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T1 ________________	**1903848**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**A**	F4 ________________

2019

MCM/ICM

Summary Sheet

Survival or death: dragons living today

Summary

In the novel *Song of Ice and Fire*, the growth and survival of the three **dragons** are limited by the ecological environment. Our work is to simulate the **growth models** of the three dragons in different living environments. Based on this problem, the key to our consideration is energy consumption. Different living environments, different weights, and different characteristics will ultimately affect the supply and consumption of energy. Therefore, we focus on modeling energy.

Firstly, we use the variation of the animal growth model of Luis Orlindo Tedeschi et al. [3] (traditional model) to calculate the weight gain and energy consumption of a dragon under different external environments and different body weights. We use the data of elephants, rhinos and cattle to train the traditional model, making it more robust to the growth data of common animals.

Secondly, we calculate the extra energy required by a dragon to sustain life by modeling the **physical activity factor** based on the characteristics of a dragon's ability to fly. For the feature of resisting trauma, we modify the dragon model by using the data of crocodile, a species with strong skin, and combining the prediction of the traditional model with the actual data to obtain the proportion of energy required for the growth of crocodile skin. At the same time, we study the principle of a dragon's fire breathing, and draw the conclusion that a dragon's fire breathing almost does not need to consume energy.

Finally, we use the model to calculate the energy expenditure of a dragon in different environments to which it migrates, related to the environment factor(CETI). Then it is combined with **net primary production** (NPP) in different ecological environments to obtain the predation area required by a dragon's life. We conclude that it’s difficult for dragons to survive in desert or polar environments, and suggest that they can survive in grasslands.

Key words: dragons; growth model; traditional model; physical activity factor; net primary production

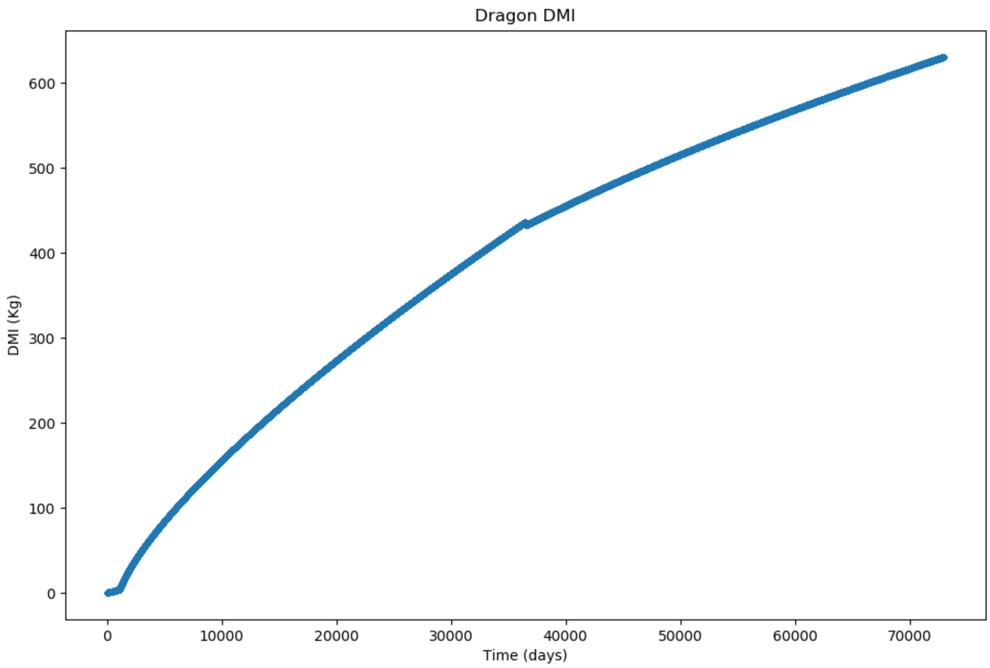
I Letter to Author of A Song of Ice and Fire

To: George RR Martin   Date: 27, January, 2018

Dear Mr.Martin,

We are great fans of your novel *Song of Ice and Fire*, and recently we have done an interesting mathematical modeling research about the three dragons appearing in this story world. What we want to figure out is how to maintain the realistic ecological underpinning of the story, especially migration, if the fictional dragons were living today. Next we will share the results we have come out in the research.

In the real environment, dragons are carnivorous animals. Based on the assumption that a dragon grows from 10kg to 30-40kg one year after birth, its daily food intake at birth is 0.536kg, and its food intake is 5.49kg and body weight is 164kg within 0 to 3 years after birth. From 3 years to 100 years old, a dragon is in the growth stage, growing rapidly, and it can reach 55 tons at 100 years old, and its daily food intake is 437kg. After that is the mature period, and the growth slows down. The growth model of a dragon is shown in the figure below, where DMI is the daily food intake.



The conclusions we draw from our model of the living environment are based on different assumptions. If a dragon uses fire as a defense tool, then it is suitable to live in forest and wetland environments, because these environments have high energy reserves, abundant species and high stability.

If a dragon preys by spurting the fire, the forest ecosystem is easily destroyed, so it generally lives in the mountainous area, and because of the small amount of biomass in the mountainous environment, and the lack of species, the stability of the ecological environment is poor, the dragon will be devastating to the local environment, so the dragon often needs to migrate to other suitable places.

Our consideration is that a dragon is strong enough and agile enough so that it does not have to hunt by means of the fire. In fact, a dragon should eat raw food like other hunting creatures. Therefore, we only regard fire-breathing as a means of defense. In addition, we believe that the fire does not directly spit out the flame from a dragon's mouth, but through the chemical reaction to make the air spontaneously ignite and produce a flame, so a dragon's fire-breathing itself consumes almost no energy, and the energy consumption is mainly in flight and the formation of solid skin.

Our model shows that small changes in temperature itself would not have much effect on a dragon's own food intake, but that enough high or enough low temperatures (desert and polar) would have a large effect on a dragon's food intake. At the same time, the desert, the polar region are not suitable for a dragon's residence because of its small biomass.

Finally, through model analysis, we select the wetland as the most suitable environment for a dragon, because the temperature is relatively appropriate and the occasional fire breathing will not cause great impact on the wetland ecology. After combining the net primary production of the wetland with the model, we draw the conclusion that for adult dragons, the wetland area required for survival is $40000m^2$, which is a reasonable assumption due to the abundance of wetland species.

To conclude, we sincerely hope that the studies of us will be helpful for you and bring some inspiration to your literary creation.

Sincerely yours,

Team #1903848.

Contents

II Introduction

II.1 Problem Background

Dragon is a giant monster originating from ancient mythology. It resembles a crocodile, covered with scales, has giant claws and wings, can swim, fly and even spurt fire, is fierce and extremely destructive. This mysterious and powerful creature often appears in works of art such as literature, architecture, and painting[1].

