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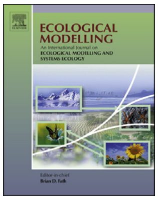

Giant panda survival crisis remains serious based on the ecosystem catastrophe model

Zhigang Yan, Junqing Li*

College of Forestry, Beijing Forestry University, 44#, Qinghua East Road, Haidian District, Beijing, 100083, PR China

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ABSTRACT

The habitat area of the giant panda and the number of wild populations have increased significantly over the past decade, while habitat fragmentation and survival crisis of local populations have become more serious. To assess the current survival status of the giant panda, we analyzed the Third and Fourth National Panda Survey data using trend line analysis, moving T-test, and catastrophe theory. The catastrophe potential function and the cusp catastrophe model were constructed to analyze the ecosystem stability. The results showed that over the past decade, each single index, such as habitat area or population size, increased, and the discreteness of local population size and habitat patch area improved. However, no substantial improvement was identified in discreteness, whereas ecosystem stability was weakened by severe habitat fragmentation and population isolation.

1. Introduction

The giant panda, as a highly specialized species, is highly vulnerable to habitat loss and fragmentation. Although global climate change is the primary force that drives population fluctuations through the years, human activities may also underlie the recent significant decline in population sizes (Zhao et al., 2013). The wild panda populations and habitats have been in continuous recovery due to several protection acts. Compared with the period of the Third National Panda Survey (T3NS, 1999–2003), the habitat area of wild pandas has increased by 2720 km^2 and the population size by 268 individuals during the period of the Fourth National Survey (T4NS, 2011–2014).

Although the habitat area and population size increased by 11.8% and 16.8%, respectively, some negative effects became prominent, including habitat fragmentation and human disturbance. The existing wild pandas are divided into 33 local populations, of which, 24 face a high risk of extinction and 18 include less than 10 individuals. Owing to the spatial isolation and human disturbance, panda habitat is severely fragmented (WWF, 2015). Therefore, the current survival status of pandas underlies a paradox; the population size and habitat area increases, whereas population isolation and habitat fragmentation become more serious.

The giant panda is adapted to a special forest ecosystem, in which understory bamboo species are an essential component (Tuanmu et al., 2013). The forest-bamboo-panda system includes co-evolution and interaction of the components (Shen, 2002). Thus, the local population size (LPS) and habitat patch area (HPA) can constitute a two-variable system (TVS). The survival risk evaluation of the wild panda population needs to be based on TVS rather than a single index such as habitat or population. Thus, the important issues for the protection of pandas include the state of TVS composed by a panda population and habitat as well as any changes in the state of TVS over the last decade.

Ecosystem degradation is often related to the stable state transition, which is closely related to the resilience of the ecosystem (Feng et al., 2009). Ecosystem resilience is associated with the ability of a system to recover from a disturbance (Wen and He, 1981). The ecosystem is resistant to state shifts and tends to maintain the current stable state because of the negative feedback. Serious perturbations are usually required to overcome ecological thresholds and drive shifts from one state to another. Thus, under certain environmental conditions, the ecosystem has two alternative stable states, separated by an unstable equilibrium that is the border between the "basins of attraction" of the two states (Scheffer et al., 2001).

Under substantial perturbations, an ecosystem switches from one resilient configuration to another, and slow ecological response processes occur simultaneously (Kharrazi et al., 2016). However, extreme changes and fast response processes may occur, leading to a catastrophe. Therefore, ecosystems have different responses to external disturbances.

In some cases, the response curve between the state of the ecosystem and the external action is smooth and continuous

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* Corresponding author.
E-mail address: lijq@bjfu.edu.cn (J. Li).

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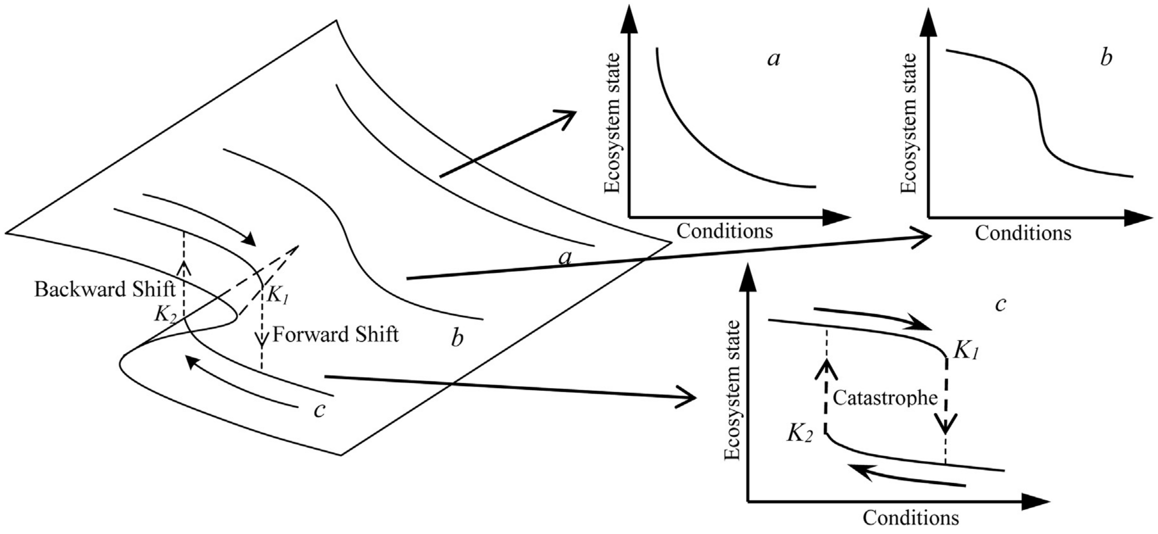

