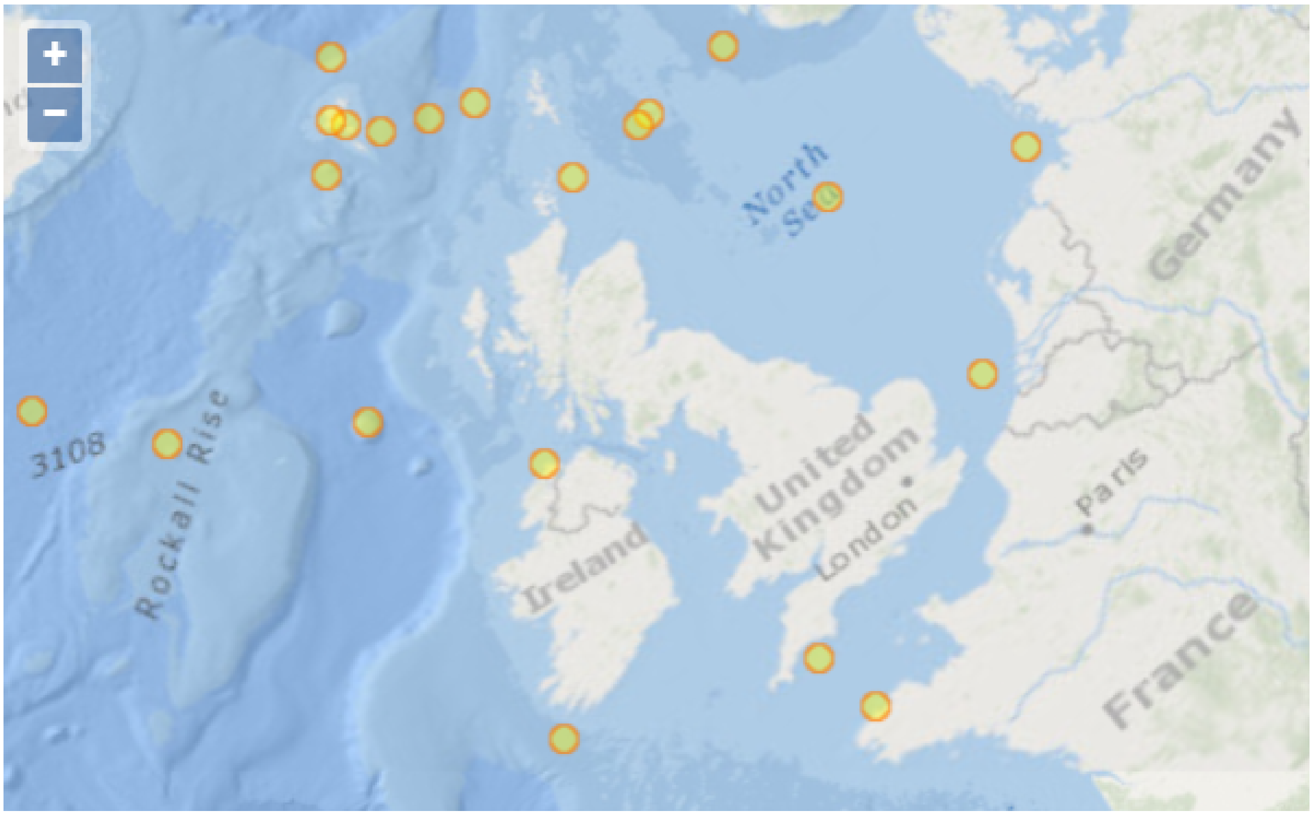

Figure 1: sea temperature observations in the North Atlantic

The theory of gray system holds that although the objective appearance is complex, it always has overall function, so it must contain some inherent law. The key is how to choose the appropriate way to mine and use it. The gray system seeks its changing laws through the collation of the original data. This is a way to seek the actual laws of the data based on the data, that is, the production of gray sequences. All gray sequences can weaken their randomness and show their regularity through some kind of generation. The common methods of data generation are Accumulating Generation, Accumulating Generation, and Weighted Accumulating Generation. The Commonly used is Accumulating Generation.

