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The Research of Scottish Herring and Mackerel's Movement Simulation

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Abstract: Global warming has a great effect to marine species. In this paper, the author aims to construct mathematical to simulate the movement of two species, Herring and Mackerel. In order to describe its randomness and the background of global warming, the author improves Random Walk to weighted Random Walk as the model to describe the species movement, and the weight is affected by ocean temperature. Furthermore, to make the results more persuasive, the author uses interpolation algorithm to expand the data sets. After that, the author uses the model and data to simulate the trace of two species in 50 years. The trace is during the next 50 years, Mackerel will move 22.36 kilometers while Scottish Herring will move 29.15 kilometers, which shows that the two species will move a distance that cannot be ignored. Finally, based on above results, the author gets some conclusions and gives some advice to help fisheries companies to deal with it.

Keywords: Global Warming; Weighed Random Walk model; Interpolation Algorithm; Movement of Species

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1 Introduction

The phenomenon of increasing average air temperatures near the surface of earth has been going on for nearly one to two centuries. As a result, populations of some organisms are affected by climate change. For example, the American lobster has become the most valuable fishery resource in North America[1], coincident with the recent exceptional warming of the northwest Atlantic Ocean. In order to seek for more suitable habitat, marine creatures have to migrate north. In this article, the author will build a model to simulate the species movement of Scottish Herring and Mackerel.

2 Assumption and Notation

For ease of understanding, the assumption and notation are as follows. More detailed assumptions will be listed if needed.

(1) Assumptions

The movement of two species follows Weighed Random Walk.

The directions of movement only contain North, South, East and West.

The ocean temperature grow linearly with time going by.

Both species are moving all the time, with the same speed 5 kilometers per year.

(2) Notations

The notations are shown in figure 1.

h	The distance of one move, also width of the grid.
t	Time, whose unit is year.
$T(t)$	Ocean temperature, which is a function of time.
k	Average growth of temperature per year.
$\mu_l\ (l=1,2)$	Suitable temperature for two species. $l=1$ represents to Mackerel while $l=2$ represents to Scottish Herring
$A_i\ (i=1,2,3,4)$	Four vectors to describe the next move of fish species. A_1, A_2, A_3, A_4 separately means species go North, East, South and West. i.e. $A_1 := (0,h), A_2 := (h,0), A_3 := (0,-h), A_4 := (-h,0)$
$Q(t) := (x(t), y(t))$	The location of the fish species after t years.
M_{Qi}	Absolute Impact Factor on Temperature of next move (We will define it later.)
P_{Qi}	The probability of next move.
$X_Q(t)$	The Random Variable of next move.

Figure 1. Notations

3 Weighted Random Walk

From the reference, we can know the Simple Random Walk model on R[2]. In that case, we expand Simple Random Walk to R^2. However, in order to describe the effect of sea temperature, we need to improve it to Weighted Random Walk, which means that each move of species has a weight instead of constant 0.5.

Absolute Impact Factor is to describe the influence of temperature, be marked as AIFT. It reflects the extent of that species are affected by temperature. According to probability theory, we assume that AIFT obeys normal distribution to simplify the research model.

Step one is shown in figure 2.

$$M_{Qi}(T_{Qi}) := \frac{1}{\sqrt{2\pi}} e^{-\frac{(T_{Qi}-\mu)^2}{2}}$$

Figure 2. Step one

Where μ is a parameter that represents the suitable temperature for species. In that case, we assume the probability of next move in step two.

$$P_{Qi}(T_{Qi}) := \frac{M_{Qi}(T_{Qi})}{\sum_{j=1}^{4} M_{Qj}(T_{Qj})}$$

Figure 3. Step two

As we assumed, T_{Qi} grow linearly with time going by. Thus,T_{Qi}:= k(t-t_0) + T_{Qi0}, that is step three. Where t0 is initial time, $T_{Qi0}(t_0) = T_{Qi0}$ and k is the parameter, which is average growth of temperature per year.

