The impact of the environment on bird migration

Weifeng Peng *
School of electrical and electronic engineering, North China Electric Power University, Baoding, China

*Corresponding author e-mail: pengweifeng2@163.com

Abstract. Migration is the basic survival skill of birds. It is of great significance to study the migratory behavior of birds. This paper mainly studies the relationship between bird migration and self-energy consumption through the energy expenditures model in flight, and provides simple migration for birds.

1. Introduction
Migration is a survival instinct of animals, especially birds, following the natural environment.

Studying the migratory behavior of birds and understanding the migratory routes of migratory birds can provide a scientific basis for the protection and maintenance of ecological balance of birds. Humans bring enormous social and economic benefits as well as ecological benefits.

2. The migrations of birds

2.1. Selection of region and environment
In order to facilitate the fitting of species and environment, we selected seven different regions as shown in Fig 1, corresponding to seven different climates.

Figure 1. Seven regions
We conducted research on seven regions and obtained data as shown in Table 1.

Table 1. The data of region index

| Region number | Species richness | Food intake (kg) | Community index | Rainfall (mL/year) | Living space (km²) | Average temperature (°C) |
|---------------|------------------|------------------|-----------------|-------------------|-------------------|--------------------------|
| 1             | 410              | 87.9             | 0.08242         | 320               | 8983.17           | 4                        |
| 2             | 391              | 84.29            | 0.07909         | 750               | 3885.77           | 13                       |
| 3             | 350              | 76.5             | 0.116157        | 525               | 2849              | 20                       |
| 4             | 320              | 70.8             | 0.044535        | 1750              | 430               | 23                       |
| 5             | 545              | 113.55           | 0.050105        | 850               | 1800              | 25                       |
| 6             | 539              | 112.41           | 0.049832        | 3000              | 2417.76           | 26                       |
| 7             | 250              | 57.5             | 0.577862        | 220               | 972000            | -25                      |

2.2. The energy expenditure model in flight

According to the analysis of Dennis G. Raveling and Eugene A. LeFebvre, the energy expenditure in flight is linear to the weight of birds. They believe that the estimate of weight loss per hour of flight is 0.56% total weight/hour [1]. We research the flight energy consumption situation of birds to obtain the energy expenditures model in flight of other birds after modifying.

2.3. The climate effect model

In the Table 1, we can see the data of special climate conditions indicated by rainfall and temperature. In Fig 2, we obtain the relational expression, listed in formula (1), between mass and climate conditions in the way of multivariate regression analysis.

\[ z = p_{00} + p_{10}x + p_{01}y + p_{20}x^2 + p_{11}xy + p_{02}y^2 \]

Where \( x \) is the rainfall, \( y \) is the temperature, \( z \) is the mass, and \( p_{00} = 3393 \) (4891, 1.168e+04), \( p_{10} = 2.95\) (-15.82, 21.72), \( p_{01} = -7.431 \) (-370.4, 355.6), \( p_{20} = 0.0007211 \) (-0.003498, 0.00494), \( p_{11} = -0.2321 \) (-1.401, 0.9365), \( p_{02} = 3.308 \) (-7.787, 14.4).

Figure 2. Mass vs rainfall, temperature

2.4. The migratory pathway

We regarded the four places of arid regions as the nine points of first layer, two places of the temperate regions as the nine points of the second layer, and one place of the arctic region as the one point of the third layer.

In order to simplify the problem, we set a number of assumptions. Firstly, the bird reached the maturity mass before leaving the region. Secondly, the bird should have a lower bound of the mass. According to Kleiber’s law, the animals’s metabolic rate scales to the \( \frac{3}{4} \) power of the its mass. Symbolically, if \( q_0 \) is the bird’s metabolic rate and \( M \) the its mass, then Kleiber's law states that \( q_0 \sim M^{\frac{3}{4}} \) [2]. Once the instant mass equal to the limitation, the bird would hunt food and maintain the mass. Thirdly, the consumption of energy during the migration transfer to the decrease of the mass. According
to the study of Dennis G. Raveling and Eugene A. LeFebvre, we supposed the decrease of the mass is continuous with respect to time. At every moment the decrement is proportional to the magnitude of last moment and the ratio is 0.56%. Based on this, we have the equation below.

\[
1.0056 \frac{d^2m}{dt^2} + 0.0056 \frac{dm}{dt} = 0
\]

To find the relationship between mass and migration distance, we set the velocity of the migration and two boundary conditions. With all information above, we can solve the expected derivative function.

3. The birds’ migration

3.1. The energy expenditures in flight

The picture below shows one of the solutions of the derivative function.

The general result is,

\[
y = \frac{\exp(-x(0.0056-\sqrt{1.0056^2-4*1.0056*0})/(2*1.0056))\ast(2*1.0056\ast x\ast m_0-m_0\ast(0.0056^2-4*1.0056\ast 0)^(1/2))/2*(0.0056^2-4*1.0056*0)^(1/2))-(\exp(-x(0.0056+\sqrt{1.0056^2-4*1.0056*0})/(2*1.0056))\ast(2*1.0056\ast x\ast m_0-m_0\ast(0.0056^2-4*1.0056\ast 0)^(1/2))/2*(0.0056^2-4*1.0056*0)^(1/2))}{(2*1.0056\ast m_0+m_0\ast(0.0056^2-4*1.0056\ast 0)^(1/2))/2*(0.0056^2-4*1.0056*0)^(1/2))}
\]

where \(m_0\) is the initial mass. It is clear that the mass decrease is more and more moderate with respect to time which is conform to our knowledge that the greater mass, the greater resistance and vice versa.

![Figure 3. Weight loss curve](image)

3.2. The best fit migratory pathway

Based on the assumptions and the model we can find out the ideal way to travel. Fig 4 illustrates the result of the problem. The bird should start from Jakarta and then migrate to the northeast of China and finally get Greenland.
4. Conclusion
In this paper, we built the models to analyze migratory pathway of birds. Firstly, we built the energy expenditures model in flight according to the analysis of Dennis G. Raveling and Eugene A. LeFebvre. Then we built the climate effect model to obtain the relational expression between mass and climate conditions in the way of multivariate regression analysis. According to the study of Dennis G. Raveling and Eugene A. LeFebvre, we found the relationship between mass and migration distance, we set the velocity of the migration and two boundary conditions. Finally, we took the effect of different climate conditions and energy expenditures in flight when migrating into account, and then we made a best fit migratory pathway.

References
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