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Computer numerical simulation of diffusion on the giant panda population dynamics models among small areas

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Abstract

Habitats of the giant panda, total area 80.04 km\textsuperscript{2}, in the Xiaoxiangling Mountains are distributed in Shimian County of Ya'an municipality, Mianning County of Liangshan Prefecture, Jiulong County of Ganzi Prefecture. Habitats of the giant panda in Shimian are the largest with 54.48% of total area and that of Jiulong County the smallest with 4.40%. Because of over-deforestation along the Tuowu Mountains and frequent anthropological activities, the giant panda population in Xiaoxiangling mountains has been separated into two parts, i.e. Population A and Population B. This environment of small regional (or patches, islands) is a potential threat to the diversity and the survival of biological species. For studying the influence of the diffusion of giant panda population among small areas on its permanence, building corridors and migrating the living environment of giant pandas are adopted to protect the giant panda. Thus, an nonlinear dynamic model of the giant panda habit in Xiaoxiangling Mountains is established. Using computer simulation, the periodic solutions and phase diagrams of the dynamical systems are drawn, and the numerical simulation results shows that: the diffusion of giant pandas will promote their permanence.

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1. Introduction

Giant Panda (Ailuropodia melanoleuca) is a flag species for biodiversity conservation in China. The protection of giant pandas and their habitat is an important step for the conservation of the integrity and stability of biological diversity and ecosystem function[1]. Because of rapid increase of human population
and overexploitation of forest resources, the ranges of the giant panda are shrinking, population size is declining, and habitats are fragmenting. Now they are occurring only in high mountains and steep valleys of the east edge of Qingzang plateau, i.e. Minshan, Qionglaishan, Daxiangling, Xiaoxiangling, Liangshan and Qinling. The giant panda populations living in these mountains have been separated completely. Even in one mountain system, where the giant panda is distributed, fragmentation of habitats and populations is severe.

Giant panda habitats in the Xiaoxiangling mountains are located within 17 towns of 3 counties and 3 nature reserves, including the Sichuan Yele Provincial Nature Reserve of Mianing County, the Sichuan Liziping Nature Reserve of Shimian County and the Shimian part of the Sichuan Gonggashan Nature Reserve. The residents, most of them are Yi and Zang (Tibetan) people, are living on forests resources. Economy is underdeveloped. There are panda habitats of 489.68 km² and population of 24 pandas in 3 reserves, which is, respectively, 61.05% of total habitats and 75.0% of total population in Xiaoxiangling mountains. In fact, they are a metapopulation of giant pandas, which consists of two populations distributing along both sides of No 108 National Highway. The nearest distance between traces of the individuals of both populations is 13.2 km. Population A is, to the east of No 108 National Highway, in the Sichuan Liziping Nature Reserve.

On the studies of the giant panda protection projects [3,4], we often face the fact that giant pandas sometimes migrate from one patch to another for finding food, mating, etc. In order to protect the rare species, we should investigate the circumstance of every patch and control the diffusive rates among different patches.

The organization of this paper is as follows. In the next section, a nonlinear dynamic model of the giant panda habit in Xiaoxiangling mountains is given. The periodic solutions and phase diagrams of the dynamical systems are drawn by using computer simulation. The biological meaning of the results obtained in Sections 2 are discussed in Section 3.

2. Dynamic Models

In order to explain our conclusion directly, at first, we now establish giant pandas models under the environment with two isolated habitats. Then, we suppose that the corridors between the two isolated habitats are established on purpose, which are supplied for giant pandas to spread and pass through between the habitats. Consequently, by comparing and contrasting, our arguments were advanced.

To solve the problem that was put forward in Section 1, we suppose that the ecosystem is composed of two isolated patches and occupied by a single species whose individual members have a life history that takes them through two stages, immature and mature. Further, breeding areas are damaged in Patch 2. Let \( P_{IA}(t) \) and \( P_{MA}(t) \) denote the density of immature and mature giant pandas populations in the patch of Population A, respectively; and \( P_{IB}(t) \) and \( P_{MB}(t) \) denote the density of immature and mature giant pandas populations in the patch of Population B, respectively. Let \( P_{IA}(0) \), \( P_{MA}(0) \), \( P_{IB}(0) \) and \( P_{MB}(0) \) be the observed value of \( P_{IA}(t) \), \( P_{MA}(t) \), \( P_{IB}(t) \) and \( P_{MB}(t) \) at initial time \( t = 0 \), respectively.