In the fictional television series Game of Thrones, based on the series of epic fantasy novels *A Song of Ice and Fire*[2], three dragons are raised by Daenerys Targaryen, the “Mother of Dragons.” Dragons grow all their lives, but it's not clear how long they generally live or how big they get. The maesters believed that the size of dragons depends on the living conditions and amount of food available to them.

For us, dragon has a strong appeal and we are also fans of Game of Thrones. We hope that the results of our research can bring some inspiration to the author.

II.2 Our Works

Under this background, we assume the current era that the three dragons live, and conduct mathematical modeling based on the assumptions of Chapter III and the data of other similar creatures, to consider the characteristics, behaviors, habits, diet of dragons, and their interaction with the environment in modern life, through the comprehensive analysis of different modern species, analogical reasoning to predict the realistic characteristics of the fictional dragon.

In the rest of this article, we will focus on solving the following issues:

- The ecological impact and requirements of the dragons. This is the primary topic. We must clarify the minimum necessary ecological conditions that the dragons need to survive in the modern environment. On this basis, we can further explore the other behavioral characteristics of the dragons. While the impact always goes both ways, the environment has a certain impact on the life of the dragons. We will discuss it here by the way.
- The energy expenditures of the dragons and their caloric intake requirements. The energy model will be the focus of this paper. The starting point of our mathematical modeling is also the flow and utilization of energy. Therefore, here we will analyze the growth process of a dragon, discuss the energy required by a dragon in its growth process, the weight and volume of its growth after energy intake, etc
- Area required for three dragons. Based on the novel Song of Ice and Fire, we explore the life of the three dragons in the novel. In order to support the

minimum space required for their life activities, the discussion of space here is handled in terms of the average living environment. We will discuss the effects of environmental, climatic, and temperature conditions in detail in later chapters.

- Community area for dragons. Animal life is not only basic life activities, every animal needs to have their own living space to rest, hide, breed, prey, etc. Here we discuss the total area of the community required for a dragon to live, and the discussion of space is also handled in terms of the average living environment.
- The dragon's migration. According to the assumption, the dragon can fly and can travel far, and can migrate to a certain extent, so the dragon must adapt to different environments in different environments, especially considering the long distance migration. Under the circumstances, we need to change the food and energy that dragons need in different environments. This is what we should consider in this section.

III General Assumptions

To build our model and analyze the the dragon's life characteristics, we m ake the following assuamptions based on the novel *A Song of Ice and Fire*.

- The dragon is egg-laying animal and belongs to the reptiles;
- The dragon has a strong body, a long thick neck, a head with horns or ruffles, sharp teeth, and a long tail;
- The dragon walks with four strong feet, and flies with a pair of giant wings like bat wings. His body is covered with scales to protect his body;
- The weight of the dragon at birth is about 10 kg, a year later grows up to 30-40 kg;
- The dragon can spit fire, is offensive, and has its own ability to protect against fire;
- The dragon has a strong defense ability to resist huge trauma;
- The dragon is a solitary creature. After adulthood, it may be fighting because of the territory.

The following model construction and feature analysis are based on assumptions proposed in this chapter.

IV Symbol Description

Table 1: **The symbol used in this article**

Symbol	Description	Symbol	Description
AFSBW	Adjusted final body weights	kg	Conversion efficiency of ME to NEg

BCS	body condition score(full 5)	LCT	Lower critical temperature
CETI	Environmental factor	ME	Meta-bolizable energy
DMI	Predicted dry matter intake	MEcs	Animal requirement for ME adjusted for cold stress
DMINC	Function of CETI	NEg	Dietary content of net energy for growth
EFG	Amount of net energy available for growth	NEm	Dietary content of net energy for maintenance
EI	Extra insulation	NEmr	Animal requirement of net energy for maintenance
EWG	Empty weight gain	NEmrcs	Animal requirement for NE for growth adjusted for cold stress
FIG	Fat in gain	PA	Physical activity
FFG	Feed intake available to support animal growth	PIG	Protein in gain
FFM	Feed intake to support animal requirement for maintenance	RE	Retained energy
GEf	Heat of combustion of fat	RHc	Relative humidity
GEp	Heat of combustion of protein	SA	Surface areas
HD	Hair depth	SWG	Shrunk weight gain
HE	Heat production Mcal/day	Tc	Average temperature
HP	Heat production	TI	Tissue (internal) insulation
IN	Total insulation		

V Growth of Dragon

V.1 Traditional Growth Model

By collecting literature and referring to the paper of Luis Orlindo Tedeschi et al. [3], we learn about the current achievements in the research on the growth of animals in agricultural cultivation. In order to enable these results to be applied to wild animals in an approximate manner, we optimize the original model and formula, removing some of the elements that are not related to the body or have little relevance in agricultural farming (such as the wind speed and illumination of the field, etc.), simplifing the the formula mentioned in the original text, and reusing the existing wild animal data[4] to train the model, which are the following two mathematical models.

The figure 1 is the flowchart of traditional growth model.

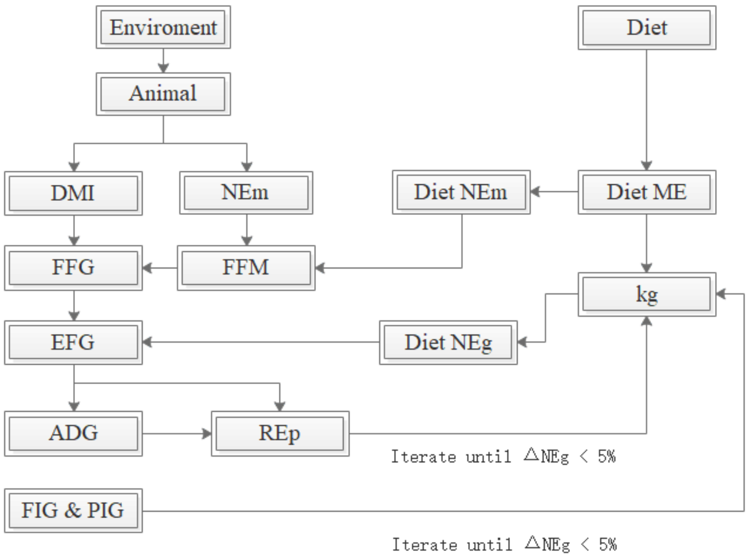


Figure 1: **Traditional Growth Model**

V.1.1 Animal's energy intake model

According to the paper of Luis Orlindo Tedeschi et al.[3], the food intake of animals can be described by the following equations.

