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Simulation study on giant panda population dynamics model with due consideration for deforestation

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Abstract

Deforestation has destroyed the home of giant panda and poses a direct threat to their survival. Based on the idea of habitat protection of the trinity of "forest-bamboo-giant panda", a "forest-bamboo-giant panda" nonlinear dynamics model is established with due consideration for pulse deforestation. Computer numerical simulation is used to study the periodic solutions of this dynamics model and chaos strange attractor, and the ecological significance of the dynamic results. A threshold value in deforestation is thus obtained. That is, when the pulse intensity of deforestation is beyond a given threshold, the giant panda population will be almost extinct even though some forest still remains. When the pulse intensity of deforestation is within a given threshold, an ecological balance among "Forest-bamboo-giant panda" will kept for them to continue to exist.

Keywords: Dynamics model, giant panda, pulse, periodic solution, strange attractor

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1. Introduction

Wanglang National Nature Reserve in Sichuan was set up in 1965, one of the first four nature reserves to protect giant pandas and other rare wild animals and their habitats. The area is located in the alpine and canyon regions in West Sichuan in the northern edge of Hengduan Mountains, where Qinghai-Tibet Plateau and Sichuan Basin meet. The terrain tilts from the northwest to the southeast, a cutting-type-mountain mountainous region, with peaks rising one higher than another, high mountains and narrow valleys, and crisscross streams [1]. Currently, what poses a threat to the giant panda is habitat destruction,

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especially habitat degradation mainly due to human activities in today's social conditions which threaten the survival of giant pandas, rather than the direct disturbance of hunting or prey and competition, etc. Habitats are where animals inhabit, exist and multiply. Animals dwelling in this habitat have gradually adapted to the environment of the habitat with millions of years of natural evolution. They and their habitat interact and depend on each other to create a basic ecological system. Like all other wild animals, giant pandas' survival conditions, chances and quality must also be subject to the surrounding environment and its living resources. As the habitat is a decisive condition for the survival of wild giant pandas, it is necessary to carry out habitat theory and technology research to provide scientific evidence for protecting giant pandas. To this end, Li Junqing proposed the concept of habitat of "forest - bamboo - giant pandas" trinity. To establish a "forest - bamboo - giant pandas" trinity protection system [1-4] is key in giant panda protection.

Habitats can have different understandings, or different dimensions. First, the habitat must be an environmental space for giant pandas to live and multiply, including the forests where giant pandas dwell in, staple food bamboo and other natural environment suitable for survival. As giant pandas are forest animals, we have realized that deforestation has destroyed the home of giant pandas, a direct threat to their survival, the consequences of which are the same with direct killing even though deforestation is not meant to kill them. Moreover, even the update, growth and development of constructive species in the forest will have different degrees of impact on giant pandas, therefore, to protect the giant panda should first of all protect forests and the renewal and growth of important forest constructive species, that is, protect their habitats [5].

Both the establishment of dynamics model to study the giant panda survival and qualitative analysis and computer numerical simulation to give theoretical explanation of giant panda survival and extinction are of great theoretical significance [6-8] for the protection of giant pandas and their habitats. Li Junqing, in his habitat protection concept of the trinity of "Forest - bamboo - giant pandas" for Wanglang Nature Reserve, for the first time divides staple food bamboo into two phases: bamboo shoots and bamboo; divides the forest into two stages: sprouts (including saplings and seedlings) and trees, takes into account of the impact of deforestation, and establishes a description of "forest - bamboo - the giant panda" nonlinear dynamics model. Computer numerical simulation further proves Li Junqing's theory and practice [1-5].

2. Giant panda Population Dynamics Modeling

Staple food bamboo is divided into two stages: bamboo shoots and bamboo, where bamboo shoot density recorded as $Z_I(t)$ and $Z_M(t)$ denotes bamboo density. The forest is divided into two stages of sprouts (including saplings and seedlings) and trees, where sprout density denoted as $Q_I(t)$, tree density as $Q_M(t)$, and panda density as $x(t)$. With the help of model ideas and research methods in literature [9-13], the following "forest - bamboo - the giant panda" nonlinear dynamics model is built to simulate the dynamic relationship between forest, bamboo and panda.