Let the raw data be $x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$

5.2.1 Accumulating Generation

$$x^1(1) = x^0(1)$$
$$x^1(2) = x^0(1) + x^0(2)$$
$$x^1(3) = x^0(1) + x^0(2) + x^0(3)$$
$$\cdots$$
$$x^1(n) = x^0(1) + x^0(2) + \cdots + x^0(n)$$

So we get the cumulative date is $x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(n))$

5.2.2 The Weighted Temporary Array Generation

$$z^0(2) = \alpha x^0(2) + (1-\alpha)x^0(1)$$
$$z^0(3) = \alpha x^0(3) + (1-\alpha)x^0(2)$$
$$z^0(4) = \alpha x^0(4) + (1-\alpha)x^0(3)$$
$$\cdots$$
$$z^1(n) = \alpha x^0(n) + (1-\alpha)x^0(n-1)$$

The resulting sequence is called the generation number with neighbors, and the weight α is also called the generation coefficient. In particular, the number sequence is called the mean generation number, and is also called the equal-weight generation number with neighbors, when the generation coefficient $\alpha = 0.5$.

5.2.3 Gray model GM (1,1)

GM stands for grey model, and GM (1,1) is a first order differential equation model.

Data inspection Modeling with GM (1,1) requires testing the data. First, we calculate the rank ratio of the series. $\lambda(k) = \frac{x^0(k-1)}{x^0(k)}, k = 2, 3, \cdots, n$

If all the step ratios fall within the tolerable coverage interval $X = (e^{\frac{-2}{n+1}}, e^{\frac{2}{n+1}})$,the series $x(0)$ can build a GM (1,1) model for Gray prediction.

5.2.4 Building the Gray model

Define $x^{(1)\prime}s$ gray derivative is $d(k) = x^0(k) = x^1(k) - x^1(k-1)$.

Let $z^1(k)$ be the generated sequence with neighbors of the sequence x^1, so that is $z^1(k) = \alpha x^1(k) + (1-\alpha)x^1(k-1)$.

Then, we can define the Gray Differential Equation Model of GM(1,1) is $d(k) + \alpha z^1(k) = b$.

There are a called The Development Coefficient,$z^1(k)$ called The Whitening Background Value, and b called The Gray Effect Value in the above model.So we get the equation set, which is as follows:

$$\begin{gathered} x^0(2) + \alpha z^1(2) = b \\ x^0(3) + \alpha z^1(3) = b \\ \cdots \\ x^0(n) + \alpha z^1(n) = b \end{gathered}$$

We can get $u = \begin{bmatrix} a \\ b \end{bmatrix}$,$Y = \begin{bmatrix} x^0(2) \\ x^0(3) \\ \cdots \\ x^0(n) \end{bmatrix}$,$B = \begin{bmatrix} -z^1(2) & 1 \\ -z^1(3) & 1 \\ \cdots & \\ -z^1(n) & 1 \end{bmatrix}$ by the method of matrix, then GM(1,1) can be expressed as $Y = Bu$.So we can get the value of α and b by Linear Regression or $(B^T B)^{-1} B^T Y$ which is Normal Equation, following the principle of Least Squares. We can let a be any number when we list equations, such as $\frac{1}{2}$,then α and $(1-\alpha)$ can be the same to be taken out to write conveniently.

5.2.5 Prediction

The corresponding whitening model is $\frac{dx^1(t)}{dt} + \alpha x^1(t) = b$,so we get the solution of $x^1(t)$ is $x^1(t) = (x^0(t) - \frac{b}{\alpha})e^{-\alpha(t-1)} + \frac{b}{\alpha}$.

Let $t+1 = t$,we get $x^1(t+1) = (x^0(1) - \frac{b}{\alpha})e^{-\alpha} + \frac{b}{\alpha}, k = 1, 2, 3, \cdots, n-1$.

As mentioned above, this is our predictive value.

5.2.6 Test

There are three precision inspection methods of Gray model, which are Relative Error Test, Correlation Test, and Final Error Test. And we choose the Final Error Test.

