Ecological Modeling of Arrow Bamboo

GAO Duo1, Itzel Zamora-Vilchis2, YANG Wei3, ZHU Xiaowu1, ZHANG Tongli4
(Email abcduogao@163.com to contact GAO Duo)
1 Peking University, China;
2 James Cook University, Australia;
3 Cardiovascular Institute & Fu Wai Hospital, China;
4 Virginia Tech., USA

Abstract: Using three different models we demonstrated that global warming is a possible explanation of the decrements of arrow bamboos in Mount Shennongjia and we predict shifts upwards on the distribution of bamboos and a possible extinction under different scenarios (Temperature increments of 1.5°C, 4°C and 6°C) of global warming.

Keywords: Arrow bamboo; Agent-based model; Statistics Model; System Dynamics Model; Altitude; Temperature; Bamboo death

1 Introduction

Bamboos are widely distributed in the sub-tropics of China. A special species which has been used to make arrows in ancient Chinese is arrow bamboo (Fargesia spathacea). Arrow bamboo is special in modern days because it is almost the only food for another species in danger, the giant panda. And the bamboo has important ecological roles in these areas.

Bamboo is known to be one of the fastest growing plants in the world (Liese 1985; Janssen 1991). A single stem of bamboo from an established root system typically reaches full height in just one year, and then persists for several years, gradually increasing the number of side branches and branchlets. Its propagation takes in two forms. One is by seed. All the individuals of the species will flower at the same time in a large geographical region. After that, they give seeds and die. This is thought to have evolved to reduce the effect of predators of the seed, which would be unable to depend on a predictable food supply. The other propagation strategy is to spread through their rhizomes, which can spread widely underground and send off new culms to break through the surface.

The Shennongjia National Nature Reserve in Central China, where bamboo dominates the understorey of the forests in the mountain ranges, used to be a habitat of the giant panda. Studies (L. Zhao-hua, 2002; J. T. Houghton, 2001) on the population of arrow bamboos (Fargesia spathacea) of Mount Shennongjia (Fig. 1) report the death of arrow bamboo in areas where they used to be distributed (Fig 2). It is assumed that these decrements are caused by changes on the temperature and humidity conditions. It is accepted that contemporary climate change is already causing shifts in species distributions. This century we will experience an increase of 1.4°C to 5.8°C. Some researches suggest that arrow bamboo is very sensitive to temperature. So whatever for monitoring global climatic changes or for protecting rare animal giant pandas, it’s valuable to research the ecological environment and the death mechanism of arrow bamboo.
A number of recent studies have debated the significant of self-organization vs. natural selection as the cause of evolutionary change or adaptation (Depew&Weber, 1995; Kauffman, 1993; Maynard Smith, 1995; Saunders, 1994). Also, Lansing argued that system-dependent selection produces functional organization at the level of the system as a whole, rather than at the level of the individual organism. Lansing use James Lovelock’s model of the imaginary planet Daisy world to describe the unusual dynamics of this selective process and then use a similar model to examine the structure of an ancient system of wet-rice farming on the Indonesian island of Bali (Lansing, 1999). We absorb some ideas from these reference to explain the death of arrow bamboos.

2 Methodologies

To build ecological model of arrow bamboo, we adopted three methodologies, statistics model based on field study, system dynamics model and agent-based model.

With these different methodologies, we aimed at several different problems. Firstly, Using temperature as a principal variable, explain the decrements on the population of arrow bamboos of Mount Shennongjia. Secondly, determine the effect of climate change on the dynamic population of arrow bamboo of Mount Shennongjia. Thirdly, compare three kinds of research methodologies and find the way how to combine the three ways together.

3 Research Frameworks and Results

3.1 Statistics Model

Using an altitudinal abundance surveys of arrow bamboos in 2000 and 2001 in Mount Shennongjia (L. Zhao-hua, 2002.) we model the dynamics of arrow bamboo distribution and abundance under two different scenarios (Temperature increments of 1.5 °C and 6 °C). Specifically, we use expected upslope shifts in bamboo distribution with increasing temperature and empirical altitude-abundance patterns to predict change in the relative population size of species under a range of probable future climates (Shoo, L. P., Williams, S. E., Hero, J., 2005.).

The facts used in the model are shown as follows. The height of Mount Shennongjia is 3100 m, the actual distribution of bamboos is from 1600 m to 2500 m. Temperature decreased at a rate of about 1 °C per 200m altitude. Bamboos grow vegetatively for 40 years, flower and die back.