The model was deduced under the following assumption conditions.

\((H_i)\) The birth rate into the immature giant pandas population in Patch of Population A(B) is proportional to the existing mature population with proportionality[5,6]

\[
\frac{b_A(t)P_{MA}(t)}{N_A(t) + P_{MA}(t)} \left( \frac{b_B(t)P_{MB}(t)}{N_B(t) + P_{MB}(t)} \right).
\]
The death rate of the immature population in Patch of Population A(B) is proportional both to the existing immature population and to the square of it with proportionality constants \( d_A(d_B) \) and \( e_A(e_B) \), respectively.

The death rate of the mature population in the Patch of Population A(B) is of a logistic nature, i.e., proportional to the square of the population with proportionality \( c_A(c_B) \).

The rate of transition from immature individuals to mature individuals is proportional to the existing immature population with proportionality \( a_A(a_B(t)) \).

\( \tau_A(\tau_B) > 0 \) denotes the length of time from the birth to maturity of giant pandas population. Those immature individuals of giant pandas population born at time \( t - \tau_A(\tau_B) \) and surviving to the time \( t \) exit from the immature stage and enter into the mature population.

The models of giant pandas established by us under the habitat with two isolated islands are as following[7,8]

\[
\begin{align*}
\frac{dP_{IA}(t)}{dt} &= \frac{b_A(t)P_{MA}(t)}{N_A(t) + P_{MA}(t)} - d_A P_{IA}(t) - e_A P_{IA}^2(t) - a_A(t)e^{-\lambda t A} P_{MA}(t - \tau_A), \\
\frac{dP_{MA}(t)}{dt} &= a_A(t)e^{-\lambda A t A} P_{MA}(t - \tau_A) - c_A P_{MA}^2(t),
\end{align*}
\]

and

\[
\begin{align*}
\frac{dP_{IB}(t)}{dt} &= \frac{b_B(t)P_{MB}(t)}{N_B(t) + P_{MB}(t)} - d_B P_{IB}(t) - e_B P_{IB}^2(t) - a_B(t)e^{-\lambda B t B} P_{MB}(t - \tau_B), \\
\frac{dP_{MB}(t)}{dt} &= a_B(t)e^{-\lambda B t B} P_{MB}(t - \tau_B) - c_B P_{MB}^2(t).
\end{align*}
\]

We studied the model (1) by using the numerical simulation method and chose

\[
\begin{align*}
b_A &= 0.643, \quad N_A = 0.0153, \quad a_A = 0.465, \quad c_A = 0.253, \quad e_A = 0.248, \\
b_B &= 0.453, \quad N_B = 0.5367, \quad a_B = 0.143, \quad c_B = 0.176, \quad e_B = 0.453, \\
b_A(t) &= b_A([\sin 4t] - \sin 4t), \quad N_A(t) = N_A([\sin 4t] - \sin 4t), \quad a_A(t) = a_A(1 - 0.5 \sin 4t), \\
b_B(t) &= b_B([\sin 4t] - \sin 4t), \quad N_B(t) = N_B([\sin 4t] - \sin 4t), \quad a_B(t) = a_B(1 - 0.5 \sin 4t).
\end{align*}
\]

Figs.1-2 show that first habitat A is better suitable for survival of immature and mature Giant panda population, however, numerical simulation showed that continuous survival and periodical solution of population were destroyed and the population of Giant pandas in the second habitat B will be gradually extinct due to environmental destruction in it(see Fig.1-4).
If we establish a corridor connecting between two Giant pandas habitats, we further suppose:

\((H_0)\) Spaces between two isolated habitats are artificially connected, so Giant pandas can spread and crawl back and forth between two habitats. The net exchange of the mature population from Patch A(B) to Patch B(A) is proportional to the difference of the concentrations \(P_{MA}(t) - P_{MB}(t) \ (P_{MB}(t) - P_{MA}(t))\) with proportionality \(D_{AB}(t) \ (D_{BA}(t))\).