1) We can get $\hat{x}^0$ by decrement of the predicted $\hat{x}^1$

$$\hat{x}^0(k) = \hat{x}^1(k) - \hat{x}^1(k-1), k = 2, 3, \cdots, n$$

2) Calculate residual.

$$e(k) = x^0(k) - \hat{x}^0(k), k = 1, 2, \cdots, n$$

3) Calculate the variance $s1$ of original sequence x_0 and the variance s_2 of residual e.

$$S_1 = \frac{1}{n}\sum_{k=1}^{n}(x^0(k) - \bar{x})^2 \; S_2 = \frac{1}{n}\sum_{k=1}^{n}(e(k) - \bar{e})^2$$

4) Calculate the variance ratio.

$$C = \frac{S_2}{S_1}$$

5) Observe the effect with viewing form.

$$C = \frac{S_2}{S_1}$$

The models accuracy level	The mean square error ratio
Level 1 (Good)	$C \leq 0.35$
Level 2 (Qualified)	$0.35 < C \leq 0.58$
Level 3 (Reluctantly)	$0.5 < C \leq 0.65$
Level 4 (Disqualified)	$C > 0.65$

We obtain the annual average sea temperature of the seven observation points of the North Atlantic Ocean from 1950 to 2011 ($datacanbedownloadedfromhttps://ocean.ices.dk/iroc/$). The default value is the unobtained observation value and part of the data is shown in the following figure:

Latitude:	57.5 N	Latitude:	59 N	Latitude:	59 N	Latitude:	55.99 N	Latitude:	61 N	Latitude:	61.25 N	Latitude:	61.5 N
Longitude	11.00 W	Longitude	2 W	Longitude	0.5 E	Longitude	3.201 E	Longitude	3 W	Longitude	4.5 W	Longitude	6 W
Decimal Y	Temperature	Year	Temperature	Year	Temperature	Year	Temperature	Year	Temperature	Year	Temperature	Year	Temperature
1975	4.36	1960		1970	5.9	1981	9.46	1950	9.71	1950	-0.47	1950	8.15
1976	4.21	1961	9.7	1971	6.7	1982	9.83	1951	9.38	1951	-0.43	1951	8.03
1977	4.26	1962	9.57	1972	6.75	1983	9.84	1952	9.6	1952	-0.4	1952	7.84
1978	4.26	1963		1973	6.95	1984	9.78	1953	9.75	1953	-0.46	1953	7.82
1979	4.6	1964		1974	6.6	1985	9.37	1954	9.69	1954	-0.55	1954	7.78
1980	4.2	1965		1975	6.6	1986	9.16	1955	9.76	1955	-0.47	1955	7.8
1981	4.33	1966		1976	6.2	1987	9.33	1956	9.81	1956	-0.43	1956	8.25
1982		1967		1977	6.3	1988	10.21	1957	9.73	1957	-0.4	1957	8.15
1983	4.2	1968	9.47	1978	6.3	1989	10.68	1958	9.92	1958	-0.39	1958	8.12
1984	4.27	1969	9.46	1979	5.95	1990	10.71	1959	10.01	1959	-0.43	1959	8.35
1985	4.17	1970	9.4	1980		1991	10.02	1960	9.82	1960	-0.49	1960	8.54
1986		1971	9.34	1981	6.25	1992	10.32	1961	9.92	1961	-0.46	1961	8.48
1987	4.12	1972	9.32	1982	6.55	1993	9.58	1962	9.79	1962	-0.45	1962	8.36
1988	4.19	1973	9.45	1983	6.65	1994	10.07	1963	9.6	1963	-0.5	1963	8.21
1989	4.2	1974	9.73	1984	6.05	1995	10.5	1964	9.73	1964	-0.53	1964	7.98
1990	3.97	1975	9.81	1985	6.55	1996	9.34	1965	9.48	1965	-0.53	1965	7.81
1991		1976	10.1	1986	6.04	1997	10.52	1966	9.3	1966	-0.54	1966	7.72
1992	3.96	1977	9.65	1987	5.97	1998	10.27	1967	9.5	1967	-0.6	1967	7.64
1993	4.13	1978	9.21	1988	6.61	1999	10.69	1968	9.52	1968	-0.51	1968	7.97
1994	4.07	1979	9.26	1989	7.42	2000	10.4	1969	9.35	1969	-0.49	1969	8.12
1995	4.09	1980	9.3	1990	7.41	2001	10.44	1970	9.65	1970	-0.53	1970	8.07
1996	4.1	1981	9.28	1991	7.1	2002	10.94	1971	9.83	1971	-0.43	1971	8.11
1997	4.12	1982	9.51	1992	7.12	2003	11	1972	9.81	1972	-0.38	1972	8.17
1998	4.16	1983	9.58	1993	6.52	2004	10.73	1973	9.76	1973	-0.62	1973	7.91
1999	4.18	1984	9.59	1994	5.81	2005	10.52	1974	9.77	1974	-0.64	1974	7.91
2000	4.17	1985	9.49	1995	6.53	2006	10.69	1975	9.61	1975	-0.57	1975	8.16
2001	4.02	1986	9.27	1996	6.03	2007	10.91	1976	9.59	1976	-0.53	1976	8.01
2002		1987	9.58	1997	7.13	2008	10.75	1977	9.54	1977	-0.52	1977	7.89
2003	4.23	1988	9.96	1998	7.14	2009	10.64	1978	9.39	1978	-0.57	1978	7.87
2004	4.14	1989	9.81	1999	7.34	2010	9.95	1979	9.79	1979	-0.6	1979	7.57
2005	4.36	1990	9.93	2000	6.8	2011	10.38	1980	9.72	1980	-0.44	1980	7.73

