

Spatiotemporal Dynamics of a Memory-Diffusion Predator-Prey System with Two Delays and Nonlocal Competition*

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Abstract Predator gestation delay and memory period, along with nonlocal competition, play key roles in controlling population density and maintaining the stability of ecosystems. To control the population density of the Dendrolimus superans, which causes significant damage to forests, we propose a pest control system incorporating both two delays and nonlocal competition considering Holling II type functional response. We analyze the conditions for the existence of Hopf bifurcation and derive the normal form of Hopf bifurcation using multiple time scales method. Considering the biological significance, we employ appropriate parameters for numerical simulations. Furthermore, we find that varying habitat complexity parameters leads to different moduli of bifurcation periodic solutions. Especially, both two delays contribute to maintaining the stability of steady states.

Keywords Pest control model, two delays, Hopf bifurcation, nonlocal competition, habitat complexity

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1. Introduction

The Dendrolimus superans, a common forest pest, is widely distributed worldwide. Dendrolimus superans is found in Siberia and the Far East of Russia, northern Mongolia, northern Korea, China, and Japan. Due to its widespread distribution, rapid spread and strong reproductive capability, Dendrolimus superans causes significant damage to agriculture and forestry economies. The Dendrolimus superans primarily infests coniferous trees such as larch, pine, and spruce, with its larvae extensively feeding and causing severe damage to the trees, ultimately leading to widespread destruction and even large-scale mortality. It exhibits a cyclical pattern of outbreaks and is difficult to control, resulting in significant economic losses to the local agriculture and forestry sectors. Furthermore, the extensive reproduction and feeding of Dendrolimus superans disrupt the ecological balance of local forest ecosystems, impacting the survival and reproduction of other biological populations. The life cycle of the Dendrolimus superans consists of four stages: egg, larva, pupa,

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and adult, with the larval stage being the most destructive to forests. The spread mechanism of the *Dendrolimus superans* is illustrated in Fig.1: female moths exhibit a tendency to oviposit in healthy forest stands; however, in cases of poor stand health, they will migrate to adjacent healthy stands. (In the figure, the darker trees represent unhealthy trees, while the lighter trees represent healthy trees.)

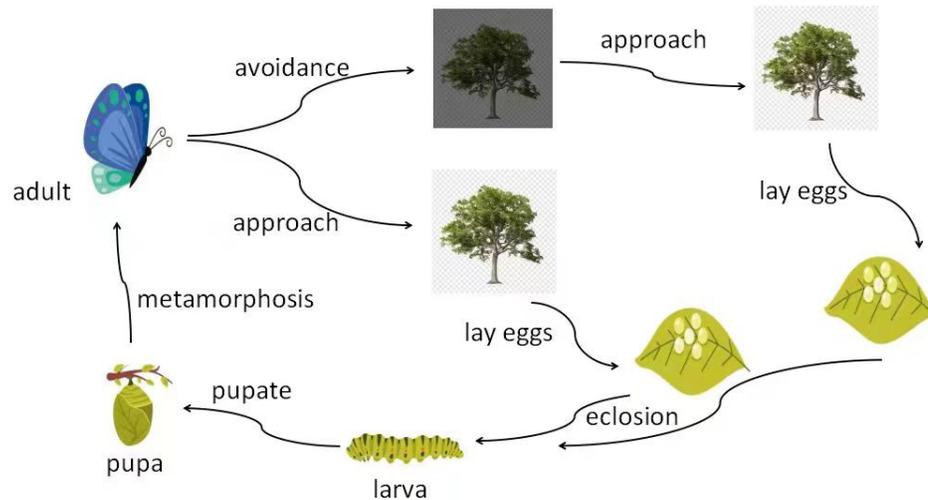


Figure 1. Spread mechanism of *Dendrolimus superans* infestation.

Three main methods are employed for the prevention and control of the *Dendrolimus superans*: physical control, chemical control, and biological control. Physical control primarily targets the behavioral patterns and characteristics of the *Dendrolimus superans*. It involves manual and simple tool interventions when the infestation area is small. However, this method requires a significant amount of manpower and resources, making it unsuitable for large-scale control of the *Dendrolimus superans*. Chemical control, on the other hand, is effective for large-scale infestations. Pesticides and other chemical agents are used to control the *Dendrolimus superans* [1]. Despite significant improvements in chemical control methods, they still pose certain risks to forest ecosystems and contribute to environmental pollution. Considering the principles of sustainable development and minimizing environmental damage, there is a growing interest in biological control. The natural enemies of the *Dendrolimus superans* can be classified into two categories: parasitic and predatory enemies. Parasitic enemies include species such as the Trichogrammatid and Tachinid fly, while predatory enemies include birds like the *Parus cinereus* and *Garrulus glandarius*, as illustrated in Fig.2.

In characterizing the relationship between the *Dendrolimus superans* and its natural enemies, we commonly employ predator-prey models, which are vital in the field of mathematical biology for studying the growth dynamics of two populations with predator-prey relationships. Scholars have continuously improved and refined these models in the past studies [2-7]. The flight range of adult female *Dendrolimus superans* is approximately 1 km, indicating limited dispersal ability. Hence, in