Fig. 1. Ecosystem response to external effects (adapted with permission from Scheffer et al., 2001. Copyright 2001NPG).

(Fig. 1a), whereas in other cases, minor changes cause a strong response to the system state, but the significant change is continuous and reversible (Fig. 1b). However, there is another response process in the ecosystem, which is discontinuous and irreversible, known as a catastrophe. As shown in Fig. 1c, if the system is at the upper stable state) and close to the bifurcation point K_1, a slight incremental change may induce a catastrophic shift to the lower alternative stable state ("forward shift"). If one tries to restore the upper stable state by reversing the conditions, the system shows hysteresis. A backward shift occurs only if the conditions are reversed far enough to reach the other bifurcation point K_2 (Scheffer et al., 2001).

Catastrophe is a characteristic of complex systems, which are hierarchical structures that include numerous interdependent subsystems. The subsystems have a synergistic, co-evolving, and strongly coupled relationship. Catastrophe is either referred to the property of the complex system or the subsystems within the complex system or the property of some certain sub-levels of the complex system or subsystems (Yan, 1993).

Catastrophes are bifurcations between different equilibria or fixed point attractors, and the catastrophe theory is a branch of the bifurcation theory in dynamic systems. The mathematical description of catastrophes includes discontinuous phenomena, called elementary catastrophes. The catastrophe theory studies the changes in the equilibria in relation to those in the control parameters. By changing some externally controlled parameters, the equilibrium state of a system is displaced. A small change in these parameters usually results in a small displacement of the equilibrium. In some cases, small changes result in the appearance of a new equilibrium or the disappearance of a previously existing equilibrium. It is the latter instance that can lead to a catastrophic sudden jump, and consequently, catastrophes are classified based on the number of control parameters that show simultaneous variation.

In the catastrophe theory, the system state at any moment is determined by n dependent variables ($x_1, x_2, \ldots, x_n$), and the system is controlled by m independent variables ($u_1, u_2, \ldots, u_m$). The x_i is called behavioral variable and the u_i control variable. Thom and Fowler (1975) showed that for a range of structurally stable conditions, the system exhibits discontinuous behavior (up to two behavioral variables and four control variables) and that only seven stable unfolding patterns and thus, seven elementary catastrophes are possible (Ghorbani et al., 2010). The different types of elementary catastrophes are listed in Table 1.

As a method of system analysis, the catastrophe theory mainly studies the overall stability of a system by some key parameters. In this study, we combined the trend line and moving T-test (MTT) using single index data to ensure the comprehensiveness of the analysis. The trend line was mainly used to analyze the overall distribution trend of discrete data based on each single index. By comparing the results of T3NS and T4NS, we aimed to identify changes that occurred over the past decade. MTT was used for each single index to determine the occurrence of abrupt changes within the data. The occurrence of an abrupt change indicates large data discreteness and thus, the occurrence of a qualitative change for the index. The discreteness of the index is important for system catastrophe. If the data are very concentrated, it indicates that the system is almost in a resting state and tends to an ideal stable state; therefore, a catastrophic change of the system is unlikely to occur.

2. Methods and data sources

2.1. Data sources

Pandas are currently restricted to the bamboo forests of six mountain ranges in Sichuan, Shaanxi, and Gansu provinces, China. These areas are also the region of the National Panda Surveys. T3NS and T4NS reflect the recent changes in panda population and habitat. Thus, LPS and HPA from previous surveys were used as the two main data sets. These data were mainly obtained from the two investigation reports, some related documents, such as *The Third National Survey Report on Giant Panda in China* published in 2006, *The Fourth National Survey Report on Giant Panda in China* reported in 2014, *The Pandas of Sichuan: The 4th Survey Report on Giant Panda in Sichuan Province* published in 2015, and several published reports (Jin et al., 2012; Zhang and Hu, 2003; Xu et al., 2006; Hu, 2000; Jin, 2008; Sun et al., 2006; Ran et al., 2006, 2005; Ran, 2004; Cao et al., 2008; State Forestry Administration, 2006, 2014; Sichuan Forestry Department, 2015). Due to technical limitations, the survey data did not include pandas under the age of 1.5. The temporal range of the data was from 1999 to 2014, and the spatial range was the six mountain ranges. LPS was expressed in individuals and HPA in km^2.

2.2. Independent statistical analysis based on single index

Without considering the relevance of survey data in time or space, each single index (LPS or HPA) was analyzed separately. Each