Figure 2: Annual mean observed sea temperature of 7 observation points near Shetland Islands from 1950 to 2011

For example, take the data from one of the observation points and use the Gray Prediction Model to predict the trend of temperature change in the next 50 years.

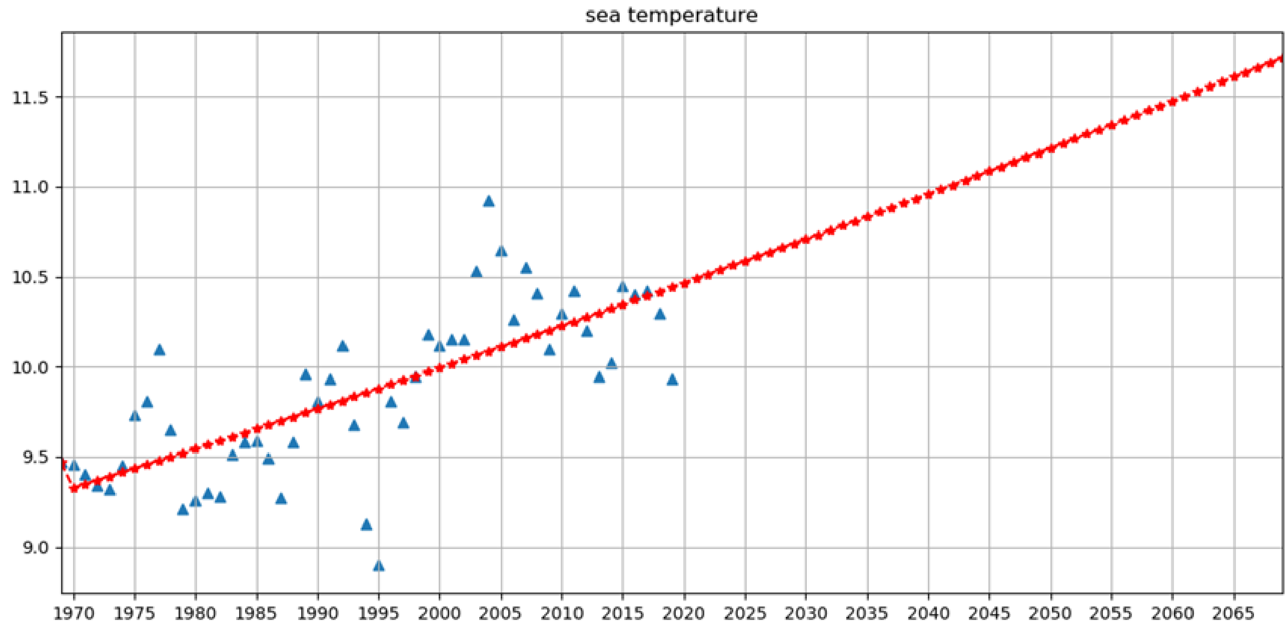

Figure 3: the predict of temperature

We made the same predictions for 7 observation points. According to the requirements of herring and mackerel for habitat temperature, the annual average temperature of the North Sea will reach $11.25°C$ around 2048-2053, which is no longer suitable for two fish foraging, resulting in the change of migratory route of the two fish. The change of trajectory is shown in the Figure4:

So we draw the conclusion: In the next 50 years, herring and mackerel populations will gradually migrate northward from the Shetland Islands in the North Sea along the edge of the continental shelf and then southwest to the sea area near the west of Ireland.

The average annual sea temperature near the Shetland Islands observation point is less than $10°C$, and mackerel and herring still accumulate in this area before 2020. After that, the average annual sea temperature is more than $10°C$ from 2021 based on the observation data of the observation points to make predictions, so it is no longer suitable for spawning and survival of mackerel, and herring spawning is also suppressed. As a result, the population of herring will decline. The average annual sea temperature in this area is more than $11°C$ by 2041, which is no longer suitable for herring survive. Therefore, since 2041, the fishing grounds in the Shetland Islands will encounter no harvest as early as 2021 and at the latest as 2041 due to the migration of two fish to the north.

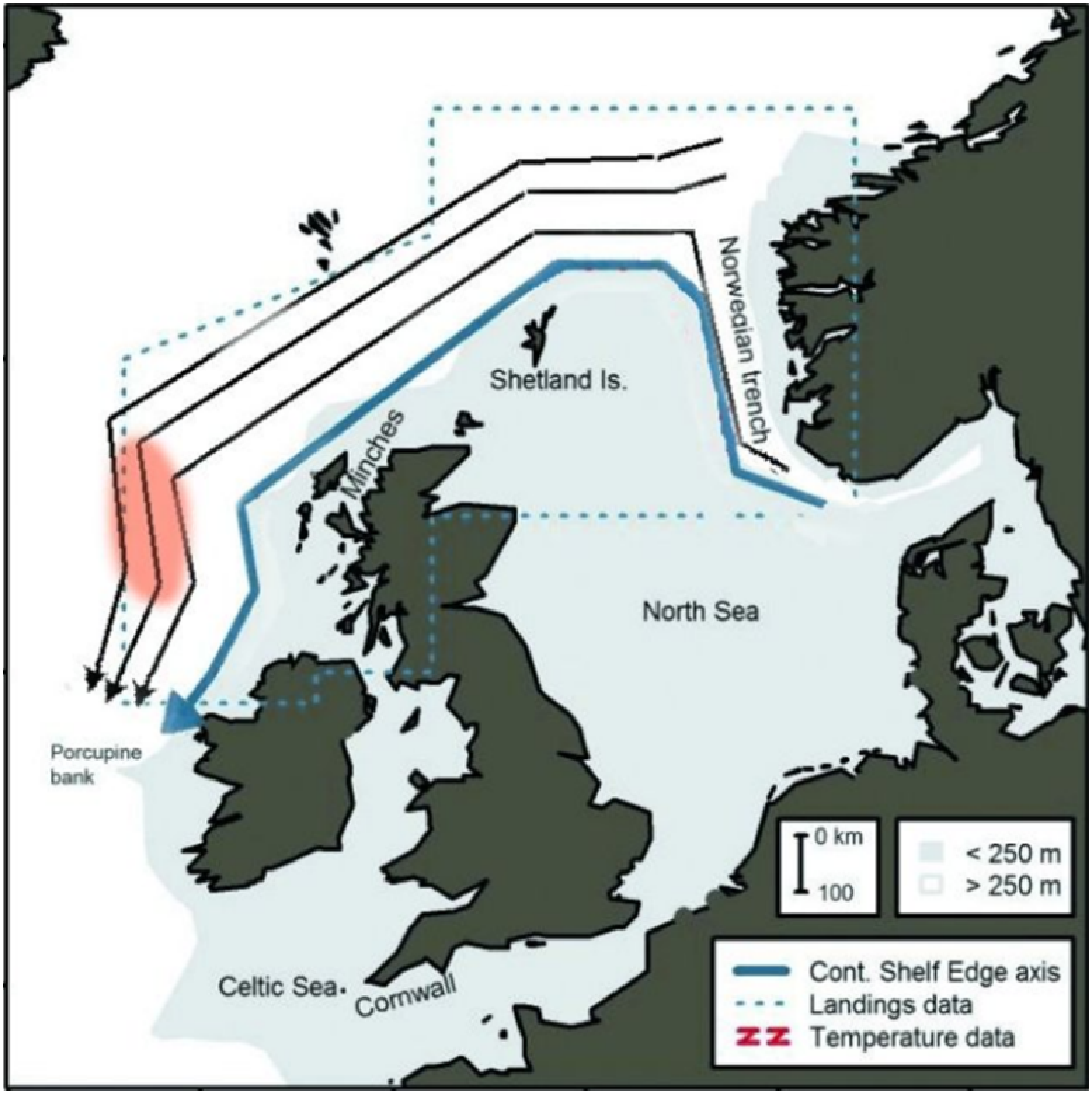

Figure 4: The change of trajectory

6 Fuzzy evaluation model

Based on the migration of two fish species, we adopt a fuzzy evaluation model and give measures to deal with fish migration to reduce the impact on fisheries effectively. The alternative measures include migrate all assets, migrate some assets, use small fishing boats, and fish systematically and categorically.

6.1 The build of the fuzzy evaluation model

Determine the alternative objects. The set X=$\{\mathrm{x}_1, x_2, x_3, x_4\}$ = {Migrate all assets, Migrate some assets, Use small fishing boats, Fish systematically and categorically}.

6.2 Determine the factors (indicators)

The set U=$\{\mathrm{u}_1, u_2, u_3\}$ = {the change of temperature, the situation of fishing, the concentration of bait}.