According to the variation law of the three populations of forest, bamboo and giant pandas, the following hypotheses are put forward:

(A) The competitive relationship between bamboo shoots and sprouts;
(B) Bamboos update and grow under the shade of arbor forest;
(C) Trees provide a habitat for giant pandas, and give the necessary shade to bamboos;
(D) The growth of giant pandas staple bamboo limits the process of seedlings' update and addition;
(E) Deforestation is cyclical;
(F) The consequences of deforestation and direct killing of giant pandas is the same.

(G) $\exists t_k \in Z_+ = \{1,2,...\}$, $0 < t_1 < t_2 < \cdots < t_k < \cdots$ and $\lim_{t\to+\infty} t_k = +\infty$. Suppose $\alpha_k (k \in Z_+)$ has a positive integral q such that $t_{k+q} = t_k + \omega$, $\alpha_{k+q} = \alpha_k$, $0 < t_{k+1} - t_k < \omega$.
Under the above assumption，“forest - bamboo - the giant panda” nonlinear dynamics model is:

$$\begin{cases} \dfrac{dx}{dt} = \dfrac{b(t)x^3}{N(t)+x^2} - dx - ex^2 + a_{12}xZ_I + a_{13}xZ_M + a_{15}xQ_M, \\ \dfrac{dZ_I}{dt} = b_1(t)Z_M - d_1Z_I - a_1(t)Z_I - a_{21}xZ_I - c_{12}Z_IQ_I + r_1Z_IQ_M, \\ \dfrac{dZ_M}{dt} = a_1(t)Z_I - e_1Z_M^2 - a_{31}xZ_M + p_{12}Z_MQ_M, \\ \dfrac{dQ_I}{dt} = b_2(t)Q_M - d_2Q_I - a_2(t)Q_I - c_{21}Z_IQ_I - p_{21}Z_MQ_I, \\ \dfrac{dQ_M}{dt} = a_2(t)Q_I - e_2Q_M^2, \\ \left.\begin{array}{l} \Delta Q_I(t_k) = Q_I(t_k^+) - Q_I(t_k^-) = -\alpha_k Q_I(t_k^-) \\ \Delta Q_M(t_k) = Q_M(t_k^+) - Q_M(t_k^-) = -\gamma_k Q_M(t_k^-) \\ \Delta x(t_k) = x(t_k^+) - x(t_k^-) = -\delta\gamma_k x(t_k^-) \end{array}\right\} \quad t = t_k,\ k = 1,2,...,q, \end{cases} \tag{1}$$

Where $b(t)$ stands for the birth rate coefficient of the giant panda population; $b_1(t), b_2(t)$ denote the birth rate of young bamboo and tree seedlings respectively; $N(t)$ denotes sparse coefficient; d, d_1, d_2 denote the death rate of giant pandas, young bamboo and tree seedlings respectively; e, e_1, e_2 denote the density restriction coefficient of giant pandas, young bamboo and tree seedlings respectively; $a_i(t)$, $i = 1,2$ denote the rate of the conversion of young bamboo and tree seedlings young into bamboo and trees respectively, and is ω periodic function; $r_{21}, a_{ij}, c_{ij}, p_{ij}$ are all constants greater than zero.

We can use Mawhin’s coincidence degree theory to prove that there exists a periodic solution to the system (1). As the method of proof is similar with that in [11-16], it is omitted here.