In the above step one, step two and step three, description "Qi" means a spot Qi on grid which is decided by the sum of two vectors OQ, A_i.i.e.OQ_i = OQ + A_i, (where i = 1, 2, 3, 4). Therefore, combined with step one, step two and step three, we can get the function of next move probability with time.

$$P_{Q_i}(t) = \frac{e^{-\frac{\left(k(t-t_0)+T_{Qi0}-\mu\right)^2}{2}}}{\sum_{j=1}^{4} e^{-\frac{\left(k(t-t_0)+T_{Qj0}-\mu\right)^2}{2}}}$$

Figure 4. Step four

Then, we can know the Random Variable of next move:

$$X_Q(t) = \begin{cases} A_1 & P_{Q1} \\ A_2 & P_{Q2} \\ A_3 & P_{Q3} \\ A_4 & P_{Q4} \end{cases}$$

Figure 5. Step five

Same to above, we can get the expression of Q(t):

$$Q(t) = \sum_{j=1}^{t} X_{Q(j)}(t)\ , \qquad where\ X_{Q(j)}(t) = \begin{cases} A_1 & P_{Q1} \\ A_2 & P_{Q2} \\ A_3 & P_{Q3} \\ A_4 & P_{Q4} \end{cases}$$

Figure 6. Step six

After simulation, we may get the figure like figure 7.

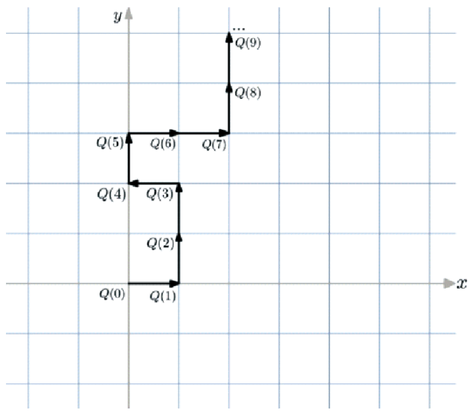

Figure 7. The trace of Q(using Weighed Random Walk model)

4 Simulation for Scottish Herring and Mackerel Movement

(1) Interpolation

Now, we will use Weighed Random Walk model to simulate the trace of two species. However, the data that we found[3] is not big enough to use. In that case, could use interpolation algorithm[4] to create a bigger data. We can see the significant difference between Figure 8 and Figure 9.

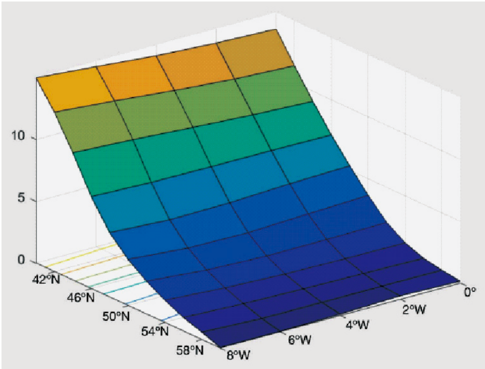

Figure 8. Data without Interpolation

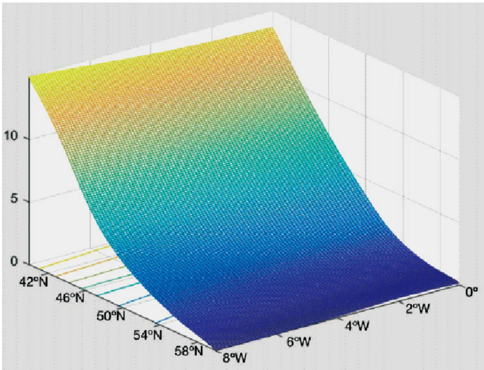

Figure 9. Data after Interpolation

Please note: These are the virtualize data of the sea surface temperature in maritime space around Scotland. In Figure 7 and Figure 8, there are three dimensions of data. The caption can be seen to explain the meaning of each axis. For these two figures, "lat" means Latitude, "lon" means Longitude and "sst" means Sea Surface Temperature.

(2) Simulation of the species trace

After we get the suitable data, the last work we will do is to simulate the path of two species in 50 years.

Referring to [5], 8 degrees Celsius is the perfect temperature for Mackerel, i.e. $\mu_1 = 8$. What is more, according to [6], the best temperature for Herring is lower than 10 degrees Celsius. In that case, we assume that 10 degrees Celsius is suitable for Herring, i.e. $\mu_2 = 10$.