Environment Influence Equations

$$\begin{cases} CTEI = 27.88 - 0.456Tc + 0.010754Tc^2 - 0.4905RHc \\ \qquad\qquad +0.00088RHc^2 + 0.019876Tc \times RHc \\ DMINC = \frac{119.62-0.9708CETI}{100} \\ DMIAF_{(t\leq -20\,℃)} = 1.16 \\ DMIAF_{(-20\,℃<t\leq 20\,℃)} = 1.0433 - 0.0044Tc + 0.001Tc^2 \\ DMIAF_{(20\,℃<t\leq 28\,℃)} = \frac{0.75(1-DMINC)+DMINC}{100} + 1 + 0.05 \\ DMIAF_{(t>28\,℃)} = \frac{0.75(1-DMINC)+DMINC}{100} + 1 \end{cases} \tag{V-1}$$

DMI Equations

$$\begin{cases} DMI_{(Days\leq 365)} = BW^{0.75} \times \frac{0.2435NEm-0.046NEm^2-0.1128}{NEm} \times DMIAF \\ DMI_{(Days>365)} = BW^{0.75} \times \frac{0.2435NEm-0.046NEm^2-0.0869}{NEm} \times DMIAF \end{cases} \tag{V-2}$$

Dry matter intake of an animal(DMI) is determined by demand to meet requirement for maintenance and growth. The prediction of DMI is adjusted for the environmental factor [Eqs.(V-2)] [6], taking temperature, humidity and other factors into consideration. Then DMI is predicted by Eqs.(V-2), determined by BW, NEm and environmental factors.

V.1.2 Animal's growth model

According to DMI and BW on the day, we can get the BW for the next day. Then, we need to calculate how much energy is converted into the energy needed for growth. To do this, we need to model and analyze kg. The initial value of kg is given by the following equations:

Growth Conditions Equations

$$\begin{cases} kg = \frac{0.0122ME^3 - 0.174ME^2 + 1.42ME - 1.65}{ME} \\ NEg = ME \times kg \\ MEmr = BW^{0.75} \times PA \times 0.075 \end{cases} \tag{V-3}$$

We use the iterative method, where the [Equals V-3] are the initial conditions of the iterative equation to obtain the initial kg and NEg, and then iterate until the gap between the previous day's NEg and the re-adjusted NEg is less than 5% of the previous day's value. This process ensures the final converged dietary value NEg will be energetic consistent between weight gain and it 's composition of fat and protein. The iterative equations are as follows:

Growth Iterative Equation

$$\begin{cases} RE = \left(DMI - \frac{NEmr}{NEm}\right) \times NEg \\ SA = 0.09BW^{0.67} \\ HE = \frac{ME \times DMI - RE}{SA} \\ EI = 7.36 + 2.55HD \\ TI = 5.25 + BCS \\ IN = EI + TI \\ LCT = 39 - 0.05IN \times HE \\ FFM = \frac{NEmrcs}{NEm} \\ FFG = DMI - FFM \\ EFG = FFG \times NEG \\ EWG = 0.956SWG \\ REc = \frac{RE}{EWG} \\ PIG = \frac{FFMp \times (REc - GEf)}{FFMp * GEp - GEf} \\ FIG = \frac{REc - FFMp \times GEp}{GEf - FFMp \times GEp} \\ REp = 0.054 + 1.6939e^{-0.5573\frac{RE}{EWG}} \\ kg_{new} = \frac{3}{4 + 11REp} \\ NEg_{new} = kg_{new} \times ME \end{cases} \tag{V-4}$$

The calculation formula of the environmental influence parameters in equation (V-4) are as follows:

$$\mathrm{MEcs}(Tc) = \begin{cases} \mathrm{SA} \times \frac{LCT - Tc}{IN}, & \mathrm{Tc} < \mathrm{LCT} \\ 0, & \mathrm{Tc} \geq \mathrm{LCT} \end{cases} \tag{V-5}$$

$$\mathrm{NEmrcs}(\mathrm{MEcs}) = \begin{cases} 0, & \mathrm{MEcs} \leq 0 \\ \mathrm{NEmr} + \frac{NEmr}{ME} \times MEcs, & \mathrm{MEcs} > 0 \end{cases} \tag{V-6}$$

The parameter calculation formula for calculating the growth is as follows::

$$\mathrm{SWG}(\mathrm{EFG}) = \begin{cases} 0, & \mathrm{EFG} \leq 0 \\ 13.91 BW^{-0.7} \times EFG^{0.9}, & \mathrm{EFG} > 0 \end{cases} \tag{V-7}$$

According to the above formula, an animal can grow only when the Amount of net energy available for growth is positive.

In order to iteratively calculate the value of the increment, equation (V-4) corrects the increment by repeated calculation, and after each iteration, the new BW is calculated by $BW_{new} = \mathrm{BW} + \mathrm{SWG}$, and the weight of the animal on the new day is finally obtained.

V.1.3 Results

By consulting data, we estimate the parameters with the infant and adult weight and growth period of common organisms provided by wikipedia, and further modify the parameters of the model with the test data of Powdermill Biological Station Small Mammal Database, and then adjust a more reasonablebiological growth model.

The following table is the weight and growth period data of some living organisms that we have consulted:

Table 2: **Weight of various stages of some animals**

Name	**Baby Weight**	**Growth period**	**Adult weight**
Cattle	40~60kg	About 2.5 years	600kg~1000kg
Rhinoceros	45~50kg	About 9 years	2000~3000kg
Africa elephant	100~120kg	About 14 years	2700~5500kg

According to our model, initial values and environmental temperature and humidity conditions suitable for the corresponding species were set to draw thegrowth model as shown below:

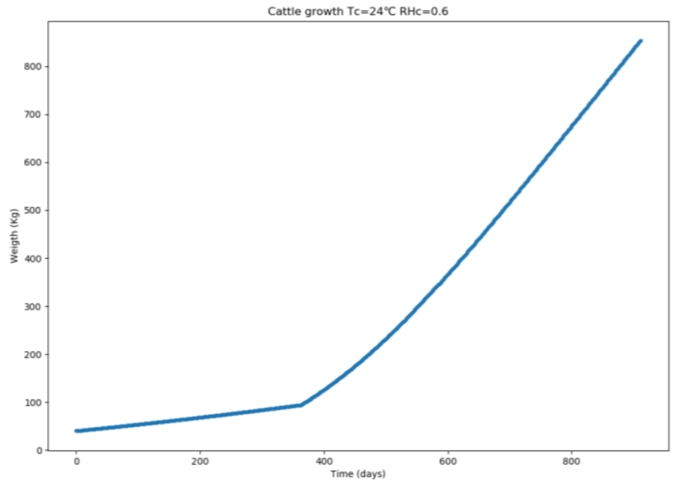


Figure 2: **Cattle Growth**

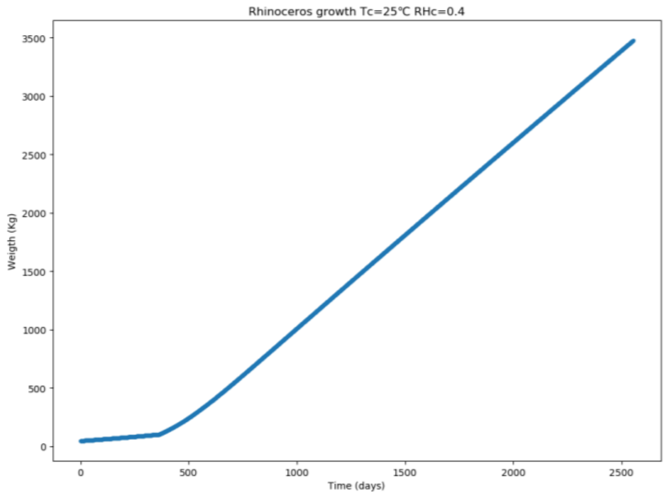


Figure 3: **Rhinoceros Growth**

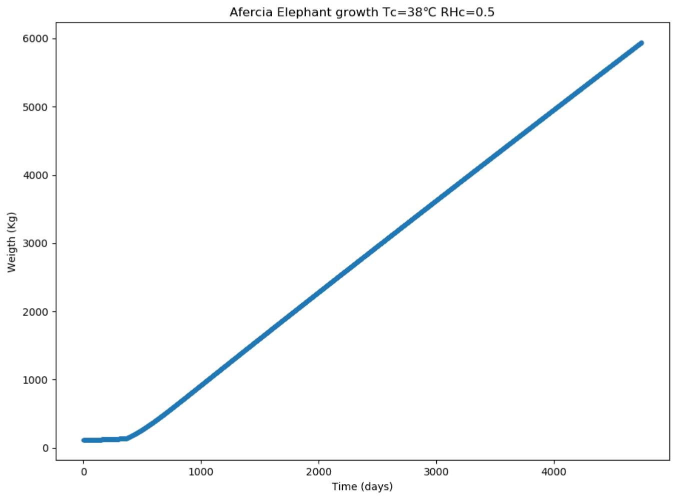


Figure 4: **Aferica Elephant Growth**

By comparing the predicted results of our model with the real results, we find that:

(1) The prediction of cattle is very good, which is in line with the growth data of cattle.

(2) For both the rhino and the African elephant, the end result of maturity is greater than the maximum body weight known.

Through analysis, we believe that the reason for this situation, that is, the problem of the model is: the original reference papers are mainly for the purpose of agricultural farming, while the cattle living in the human breeding environment have rich food and water resources from humans, and a good living environment. But wild animals such as rhinoceros and African elephants do nothave such excellent environment in the wild, facing various natural disasters and threats from other species, so the acquisition and growth of energy will deviate from artificial breeding. The animal growth curve in the environment will have a certain amplitude attenuation on the original curve, so the data predicted by the model will be greater than the maximum weight in the natural environment.

Therefore, this factor is a project that we need to focus on optimization when we discuss the dragon's growth model in Section V.2.

V.2 Improved Model

V.2.1 From the perspective of physical activity

For the specific physical activity of a dragon, the first thing occurred to us is that a dragon can spurt fire. After we consulted the relevant materials, we find description about fire-breathing dragon in the film Reign of Fire[12], combining with some existing insects which are possible to cause combustion can spurt high-temperature flammable chemicals (such as Brachinus explodens[13]), we think a dragon's fire is also caused by certain chemical reaction. Similar to the poisonous gland of the snake's mouth, the mouth of a dragon may also have glands to secrete certain chemicals. This substance is ejected in the exhalation of fire and, after some chemical reaction, begins to cause a flame at a distance from the mouth. For this reason, we do not need to consider the energy contained in the flame alone to increase the energy consumption of a dragon, while the energy needed to secrete this chemical is included in the energy required for a dragon's own growth.

In addition, in the [Equals V-3], we calculate the Animal requirement for net energy for maintenance(NEmr), which is related to the physical activity factor(PA). When considering the fact that dragons can fly, it is necessary to make a new scientific measurement of PA. Referring to the principle of bird flight, we refer to the formula in Masman and Klaassen[8]. With appropriate modifications to the formula, the formula for the energy per second consumed by a dragon in flight is as follows.

$$P = 3.329Ws^{-4.236} \times Wa^{1.926} \times BW^{0.013} \quad \text{(V-8)}$$

Where Ws is wing span; Wa is wing area; BW is body weight. We must estimate Ws and Wa. Considering that in the [Equals V-4], we have calculated surface area(SA). We assume that WA is half of SA for dragons and the Aspect Ratio(AR) in general is 6. Then Ws can be obtained from the following formula[9].

$$AR = \frac{Ws^2}{Wa} \quad \text{(V-9)}$$

At this time, we assume that a dragon flies for 2 hours a day, that is, extra energy(Ee) can be obtained by power (P). Then we can get the value of PA by the definition of PA. PA is the total amount of energy used to sustain the body divided by the amount of energy required for life activities. The total energy is composed of the energy required by life activities and the energy required by physical activities. Therefore, the calculation formula of PA is as follows.

$$PA = \frac{(NEm+E)\times 1.1}{NEm} \quad \text{(V-10)}$$

V.2.2 From the perspective of dragon growth

Then we consider a dragon's strong resistance that it can resist tremendous trauma. We referred to animals with thick outer skins and would like to analyze the composition of these animal skins. However, such data is very difficult to find, we have to find ways to estimate the energy required in the skin through other types of data.

Finally, we draw on the practice in Covolos et al. to obtain the energy needed in the skin through reverse prediction. We first predict the data of crocodiles[11] by fine-tuning the classic model, and reverse to obtain the energy required for the growth of the crocodile skin by comparing the weight of the crocodile's true growth with the model-predicted shrunk weight gain (SWG). In this way, the ratio of the energy required for skin growth to the total energy required (SK) can be calculated and applied to a dragon. The formula for the final dragon's SWG is shown below.

$$SWG = 13.91BW^{-0.7} \times EFG^{0.9} \times SK \quad \text{(V-11)}$$

After considering the effect of PA and epidermis, we reuse the model to simulate the growth of a dragon, and find that a dragon did not grow. After discussion and analysis, we come to the conclusion that due to the excessive physical activities of a dragon and the demand for the skin that can resist the trauma, the energy used for maintenance exceeded the energy absorbed by a dragon, resulting in no change in body weight.

Based on this conclusion, it is necessary to increase the energy content of dragon's food if the quality of dragon's food is not changed. Based on the energy content in real food, we believe that the value of NEm should not be based on the previous herbivorous animals, but should be based on carnivorous animals. Therefore, we set NEm as 1.105 Mcal kg-1 on the basis of Luis Orlindo Tedeschi et al.[3]. At this point, it can be guaranteed that a dragon will weigh about 35kg after one year.