3. Numerical simulation of the model

Here are numerical simulation results, without loss of generality, the model (1) coefficients selected as follows:

$$\begin{array}{lllll} b_0 = 0.343, & b_1 = 0.644, & b_2 = 0.543, & b_{21} = 0.532, & b_{22} = 0.853, \\ d = 0.328, & d_1 = 0.126, & d_2 = 0.216, & c_{12} = 0.163, & c_{21} = 0.416, \\ e = 0.248, & e_1 = 0.275, & e_2 = 0.283, & p_{12} = 0.114, & p_{21} = 0.379, \\ s_0 = 0.853, & r_{21} = 0.143, & a_{12} = 0.165, & a_{13} = 0.122, & a_{15} = 0.152, \\ a_{21} = 0.165 & a_{22} = 0.376, & a_{31} = 0.127, & & \end{array}$$

$$b(t) = b_0(|\sin t| - \sin t),\ b_1(t) = b_1(1 + 0.5\cos t),\ b_2(t) = b_2(1 + 0.5\cos 2t),$$

$$a_1(t)=b_{12}(1-0.5\cos t),\, a_2(t)=b_{22}(1-\cos 2t),\ N(t)=s_0(|\sin t|-\sin t).$$

In model (1), let $t_k=nT,\ \alpha_k=\gamma_k=0.15,\ \delta=1.5$. The system cycle of model (1) is $\omega=\pi$ and the pulse period is T. In case of $T=\omega/3=2\pi/3$, then $q=3$, model (1) has one periodic solution of 3 pulses within one cycle (see Figures 1-7).

In model (1), let $t_k=nT,\ \alpha_k=\gamma_k=0.3,\ \delta=1.5.$ The system cycle of model (1) is $\omega=\pi$, and its pulse cycle is T. If $T=\omega/3=2\pi/3$, then $q=3,$ now, in model (1), time series of bamboos keeps periodic oscillation. Though time series of forest seedlings and trees are badly damaged when pulse gains intensity $\alpha_k=\gamma_k=0.3,\ \delta=1.5$, they still maintain the existence of periodic solutions (see figures 11-12). However, in this case, the giant panda population tends to be extinct (see Fig 8). In accordance with the theorem of existence of solutions of ordinary differential equations and continuous dependence of solutions on parameters, $\delta=1.5$ has only one threshold $\alpha_k^{\varepsilon}=\gamma_k^{\varepsilon}$ and gets $0.15\le\alpha_k^{\varepsilon}=\gamma_k^{\varepsilon}\le 0.3,$ then choose model initial conditions $x(0)=0.3,\ Z_I(0)=0.5,\ Z_M(0)=0.7,\ Q_I(0)=0.4,\ Q_M(0)=0.5.$