Then, we assume that now the two species are staying at the places where the temperatures are suitable for them. According to the ocean temperature we get using interpolation, we can know their initial places separately. Finally, base on the above assumption, we can get h = 5. Base on Weighted Random Walk model, we write a MATLAB program to simulate the movement of two species and get the results: $D_1 = 22.36$ and $D_2 = 29.15$. Thus, the next two figures are their trace in next 50 years.

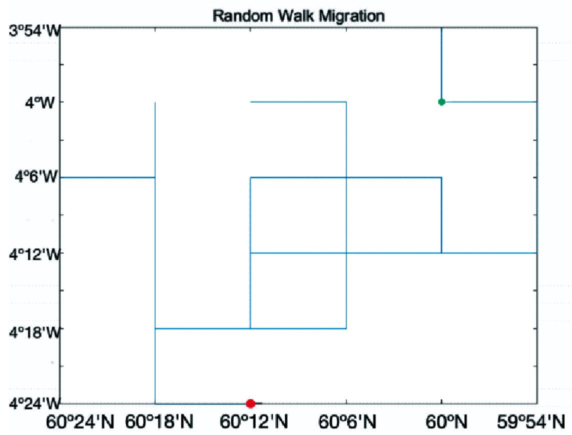

Figure 10. The movement of Mackerel in 50 years

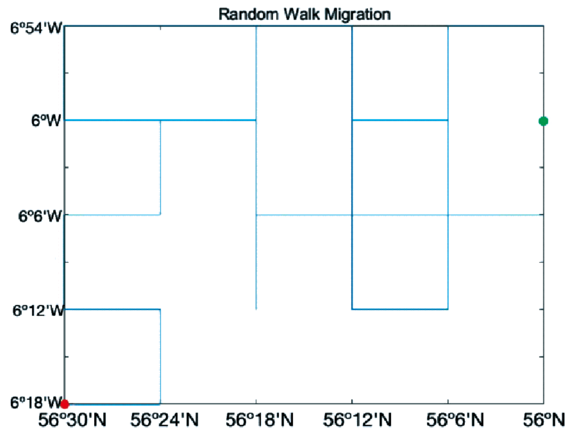

Figure 11. The movement of Scottish Herring in 50 years

Please note that l = 1 represents to Mackerel while l = 2 represents to Scottish Herring. Dl refers to the distance of l species movement in 50 years. The green points are the initial locations while the red points are the final locations.

5 Conclusions

(1) Two species both have tendency towards northwest.From the result of MATLAB program, we observe that both of the species have a trend to go north and go west. That means northwest has been becoming more suitable for Scottish Herring and Mackerel while there initial positions are no longer suitable for them.

(2) Both species will move a distance that cannot be ignored.From the result we can know that Mackerel will move 22.36 kilometers and Scottish Herring will move 29.15 kilometers. That means both of them will move a distance that cannot be ignored. In that case, it is not a good choice for fisheries companies to still stay at their places with nothing to do.

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(3) Scottish Herring will move further than Mackerel.Based on the result, we can know that Scottish Herring will move further than Mackerel, which means the changing of temperatures in Scottish Herring's habitat has more effect to Scottish Herring compared with Mackerel. In that case, the preservation of Scottish Herring may become more difficult.

6 Suggestions

(1) Move northeast. According to first and second conclusion, both of the two species have a trend towards northwest. In that case, it is much more easier for fisheries companies to catch Scottish Herring and Mackerel if the companies also choose to move northwest. Therefore, the fisheries companies are better to move northwest.

(2) Improve the fishing boats. Given that it may be difficult for many small companies to move their positions, we also suggest that those companies can improve the boats that fish Scottish Herring and Mackerel to compensate the effect of the movement of two species. What is more, this suggestion has a strength that it does not have any bad effect in other species' fishing. On the contrary, it will also improve the efficiency of others' fishing.

(3) Store Scottish Herring and Mackerel in a lower temperature environment, especially Scottish Herring. Since lower temperature can decrease cellular respiration of Scottish Herring and Mackerel, it is less likely to become degeneration for them in a lower temperature environment. Furthermore, compared to Mackerel, the changing of temperatures in Scottish Herring's habitat has more effect to Scottish Herring, based on the third conclusion. In that case, the fisheries companies should take extra care to Scottish Herring. For example, store it at lower temperature than Mackerel.

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