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A stage-structured Holling mass defence predator–prey model with impulsive perturbations on predators ☆

Jianjun Jiao [a,c,*], Xinzhu Meng [b], Lansun Chen [c]

[a] School of Mathematics and Statistics, Guizhou College of Finance & Economics, Guiyang 550004, People's Republic of China
[b] College of Science, Shandong University of Science and Technology, Qingdao 266510, People's Republic of China
[c] Department of Applied Mathematics, Dalian University of Technology, Dalian 116024, People's Republic of China

Abstract

In this work, we consider a stage-structured Holling mass defence predator–prey model with time delay and impulsive transmitting on predators. Sufficient conditions which guarantee the global attractivity of pest-extinction periodic solution and permanence of the system are obtained. We also prove that all solutions of the system are uniformly ultimately bounded. Our results provide reliable tactic basis for the practical pest management.

Keywords: Stage-structured; Time delay; Impulsive; Global attractivity; Permanence; Pest-extinction

1. Introduction

According to reports of Food and Agriculture Organization, the warfare between man and pests has sustained for thousands of years. With the development of society and progress of science and technology, man have adopted some advanced and modern weapons for instance chemical pesticides, biological pesticides, remote sensing and measure, computers, atomic energy, etc. Some brilliant achievements have been obtained. However, the warfare will never be over. Although a great deal of and a large variety of pesticide were used to control pests, the insect pests impairing crops are increasing especially because of resistance to the pesticide. With pesticides employed, the residual pests breed a large number of pests with resistance to pesticides. So the pesticide is invalid in some sense. Moreover, and insect pests will continue. On the other hand, the chemical pesticide kills not only pests but also their natural enemies. Therefore, insect pests are rampant again. Then effect of chemical control was challenged. Furthermore, the practice proves that long-term adopting chemical control may give rise to disastrous results, For example, environmental contamination and toxicosis of the man and animals and so on.

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* Corresponding author.
E-mail addresses: jiaojianjun05@126.com (J. Jiao), lschen@math.ac.cn (L. Chen).

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The use of natural enemy to suppress pests is one of the most important approaches in pest control. Biological control [3,4,24–27,29] is the purposeful introduction and establishment of one or more natural enemies from region of origin of an exotic pest, specifically for the purpose of suppressing the abundance of the pest in a new target region to a level at which it no longer causes economic damage. Virtually all insect and mite pests have some natural enemies. One approach to biological control is augmentation, which is manipulation of existing natural enemies to increase their effectiveness. This can be achieved by mass production and periodic release of natural enemies of the pest, and by genetic enhancement of the enemies to increase their effectiveness at control. The pioneering project of biological control began in 1888 when the new legendary predator, the vedalia beetle was imported from Australia and established in California, where it rapidly suppressed populations of cottony cushion scale that had been decimating the developing citrus industry [28]. Further, the biological control method is harmless to the man, animals and environments.

In the natural world, there are many species (especially insect) whose individual members have a life history that takes them through two stages, immature and mature. In [17], a stage-structured model of population growth consisting of immature and mature individuals was analyzed, where the stage-structured was modeled by introduction of a constant time delay. Other models of population growth with time delays were considered in [5,6,16–20,23]. For the above discussion. Then, we consider a stage-structured pest management predator–prey system with time delay and impulsive transmitting predators. It can be more appropriate to the nature of the pest management. We will obtain the sufficient conditions for the global attractivity of pest-extinction periodic solution and permanence of the system. Our results provide reliable tactic basis for the practical pest management.

2. Model formulation

The stage-structured model was analyzed in the literature [7–15]. The stage-structured model is described by the equation

$$\begin{cases} x'(t) = \beta_1 y(t) - rx(t) - \beta_2 x(t) - \eta_1 x^2(t), \\ y'(t) = \beta_2 x(t) - r_2 y(t) - \eta_2 y^2(t), \end{cases} \tag{2.1}$$

where $\beta_1, \beta_2, r, r_2, \eta_1, \eta_2$ are positive constants, $x(t), y(t)$ denote the immature and mature populations densities, respectively, to model stage-structured population growth. The birth rate of immature population is β_1. The death rate of the immature and the mature are r, r_2, respectively. The immature's transformation rate of mature is β_2. The immature and mature population are all density restriction $(\eta_1 x^2(t), \eta_2 y^2(t))$.

The following system was introduced by Aiello and Freedman [15] as a model for single-species stage-structured dynamics:

$$\begin{cases} x'(t) = \beta y(t) - rx(t) - \beta e^{-r\tau} y(t-\tau), \\ y'(t) = \beta e^{-r\tau} y(t-\tau) - \eta_2 y^2(t), \end{cases} \tag{2.2}$$

where $x(t), y(t)$ represent the immature and mature populations densities respectively, τ represents a constant time to maturity, and β, r and η_2 are positive constants. This model is derived as follows. We assume that at any time $t > 0$, birth into the immature population is proportional to the existing mature population with proportionality constant β. We then assume that the death rate of immature population is proportional to the existing immature population with proportionality constant r. We also assume that the death rate of mature population is of a logistic nature, that is, proportional to the square of the population with proportionality constant η_2.

And there are many works concerning predator–prey system, and many good results are obtained [14–16,18–23]. The basic predator–prey model which we consider is based on the following Lotka–Volterra predator–prey system:

$$\begin{cases} x_1'(t) = x_1(t)(r - ax_1 - bx_2(t)), \\ x_2'(t) = x_2(t)(-d + cx_1(t)), \end{cases} \tag{2.3}$$