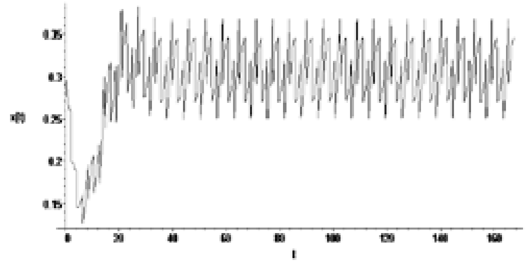

Fig 1. time series of giant panda population density $x(t)$

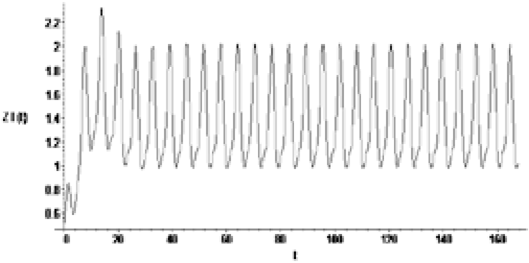

Fig 2. time series of bamboo shoot density $Z_I(t)$

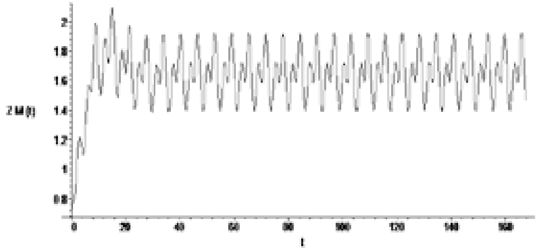

Fig 3. time series of bamboo density $Z_M(t)$

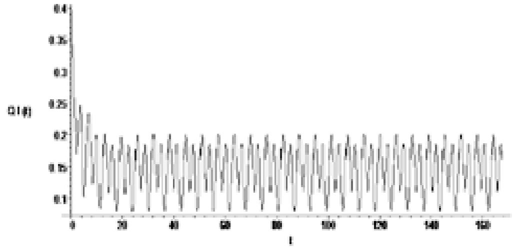

Fig 4. time series of forest sprout density $Q_I(t)$

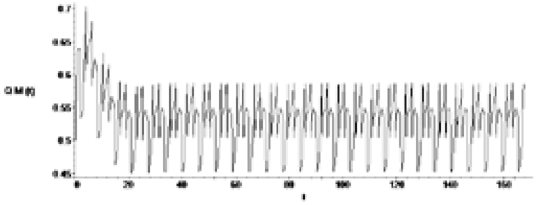

Fig 5. time series of forest density $Q_M(t)$

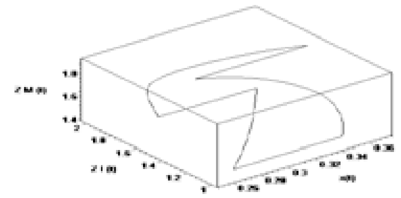

Fig 6. Phase diagram of $x(t)$, $Z_I(t)$ and $Z_M(t)$

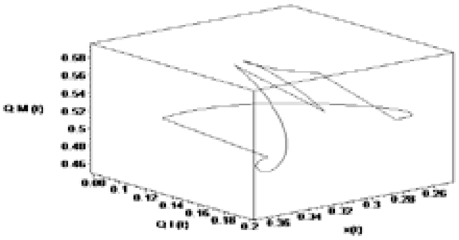

Fig 7. Phase diagram of $x(t)$ 、$Q_I(t)$ 和 $Q_M(t)$

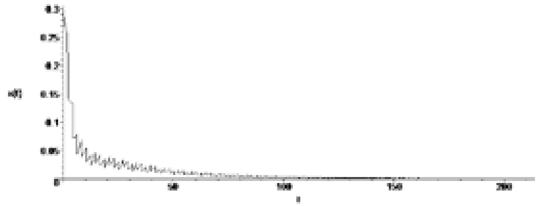

Fig 8. Time series of giant panda population density $x(t)$

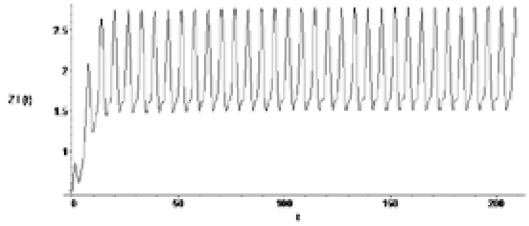

Fig 9. Time series of bamboo shoot density $Z_I(t)$

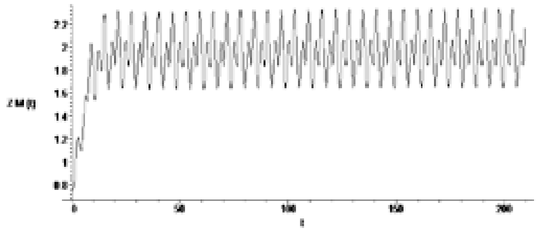

Fig 10. Time series of bamboo density $Z_M(t)$

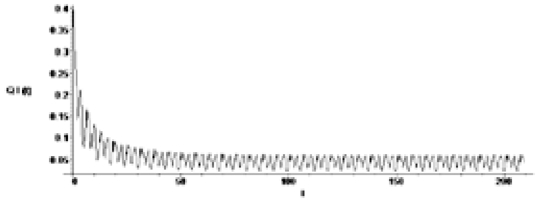

Fig 11. Time series of forest sprout density $Q_I(t)$

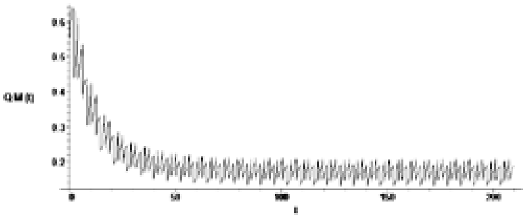

图12. Time series of forest density $Q_M(t)$

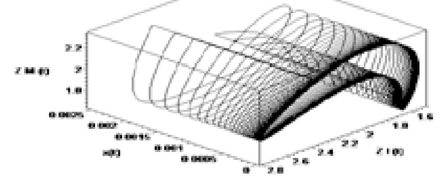

Fig 13. Phase diagram of $x(t)$, $Z_I(t)$ and $Z_M(t)$

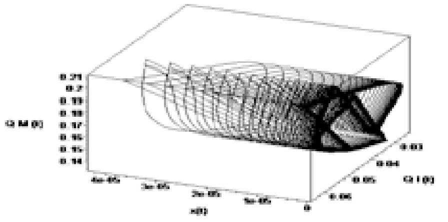

Fig 14. Phase diagram of $x(t)$, $Q_I(t)$ 和 $Q_M(t)$

In case of $T = 6$, the condition (7) will not be met, which is more realistic in reality. After numerical simulation, the periodic solution of model (1) will be destroyed. But the model (1) is found to have a kind of new chaotic strange attractors (known as Gui chaotic strange attractor [17, 18]), which is generated by pulse disturbance (see Figures 15-16, [11-18]). That chaotic strange attractors exist in "forest - bamboo -