6.3 Determine the weight vector

$A = (\alpha_1, \alpha_2, \alpha_3) = (0.3349, 0.2320, 0.2320)$.The weight is determined using Analytic Hierarchy Process:

1) Establish a hierarchical structure model:

   Objective:Determine the weight of each factor
   Solution layer:$\mathrm{x}_1, x_2, x_3, x_4$
   $Factorlayer : u_1, u_2, u_3$

So it construct a pairwise comparison matrix and hierarchical single sort.

$$A = \begin{bmatrix} 1 & \frac{4}{5} & \frac{3}{5} & \frac{2}{5} \\ \frac{5}{4} & 1 & 1 & \frac{3}{4} \\ \frac{5}{3} & 1 & 1 & \frac{3}{4} \\ \frac{5}{2} & \frac{4}{3} & \frac{4}{3} & 1 \end{bmatrix}$$

So we can get the maximum eigenvalue of A is $\lambda_{max} = 4.0164$,the corresponding normalized eigenvector $W^{(1)} = (0.1597, 0.2372, 0.2537, 0.3494)^T$,the consistency index $CI = (4.0164 - 4)/(4 - 1) = 0.0055$, and the stochastic consistency index $RI = 0.89$.

Therefore, the consistency ratio $CR = CI/RI = 0.0055/0.89 = 0.0062 < 0.1$, which passes the consistency check.

Assume that the judgment matrix of three factors on four schemes is:

$$B_1^3 = \begin{bmatrix} 1 & \frac{5}{4} & \frac{3}{5} \\ \frac{5}{4} & 1 & \frac{3}{4} \\ \frac{5}{3} & \frac{4}{3} & 1 \end{bmatrix} \text{(Migrate all assets)}$$

$$B_2^3 = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{3} \\ 2 & 1 & 1 \\ 3 & 1 & 1 \end{bmatrix} \text{(Migrate some assets)}$$

$$B_3^3 = \begin{bmatrix} 4 & 3 & 1 \\ \frac{1}{3} & \frac{1}{4} & \frac{1}{5} \\ 1 & 5 & 1 \end{bmatrix} \text{(Use small fishing boatsy)}$$

$$B_4^3 = \begin{bmatrix} 1 & 1 & \frac{1}{2} \\ 1 & 1 & \frac{1}{3} \\ 2 & 3 & 1 \end{bmatrix} \text{(Fish systematically and categoricall)}$$

Therefore, we can get the maximum eigenvalues of each scheme and the corresponding normalized eigenvectors.

