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On a Juvenile-Adult Model: The Effects of Seasonal Succession and Harvesting Pulse

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Abstract. In this paper, a juvenile-adult population model incorporating seasonal succession and pulsed harvesting is developed. The seasonal succession captures the cyclical change between favorable and unfavorable environmental conditions, while the pulsed harvesting represents a periodic human intervention, targeting the adult population exclusively during favorable seasons. The principal eigenvalue for the corresponding linearized system is defined and its dependence on both the intensity of the harvesting pulses and the duration of the unfavorable season is analyzed. Explicit expressions and analysis of the principal eigenvalue for a logistic model extended with seasonal succession and pulsed harvesting are provided specifically. Based on the principal eigenvalue, we establish sufficient conditions for population persistence and extinction. Numerical simulations are conducted to validate these analytical results. Our findings demonstrate that higher harvesting intensity during the favorable season is detrimental to species survival. Furthermore, extending the duration of the unfavorable season can trigger a critical transition from population persistence to extinction.

AMS subject classifications: 35R12, 35R35, 92D25

Key words: Age-structured model, seasonal succession, harvesting pulse, persistence, extinction.

1 Introduction

This paper presents a juvenile-adult model with seasonal succession and harvesting pulses exerting on adults in favorable seasons, of the following form:

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$$\begin{cases} u_{1t}-d_1u_{1xx}=bu_2-(a+m_1)u_1-\alpha_1u_1^2, & t\in\Omega^r_{n,\rho}, \quad x\in(-L,L), & \text{(1.1a)}\\ u_{2t}-d_2u_{2xx}=au_1-m_2u_2-\alpha_2u_2^2, & t\in\Omega^r_{n,\rho}, \quad x\in(-L,L), & \text{(1.1b)}\\ u_{1t}=-k_1u_1, & t\in\Omega^l_n, \quad x\in(-L,L), & \text{(1.1c)}\\ u_{2t}=-k_2u_2, & t\in\Omega^l_n, \quad x\in(-L,L), & \text{(1.1d)}\\ u_1\big((n\tau+(1-\delta)\rho\tau)^+,x\big)=u_1\big(n\tau+(1-\delta)\rho\tau,x\big), & x\in(-L,L), & \text{(1.1e)}\\ u_2\big((n\tau+(1-\delta)\rho\tau)^+,x\big)=hu_2\big(n\tau+(1-\delta)\rho\tau,x\big), & x\in(-L,L), & \text{(1.1f)}\\ u_i(t,-L)=u_i(t,L)=0, & t\in(0,+\infty), & \text{(1.1g)}\\ u_i(0,x)=u_{i,0}(x), \quad i=1,2, & x\in[-L,L], & \text{(1.1h)} \end{cases}$$

where, for $n=0,1,2,\ldots,$

$$\Omega^r_{n,\rho}=\big(n\tau,n\tau+(1-\delta)\rho\tau\big]\bigcup\big(\big(n\tau+(1-\delta)\rho\tau\big)^+,n\tau+(1-\delta)\tau\big],$$
$$\Omega^l_n=\big(n\tau+(1-\delta)\tau,(n+1)\tau\big]$$

with $\rho,\delta\in(0,1)$, and harvesting coefficient $h\in(0,1]$, so $(1-h)\in[0,1)$ is naturally used to characterize the harvesting rate on adults. The unknown $u_1(t,x)$ and $u_2(t,x)$ are the densities of juveniles and adults, respectively, and the positive constants d_1 and d_2 are the diffusive rates of juveniles and adults, respectively. b denotes the reproduction rate of adults and a is the rate at which juveniles mature into adults. m_1 and m_2 represent the death rates of juveniles and adults. α_1 and α_2 denote the competition coefficients of juvenile and adult individuals, respectively. Biologically, species experiences two different seasons, one favorable and one unfavorable, which we call the good season (warm season) and the bad season (cold season), in accordance with standard literature. $\Omega^r_{n,\rho}$ can be regarded as a good season (or warm days) that is beneficial for species diffusion and the species development is governed by a logistic equation, while Ω^l_n is a bad season arising from limited resources such as food and cold weather that cause a decline in the species density. Here the species development is governed by a Malthusian equation, where positive constants k_1 and k_2 are the mortality rates of juveniles and adults in the cold season, respectively. $u_2((n\tau+(1-\delta)\rho\tau)^+,x)$ with $0<\rho<1$ describes the density of the adults after being harvested at time $t=n\tau+(1-\delta)\rho\tau$ in the good season. To make it clear, we here present Fig. 1 to show the impact of the harvesting pulse and seasonal succession on adults.

It is widely recognized that environmental fluctuations over time significantly influence species' growth and developmental processes [1,4,8,12]. Notably, seasonal variations not only alter species growth patterns but also play a pivotal role in shaping community structures. A case of this is observed in temperate lakes, where phytoplankton and zooplankton thrive during warmer months before entering dormancy or perishing in winter [2,7].

To explore how seasonal succession impacts population dynamics, researchers such as Steiner *et al.* [21], Hu and Tessier [9] conducted extensive experiments, gathering data