Both scenarios predict upward shifts of bamboo populations. The second scenario (+6 °C) also predicts serious declines of the population of bamboos (>50%). The projected range loss of the bamboo population would classify arrow bamboos as an endangered species (Fig 3) (Shoo, L. P., Williams, S. E., Hero, J., 2005.).
3.2 System Dynamics Model

This model we just use extended Logistic growth model to draw the phase plane of dynamics of bamboo-grass system (Fig.4). The system which supposes that temperature is constant is consisted of bamboo and grass, so the state of the system is specified by these two populations. Each point is a state of the system, and the picture shows how the systems evolutes from one state to another. And we can infer that the bamboo-grass system will try to stay at or stay near the two equilibrium point as possible as it can.

3.3 Agent-based Model

We use an agent-based model to simulate the effect of temperature on the amount of bamboo in the mountain. To simplify the situation, there is only one competitor of arrow bamboo in the model, grass. It is the main competitor in reality and we could think of “grass” as a deputy of all competitors, and its effect as their comprehensive effect. A 301*301 matrix of cells is used to represent the mountain. The cell in the center is the top of mountain, with the altitude of 3100m. The altitude of the cells drops according to their distance to the cell in the center (-11m/unit of distance). As the altitude drops, the temperature of each cell increases at 1℃/200m on average.
We’ve taken the slope direction and sunshine into consideration. So the temperature drops more quickly in the north direction and slower in the south direction. Each cell might be occupied either by arrow bamboo, grass or left blank. Basically, we built a cellular automata model. Three “species”, bamboo, grass and blank, compete with each other to decide the state of each cell.

And we have previously observed parameters that:
- The height of Mount Shennongjia is 3100 m, the actual distribution of bamboos is from 1600 m to 2500 m.
- Temperature decreased at a rate of about 1 °C per 200 m altitude.
- Bamboos grow vegetatively for 40 years, flower and die back.

Also, we have some model rules as follows based on biology of this species:
- 1. Every 40 years, arrow bamboo gives flower. The old bamboo dies and seed will grow into new bamboo;
- 2. In the first 4 years, bamboo that grows from the seed will not shoot new bamboo;
- 3. For the culms, only at the age from 3-6, their roots could shoot new bamboos in the neighboring cells;
- 4. Over the age of 10, the culms of arrow bamboo will die;
- 5. The cells are more likely to maintain their previous status;
- 6. The seed is heavy, so only the cells that have bamboo will have seeds;
- 7. The arrow bamboo and grass both have a range of temperature suitable for growth. But arrow bamboo is more sensitive to temperature change, and the seed is most sensitive;
- 8. If 3-6 neighboring cells have bamboos, the cell is more suitable for bamboos.

And Fig. 5 is an illustration of the main algorithm.

Fig. 6 can show the bamboo and other plants distribution based on simulation.

Fig. 7 and Fig. 8 can show the amount of bamboo at different altitudes, different temperatures and different years.
Fig. 6- The bamboo and grass distribution at year 1986 based on simulation. The red squares are arrow bamboo. Green is grass. Blue is clear space.

Fig. 7- The amount of bamboo at different altitudes. As temperature increases, bamboo “moves” to live at higher altitudes. At more dramatic temperature increase, bamboos gradually become extinction.
Fig. 8-The bamboo coverage changes over the next 3 periods of flowering in 4 scenarios of temperature changing. If the temperature increases 4°C over the next 100 years, arrow bamboo will extinct from the mountain at 2106. If the temperature increase is 6°C, bamboo extinct after 2 flowering periods in 2066.

4 Conclusion and discussion

Based on the above results we can conclude that the system dynamics model can show us the macro states of survival competition about bamboo-grass system; the statistics model can show us the upward shifts of arrow bamboo populations when there are two scenarios (Temperature increments of 1.5°C and 6°C) of global warming; and the agent-based model can show us the detailed competitive states of bamboo-grass system in each flower period of arrow bamboo, also, it can present the relationship of temperature change and areas deaths of arrow bamboo in detail.

Using these models we demonstrated that global warming is a possible explanation of the decrements of arrow bamboos in Mount Shennongjia. The models predict shifts upwards on the distribution of bamboos and a possible extinction of this species as a result of global warming. It is important to monitor the dynamics of arrows bamboos because it is clear that this species is very susceptible to global warming and also because many species of animals subsist entirely on a diet of bamboo and decrements or extinction of this species can become on the extinction of these animals. Species categorized as critically endangered, like giant pandas, are more susceptible of changes on the population dynamics of bamboos.
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6 References