the giant panda" nonlinear dynamics model is indicative of the complex ecological phenomena among giant pandas, staple bamboo food and forest. On the other hand, under the conditions that initial value is greater than zero, the density function of giant pandas, staple bamboo food and forest will not tend to zero over time (see Figure 15-16), indicating that the trinity habitat protection system will ensure an ecological balance between giant pandas, staple bamboo food and forest.

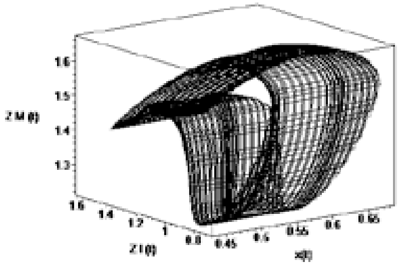

Fig 15.Chaotic strange attractor of model (1)

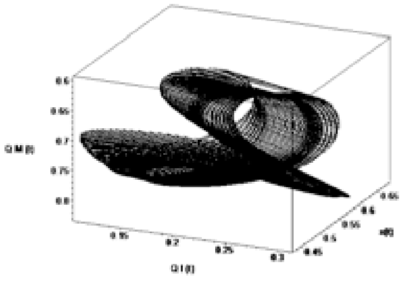

Fig 16. Chaotic strange attractor of model (1)

3. Discussion

Fuel wood collection activities exert a tremendous influence on the distribution of trees. Owing to specific historical and natural factors, there are many natural villages in the Nature Reserve and the neighboring areas, so their access to forest resources shall not be ignored at all for they live on forests. Protection of biological resources shall ensure ecosystem and sustainable use of biological species besides maintenance of essential ecological processes and life support systems to maintain genetic diversity. In other words, it is unscientific and unrealistic to simply prohibit human activities from the protected forest. As long as logging intensity coefficient is properly controlled less than the threshold, it is possible for giant pandas, staple food of bamboo and forest to have periodic solutions and chaotic strange attractors, and it is possible to ensure the survival of the three populations, that is, ecological balance. A harmonious forest environment maintained throughout among upper trees, staple bamboo food and shrubs in habitats suitable for giant pandas will provide shelter for this ancient species of giant pandas to survive and thrive.

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