In this condition, the model is as following:

\[
\begin{aligned}
\frac{dP_{IA}(t)}{dt} &= \frac{b_A P_{MA}(t)}{N_A(t) + P_{MA}(t)} - d_A P_{IA}(t) - e_A P_{IB}(t) - a_A(t)e^{-\lambda_A \tau_A} P_{MA}(t - \tau_A), \\
\frac{dP_{MA}(t)}{dt} &= a_A(t)e^{-\lambda_A \tau_A} P_{MA}(t - \tau_A) - c_A P_{MA}(t) + D_{BA}(t)(P_{MB}(t) - P_{MA}(t)), \\
\frac{dP_{IB}(t)}{dt} &= \frac{b_B P_{MB}(t)}{N_A(t) + P_{MA}(t)} - d_B P_{IB}(t) - e_B P_{IB}(t) - a_B(t)e^{-\lambda_B \tau_B} P_{MB}(t - \tau_B), \\
\frac{dP_{MB}(t)}{dt} &= a_B(t)e^{-\lambda_B \tau_B} P_{MB}(t - \tau_B) - c_B P_{MB}(t) + D_{AB}(t)(P_{MA}(t) - P_{MB}(t)).
\end{aligned}
\]

(3)

By using numerical simulation, those figures explain that model (3) has the only periodical solution under this condition. The population in two habitats (A and B) can maintain survival due to spreading occurrence. The model explains that the restoration and extension of habitats are very important to protect wild Giant pandas (see figs.5-8).
3. Discussion

Our research indicates that the present most crucial problems are to reform the ecological environment of Giant panda habitats and the major threatening factors are the patchiness, fragment and island of wild Giant panda habitat. Although Giant panda natural reserve has been established for many years, the destructions to the existed habitats are still happened. The major reasons are that the natural reserve has no right of land use. According to on-the-spot investigation, a restoration plan about habitats should be scientifically worked out. The government should strengthen the protection extent to Giant pandas and really resolve the problem of land use for natural reserve. At the same time, under the intervention of government, such works as appropriately converting cropland to forest should be done. The management sections of natural reserve should have the right to make a requisition of partial agricultural land, pond and land. The part of residents living in the sound habitat of Giant pandas should move out of those regions. By establishing corridors, the habitats with patchiness, fragment and island are connected as much as possible, in order to extend habitats suitable for Giant panda survival. On the basis of above measures, the enforcement of the project on returning Giant pandas to nature is just in significance. Otherwise, under current ecological environment, no matter how many Giant pandas are returned to nature, wild Giant pandas will be extinct eventually.

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References

[1] Shen GZ, Xie ZQ, Feng CY. Influence of the Wenchuan Earthquake on Giant Panda Habits and Strategies for Restoration. Journal of Plant Ecology, 2008; 32(6): 1417-1425 (in Chinese).
[2] Ran JH, Zeng ZY, Wang HJ. A Survey of the Giant Panda Population and Habitats in the Xiaoxiangling Mountains. Acta Theriologica Sinica, 2005; 25(4): 345-350 (in Chinese).
[3] Yang Y. Giant panda’s moving habit in coping. Acta Theriologica Sinica 1994; 14 (1): 9-14 (in Chinese).
[4] Xun Y. State, disturbance and development of Chinese giant pandas. *Chinese Wildlife* 1990; 13 (6): 9-11 (in Chinese).

[5] Kuno E. Principles of predator-prey interaction in theoretical, experimental and natural population systems. *Advances in Ecological Research*, 1987; 16(2): 252-61.

[6] Bazytin AD. *Mathematical biophysics of interacting populations*. Nauka, Moscow; 1985 (in Russian).

[7] Gui Z, Ge W. The effect of harvesting on a predator-prey system with stage structure. *Ecological Modelling*, 2005; 187: 329-40.

[8] Gui Z. *Biological Dynamic Models and Computer Simulation*. Science Press, Beijing; 2005.