Eigenvalues	λ_{max}
Migrate all assets	3
Migrate some assets	3.0183
Use small fishing boats	4.6785
Fish systematically and categorically	3.0183

2) Hierarchical total ordering:

$$W = W^{(2)}W^{(1)} = \begin{bmatrix} 0.2553 & 0.1692 & 0.6703 & 0.2402 \\ 0.3191 & 0.3874 & 0.0625 & 0.2098 \\ 0.4255 & 0.4434 & 0.2672 & 0.5499 \end{bmatrix} \begin{bmatrix} 0.1597 \\ 0.2372 \\ 0.2573 \\ 0.3494 \end{bmatrix}$$

So we can get $W = \begin{bmatrix} 0.3349 \\ 0.2320 \\ 0.2320 \end{bmatrix}$, which can determine the weight vector $A = (a_1, a_2, a_3) = (0.3349, 0.2320, 0.2320)$

6.4 Determine the evaluation set (level set)

V $= \{v1, v2\} = \{High, Low\}$

6.5 Determine the evaluation matrix

Factors	x_1		x_2		x_3		x_4	
Membership	High	Low	High	Low	High	Low	High	Low
the change of temperature	0.7	0.3	0.6	0.4	0.8	0.2	0.5	0.5
The situation of fishing	0.5	0.5	0.1	0.9	0.2	0.8	0.8	0.2
The concentration of bait	0.4	0.6	0.7	0.3	0.6	0.4	0.5	0.5

Therefore, the single-factor evaluation matrix for various measures are:

$$R_1 = \begin{bmatrix} 0.7 & 0.3 \\ 0.5 & 0.5 \\ 0.4 & 0.6 \end{bmatrix}$$
$$R_2 = \begin{bmatrix} 0.6 & 0.4 \\ 0.1 & 0.9 \\ 0.7 & 0.3 \end{bmatrix}$$
$$R_3 = \begin{bmatrix} 0.8 & 0.2 \\ 0.2 & 0.8 \\ 0.6 & 0.4 \end{bmatrix}$$
$$R_4 = \begin{bmatrix} 0.5 & 0.5 \\ 0.8 & 0.2 \\ 0.5 & 0.5 \end{bmatrix}$$

6.6 Fuzzy comprehensive evaluation

We made the fuzzy synthesis transformation between the weight vector of the evaluation factors and the evaluation matrix of various measures, and we get the fuzzy comprehensive evaluation model $B = AB$. The fuzzy synthesis operator is the ordinary matrix product algorithm here.

So we can get:

$$B_1 = AR_1 = (0.3349, 0.2320, 0.2320) \begin{bmatrix} 0.7 & 0.3 \\ 0.5 & 0.5 \\ 0.4 & 0.6 \end{bmatrix} = (0.4432, 0.3557)$$
$$B_2 = AR_2 = (0.3349, 0.2320, 0.2320) \begin{bmatrix} 0.6 & 0.4 \\ 0.1 & 0.9 \\ 0.7 & 0.3 \end{bmatrix} = (0.3865, 0.4124)$$
$$B_3 = AR_3 = (0.3349, 0.2320, 0.2320) \begin{bmatrix} 0.8 & 0.2 \\ 0.2 & 0.8 \\ 0.6 & 0.4 \end{bmatrix} = (0.4535, 0.3454)$$

$$B_4 = AR_4 = (0.3349, 0.2320, 0.2320) \begin{bmatrix} 0.5 & 0.5 \\ 0.8 & 0.2 \\ 0.5 & 0.5 \end{bmatrix} = (0.4690, 0.3298)$$

6.7 Interpret the result vector of fuzzy comprehensive evaluation.

We use the principle of maximum membership here, which is taking the element v_j corresponding to the maximum value bj in V as the evaluation result. So we can know that $b1$ is more than $b2$ in $B1$, so we choose $v1$ which is the efficiency of Migrate all assets is high. Similarly, the efficiency of Fish systematically and categorically and Use small fishing boats is also high, while the efficiency of Migrate some assets is low. According to the principle of fuzzy distribution, the membership degree of various measures with high efficiency is $0.4690 > 0.4535 > 0.4432$, which is Fish systematically and categorically > Use small fishing boats > Migrate all assets.