We assume that a dragon has three years of infancy, 97 years of growth, and thereafter maturity. Depending on the period, we define different DMI functions to simulate the growth of dragons. Dragons grow slowly in early childhood and rapidly in the growth stage, and their weight growth enters a state of slow change after adulthood. This hypothesis is in line with the biological theory, and also in line with the assumed growth rate in childhood in chapter III.

V.2.3 Conclusion

According to the model we have built, we can get the following three images, which are the weight gain of the first 10 days of the growth of a dragon, the weight gain in the early growth stage, and the weight gain of the adult dragon:

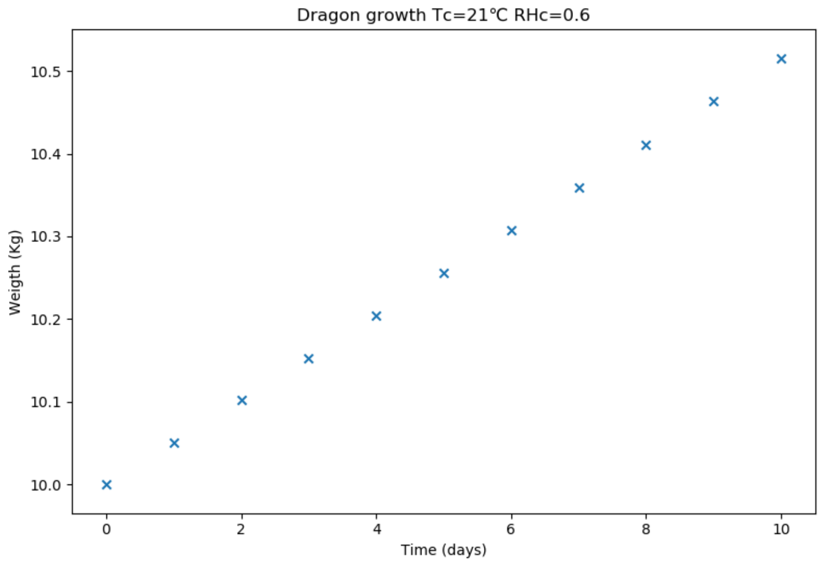


Figure 5: **First 10 days'growth of Dragon**

From the Figure 5 and Figure 6, we can see that the weight of a dragon grows slowly in the early stage, and the overall trend is approximately linear. However, as can be seen from the scatter diagram of the detail part in figure 5, the overall trend is not completely linear in fact, and the result curve generated by repeated iterations should be a complex equation of higher order curve.

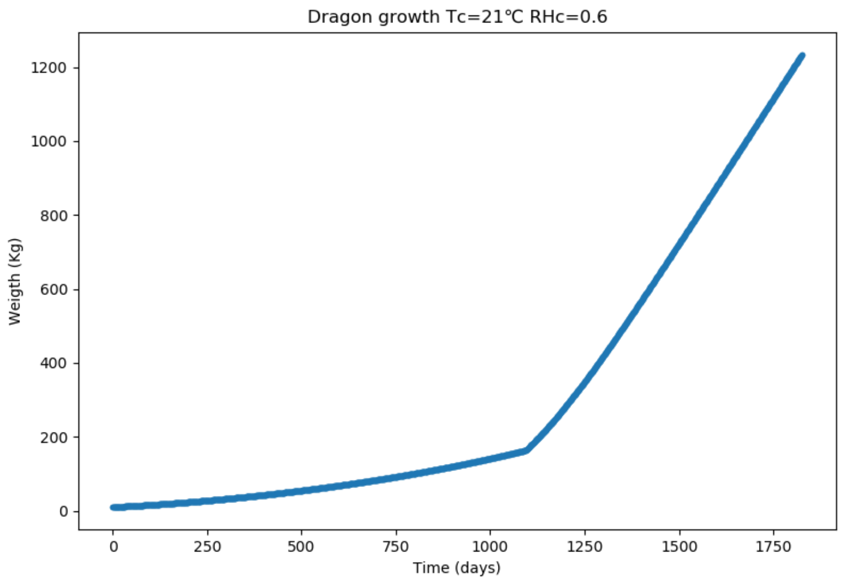


Figure 6: **Childhood'growth of Dragon**

From the weight gain of these two figures, we can see that a dragon's weight growth in the early stage of growth is relatively slow, only more than 200 kilograms after three years, much smaller than the cattle and other creatures in the same period. But in the growth period the rapid growth of weight begins, and its growth rate is also greater than that of other mammals. This also shows that the larvae of oviparous organisms are small, and they have little growth during infancy and have a fast growth period.

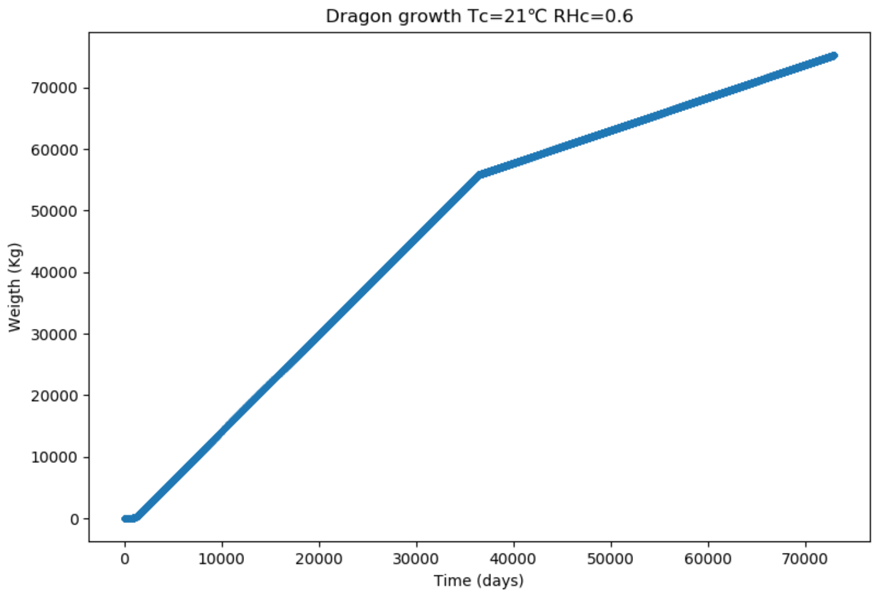


Figure 7: **Adulthood'growth of Dragon**

Figure 7 shows the weight gain of adult dragons. We can see that, according to the hypothesis, a dragon that has grown for 100 years has become a giant monster with a weight of more than 50 tons. At the same time, according to our model, it can also entirely provide support for its daily life activities including the energy required for the flight, which is consistent with the characteristics of the imaginary dragon we see in various film and television literature.

After adulthood, the weight growth of dragon begins to become gradually slow, but because the amount of food intake is greater than the consumption of various activities to sustain life, there will still be some energy accumulation.

Obviously, the weight of a dragon will not grow forever, and there will be a stage of impending the limit. After that, due to physiological health such as aging and other reasons, life activities will be weakened and eating will be reduced, but here we cannot give the hypothesis of the longevity of a dragon, so we only consider to this stage.

VI Dragon's Living Environment Solution

VI.1 The Ecological Impact and Requirements

A dragon's requirements for the ecological environment mainly lies in that the environment needs to provide enough energy for the dragon, so we need to get the energy contained in the dragon's daily food intake. According to the previous model, the energy consumed per day is equal to DMI multiplied by ME. The graph of DMI on the number of days is as follows.

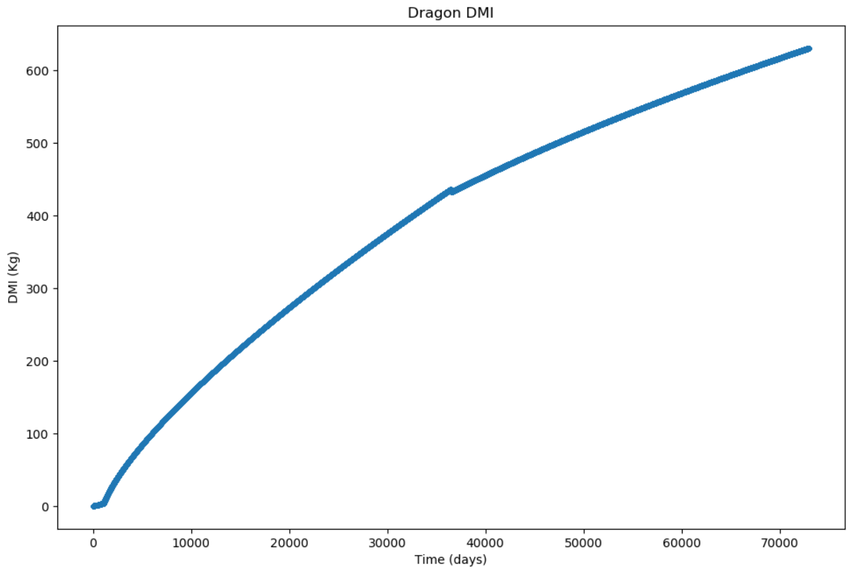


Figure 8: **DMI growth**

It can be seen from the figure that a dragon needs a lot of food consumption when it joins the ecological environment, and needs an abundant and large enough ecological environment to meet the basic survival requirements of the dragon. The area of a dragon's living space will be discussed in VI.3.

VI.2 Energy Expenditure

With the energy model of a dragon's growth we put foward in Section V.2, this problem can be easily solved.

A dragon's own energy expenditure is mainly divided into two parts. The energy contained in the food to maintain the animal's life activities (excluding flight) and the energy consumed by the flight, namely the formula:

$$(\mathrm{NEm} + \mathrm{Ee}) \times \mathrm{DMI}$$

Therefore, we use the model in chapter V.2 to draw the graph of dragon's energy expenditure as follows:

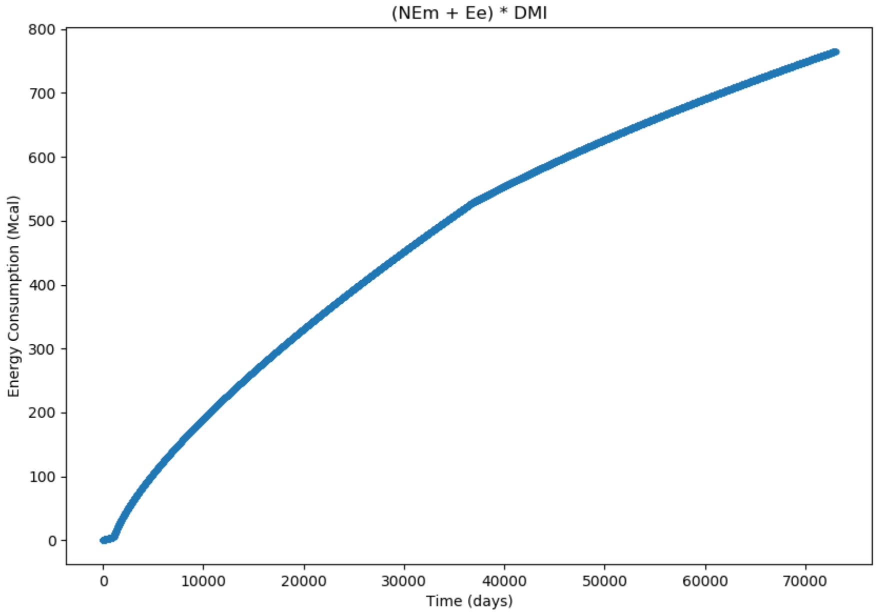


Figure 9: **Energy Expenditure**

From the curve, we can see that this is a curve close to but not completely consistent with the change of DMI, which is also related to the fact that a dragon's own energy consumption is determined by feeding on the one hand and also regulates the amount of food intake on the other.

VI.3 Area required for Three Dragons

To calculate the volume required for the three dragons to live, we need to know the energy output of each ecosystem and the trophic level of the food chain under that ecosystem. We refer to net primary production and plant biomass for the Earth [14], and the mean net primary production(NPP) of some relatively typical ecological environments are as follows.

Table 3: **Primary production and plant biomass for the earth**

Ecosystem type	**Mean NPP (g/m ²/yr)**	**Temperature (℃)**	**Relative humidity**
Tropical rainforest	2,200	26	0.95
Swamp and wetland	2000	20	0.78
Temperate evergreen forest	1300	18	0.8
Savanna	900	21	0.5
Desert and semi-desert	90	26	0.2
Extreme desert	3	30	0.08
Ice	3	-38	0.65

According to the table above, we can calculate the fixed energy of each ecosystem, using the equation:

$$1\text{g} \cdot m^{-2} \cdot a^{-1} = 1.8 \times 10^4\ J$$

We assume that a dragon does not eat plants, and that the dragon is at the Nth trophic level, and only about 10% remains after each level of energy [13]. Finally, the formula for calculating the area (Aa) required for the survival of a dragon is as follows.

$$Aa = \frac{ME \times DMI \times 365}{0.1^{N-1} \times 1.8 \times 10^4 \times NPP}$$

Using this formula, combined with the model we established in Section V.2, in the Temperate evergreen forest, with a dragon as the sixth trophic level, draw out the diagram of the minimum area required for the growth of a dragon and its age, which is as follows:

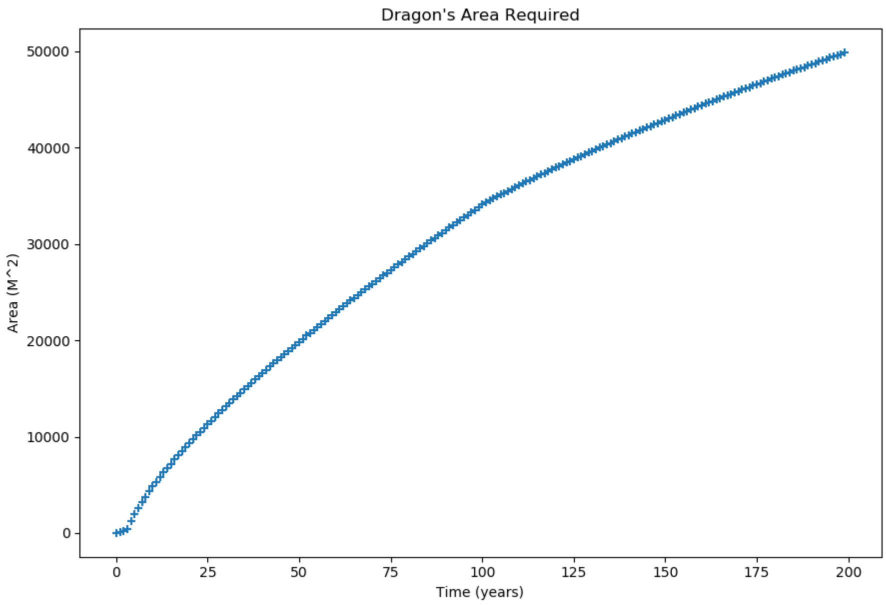


Figure10: **Area required for a dragon**

N = 6, NPP = 1300

From the figure we can see that for an adult 200-year-old dragon, the area required to maintain basic life activities is about 50 square kilometers. Since we assume in chapter III that the adult dragon is a solitary creature, in order to consider the three dragons in the novel *Ice and Fire Song* [2], we take 20 years to study and plot the 3*Aa curve as follows:

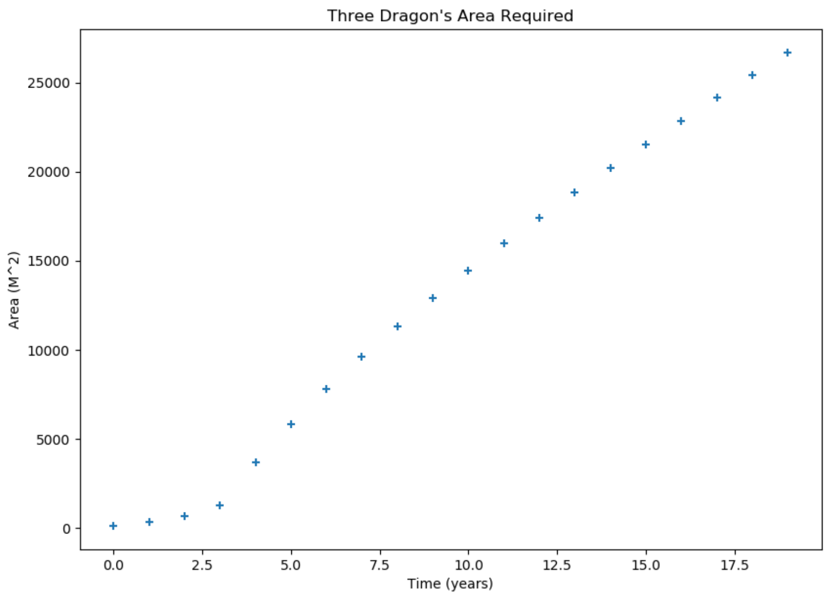


Figure 11: **Area required for a dragon**

N = 6, NPP = 1300

The above is the case in which a dragon lives in the wild environment. If a dragon lives in the artificial breeding environment, the above model will no longer be applicable. We only need to consider the requirement of dragon survival on the community, which is considered in VI.4.

VI.4 Dragon's Migration

Here we do not consider the issue of migration itself, but rather to consider the survival of a dragon in different environments to which it migrates. Because a dragon migrates mainly by its powerful wing, which has been considered in our model. But Several factors in the model that affect the overall situation are the temperature, humidity, and energy contained in the food, which are all related to the environment.

In different ecological environments, the difference in temperature and relative humidity will affect dragon requirement for NE for maintenance adjusted for cold stress (NEmrcs), which was obtained from [Equals V-6]. The difference in NEmrcs causes a dragon's food intake to be different, resulting in a different space for maintaining its life activities. Based on this inference and the data in table 3, the energy consumption of a dragon caused by environmental factors in different ecological environments is plotted as follows by using the model we build in chapter V.2 and the formula we obtained in chapter VI.3:

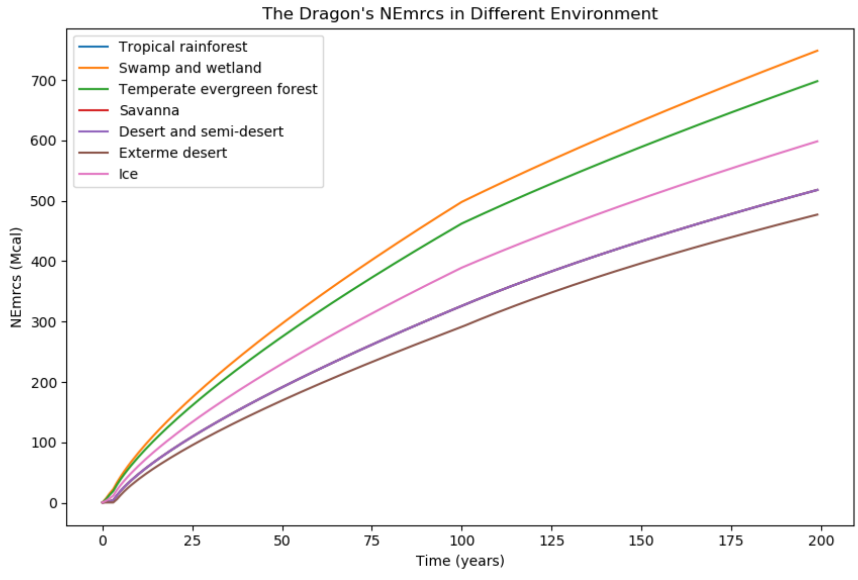


Figure 12: **Nemrcs for a dragon in different environment**

As can be seen from the figure 12, the curves of Tropical rainforest, Savanna, Desert and semi-desert almost overlap, indicating that the energy consumed by a dragon in the three environments are similar. The lowest in the curve is Exterme desert, apparently because the harsh environment affects a dragon's survival. The highest in the curve is Swamp and wetland, indicating that a dragon is active here, which is also compatible with the survival of suitable animals in the wetland environment.