6.8 Proposal to local small fishing companies

1) We recommend that the fishing grounds located in the Shetland Islands of the North Sea should give priority to fish systematically and categorically, use small fishing boats appropriately, and it can also migrate all the company's assets along the migration path of mackerel and herring to increase the company's revenue.

2) Migrating asset is not so practical if the partial school of fish migrate to territorial waters of other countries. Fishing systematically and categorically is especially important because using fishing boats without refrigerator for fishing and we must ensure the freshness of the fish to the market, so we can use some small fishing boats moderately. The benefits will eventually decline since the partial migration of fish schools.

7 Strengths and Weaknesses

7.1 Strengths

1) The main strength of our model is economical and practical. We can get the data we need easily and it has a small amount of calculation.

2) To test the practicability of the model in our daily life, we take the North Atlantic sea annual temperature into discussion.

7.2 Weaknesses

1) The fish species moving is related to specific annual sea temperature and other factors such as marine pollution.

2) To test the practicability of the model, we need time to investigate and research.

8 Explanation for fishermen

The rise in global ocean temperature will definitely affect the habitat quality of certain marine life. We take North Atlantic herring and mackerel as an example.

Herring is a cold-temperate marine upper-layer fish whose ability to adapt to water temperature is between warm-water and cold-water. It Generally lives in the areas with a water temperature of $6-11°C$ and spawns in high-salinity sea areas below $10°C$. And the mackerel lives suitably with a water temperature of about $5-10°C$ and spawns in the high-salinity sea areas below $10°C$.

The mackerel and herring begin to find other habitats that are more suitable for their current and future life and reproduction when the temperature changes too much and they can not continue to grow and spawn. For small fishing companies, this geographical migration of fish stocks will lead to a decline in fishing and greatly affect the company's income, and the income of fishermen will also be affected because herring and mackerel are important economic sources of Scottish fisheries.

In order to effectively reduce the impact of fish migration on fisheries, we have studied the migration of Scottish herring and mackerel from habitats near Scotland. The study found that the average annual sea temperature is more than $10°C$ from 2021 based on the data of the observation points near shetland Island in Scotland to make predictions, so it is no longer suitable for spawning and survival of mackerel, and herring spawning is also suppressed.

As a result, the population of herring will decline. The average annual sea temperature in this area is more than $11°C$ by 2041, which is no longer suitable for herring survive. Therefore, since 2041, the fishing grounds in the Shetland Islands will encounter no harvest as early as 2021 and at the latest as 2041 due to the migration of two fish to the north.

The herring and mackerel populations will gradually migrate northward from the Shetland Islands in the North Sea along the edge of the continental shelf and then southwest to the sea area near the west of Ireland in the next 50 years.

Therefore, we suggest it should fish systematically and categorically and use some small fishing boats with the required freshness and quality of the catch. We can consider relocating the fishing port to increase the income of small fisheries companies.

9 Reference

[1] Teunis Jansen, Henrik Gislason, Temperature affects the timing of spawning and migration of North Sea mackerel , $[online]Availableat < http://www.elsevier.com/locate/csr >$ 2010.10.21

[2] Jansen T, Campbell A, Kelly C, Hatun H, Payne MR 2012 Migration and Fisheries of North East Atlantic Mackerel $Scomberscombrus$ in Autumn and Winter. PLoS ONE 7(12) : $e51541.doi : 10.1371/journal.pone.0051541$

[3] Robin Boyda, Shovonlal Roya,b, Richard Siblyc, Robert Thorped, Kieran Hyderd, A general approach to incorporating spatial and temporal variation in individual-based models of fish populations with application to Atlantic mackerel.
$[online]Availableat < http://www.elsevier.com/locate/ecolmodel >$ 2018.9.17