On the other hand, the diagram of the minimum area required by a dragon in different environments is as follows:

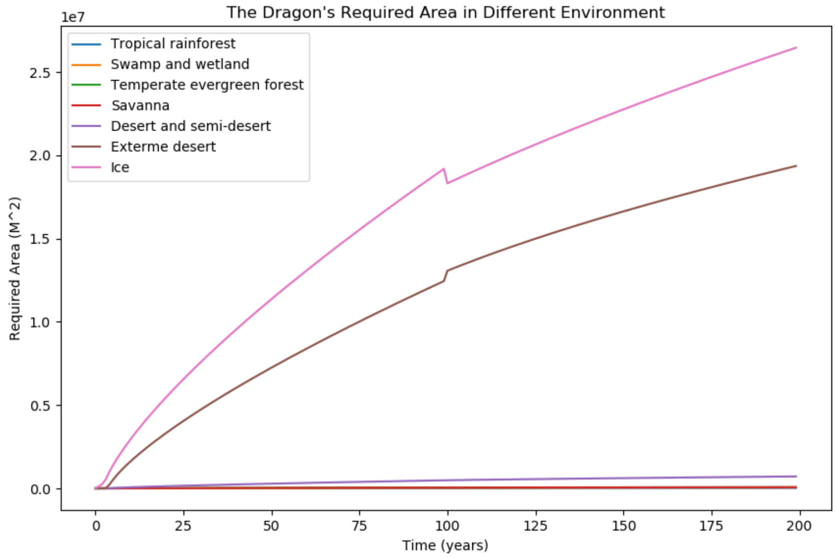


Figure 13: **Area required for a dragon in different environment**

As can be seen from Figure 13, it is clear that in two extreme environments (Exterme desert and Ice), a dragon has much higher environmental requirements than the others, so we can assume that a dragon cannot survive for a long time under such conditions. Similarly, the curves in the Desert and semi-desert environments are also much higher than in other environments, so we also cut them out and redraw the graph as follows:

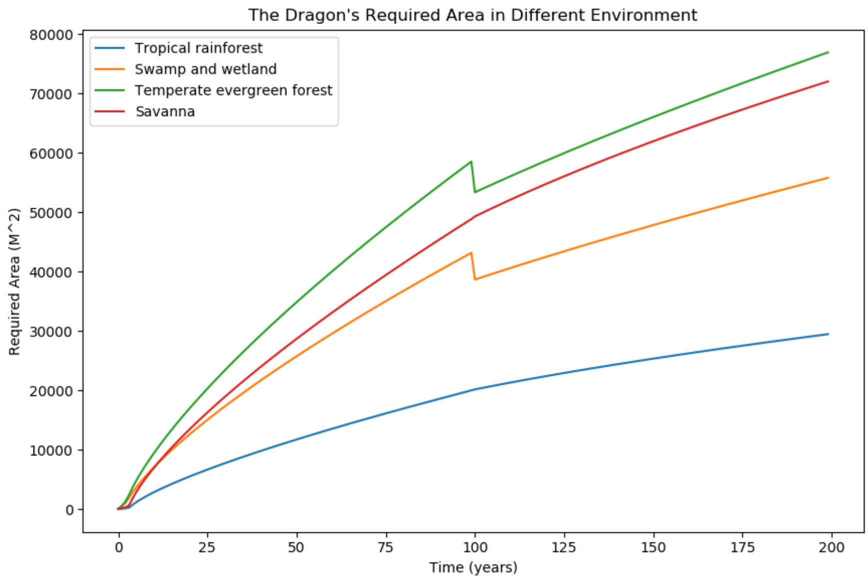


Figure 14: **Area required for a dragon in suitable environment**

As can be seen from the above figure, a dragon has the lowest living area requirement in the rainforest environment, which is also related to the high species richness of the rainforest.

In combination with Figure 12 and Figure 14, the most suitable environment for a dragon is the Tropical rainforest and Swamp and Wetland. A dragon can also migrate between various areas besides Exterme desert, Ice and Desert and semi-desert, and can guarantee their own survival. A dragon cannot stay in the above three special harsh environments for a long time. If it wants to stay for a long time, it must be accompanied by a person who is responsible for breeding, so as to ensure that the energy expenditure of a dragon is not affected by the environment.

VI.5 Community for a Dragon

A dragon has a large diet, no natural enemies, and will spurt fire when hunting. Therefore, it is necessary to ensure sufficient biodiversity to ensure high stability for the community that a dragon lives. At this point, the Tropical rainforest and the Temperate evergreen forest and the Swamp and wetland ecosystems are more suitable without considering fire breathing. But if a dragons prey by breathing fire, considering the frequency of predation, it will be devastating to these communities. Under the consideration of a dragon's fire-breathing prey, we have to consider a dragon living in the alpine region. Due to the lack of species in alpine areas, the growth of a dragon may bring about environmental disturbance and poor recovery ability. In this case, we boldly assume that a dragon constantly seeks suitable areas through migration, consume local resources, and continue to migrate when resources are exhausted.

VII Conclusion

Combining all the results of the problems obtained from the model, the most suitable living environment we finally give is the wetland (Swamp and wetland). We believe that for dragons, fire breathing is a defensive behavior rather than a predatory behavior. Therefore, the frequency of fire breathing is very low, so a dragon's suitable living environments are forest and wetland. Further considering that a dragon eats more in the wetland environment and grows better, and the occasional fire-breathing has less disturbance to the environment, so we think that the most suitable living environment is wetland.

VIII Strengths and Weaknesses

VIII.1 Strengths

- We work on the basis of the existing experimentally validated theory, and after simplifying and modifying the influence of relevant factors, the model can still be applied to cattle and other organisms, even if there are errors, the difference is not great.

- The data we use to modify the model are all from the actual data, which makes our conclusions real and credible.
- We have improved the existing model, adding the unique behavior of a dragon on the basis of the energy expenditure of ordinary organisms, deriving our model through the combination of the characteristics of different organisms, which is derived from reality and simulates imagination.
- The results of our model are basically in line with the growth law of normal animals, and the simulation of the environment is also in line with our general cognition of the natural environment. Therefore, our model can play a certain guiding role for the author who describes dragons, making the description of the dragons more authentic.

VIII.2 Weaknesses

- Our model does not consider the aging stage of a dragon, theoretically speaking, for the dragon DMI model, there must be this stage, but since the dragon is completely fictional, we cannot make an estimate of the specific expectancy of a dragon, so we did not consider this problem when building the model.
- We have a curve fault in the simulation of the area required for a dragon to survive. This shows that there are still some parameters not adjusted properly, so there is a discontinuous situation, which also is what we need to pay attention to in the future.

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