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Double time-delays induced stochastic dynamical characteristics for a metapopulation system subjected to the associated noises and a multiplicative periodic signal☆

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ABSTRACT

In this paper, we aim to investigating in detail the stability of the system, the mean extinction time and stochastic resonance (SR) phenomena caused by a multiplicative periodic signal for a dual time-delayed metapopulation system subjected to cross-correlated noises. By use of the fast descent method, the small time delay approximation method and the SR theory, we obtain the expressions of the steady state probability distribution function, the mean first-passage time and signal-to-noise ratio (SNR). Numerical results indicate that the multiplicative, additive and association noises together with time delay τ can all accelerate the transition from the stable state of big density to the extinction one and play significant roles in weakening the stability and shortening the mean extinction time of the metapopulation. In particular, the additive noise and time delay τ can result in the crash of the system, while another time delay θ can strengthen the biological system stability and extend the declining time for the population. On the other hand, with respect to the SNR, the figures show that time delay τ plays entirely antipodal roles in motivating stochastic resonance (SR) in a variety of different situations. Conversely, the multiplicative noise intensity Q and time delay θ all along produce negative effect on exciting the SR. Meanwhile, the increase of the weak additive noise intensity M can stimulate the SR phenomenon, but the bigger values of M will suppress the SNR and SR phenomenon. The strength of the noise correlation λ plays an important role in restraining the SR in most cases except that it does in the plot of SNR-Q.

1. Introduction

Over the past several decades, stochastic resonance (SR) as a kind of interesting nonlinear phenomena where noise plays a crucial role in a lot of systems [1–7] has drawn more and more attention from the physicists and biologists. Until now, the research on the SR has been extended into all kinds of interdisciplinary areas. For example, it is involved in physics, biology, neuroscience, and information processing [1–10] and so on. To this day, the conception of the SR has been expanded to a great number of different mechanisms. Simultaneously, a great deal of new application with novel types of SR has been founded [1–20]. Nicolis has originally given a theoretical description for the SR effect in a bistable system on the basis of a two-state model [3]. Later, McNamara and Wiesenfeld applied the output signal-to-noise ratio (SNR) metric to acquiring the behavior of SR, that is, a non-monotonic function of the background noise intensity [4]. From then on, the SNR has been often employed for exploring conventional (periodic) SR effects in a variety of nonlinear (static or dynamic) systems excited by a subthreshold periodic input. The SNR gain, which is named the ratio of the output SNR over the input one, has drawn a lot of interest in exploring situations where it can exceed unity [5–16]. Within the framework of the linear response theory, it has been once again noted that the gain cannot surpass the unity for a nonlinear system excited by a sinusoidal signal and Gaussian white noise [1,5,17,18]. Whereas, beyond the region in which the linear response theory are applied, we discover that in fact the gain can often exceed unity in non-dynamical systems, such as a

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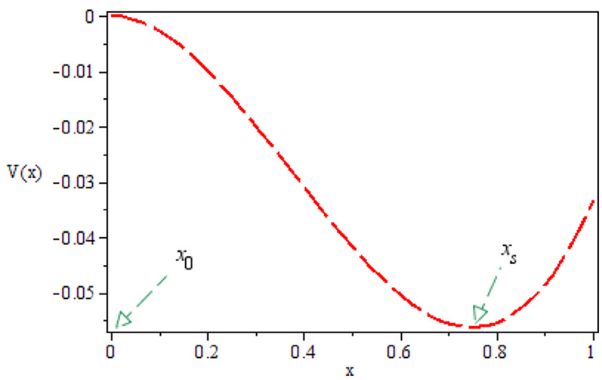

Fig. 1. The monostable potential $V(x)$. The parameters take $c = 0.8, e = 0.2$. The stable statesis$x_s = 1 - e/c$, and one unstable state is $x_0 = 0$.

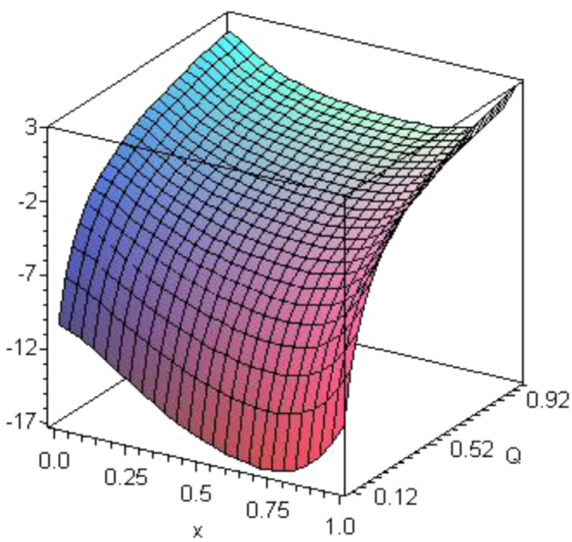

Fig. 2. Three-dimensional diagram of the generalized potential $U(x)$ versus x and Q with the other parameters taking $\lambda = 0.5$, $M = 0.03, \theta = 0.3, \tau = 0.3, c = 0.8, e = 0.2, A = 0.0$.

level-crossing detector [8], parallel arrays of threshold comparators or sensors [11,12], and also in bistable dynamical systems [7,9,13–16,19].

There exist a lot of stochastic systems with time-delayed feedback in the natural world. Time-delay feedback is a fundamental phenomenon in many science areas, especially in physics and biology [21]. The instant evolution of a system including delayed feedback not only depends on the current value of state variables, but also on the past ones. Time-delay feedback appears in a large number of nonlinear systems such as optical resonators [22–24], chemical reactions [25], biological [26,27] and artificial [28] neural nets, and genetic and other physiological control systems [9,10]. The significance of delayed feedback has been extensively explored in chaos control [24,31], chaos communication [23], and anticipatory chaos control [32]. Memory effects induced by delay feedback act on the dynamics significantly when the correlated delays are equal with or longer than the time scales of the system excluding delay feedback. A lot of such feedback systems, including excitable biological or optical systems are excited by noise and periodic inputs [33]. The impact of noise on the switching behaviors of threshold systems has drawn increasing interest in the fields of coherence resonance (CR) [35,43] and stochastic resonance (SR) [29,30,34,36–40]. Recently, much research for the enhancement by noise of the oscillations in a network of delayed-coupled oscillators [41] and in a bistable discrete-time stochastic map [42] has been made.

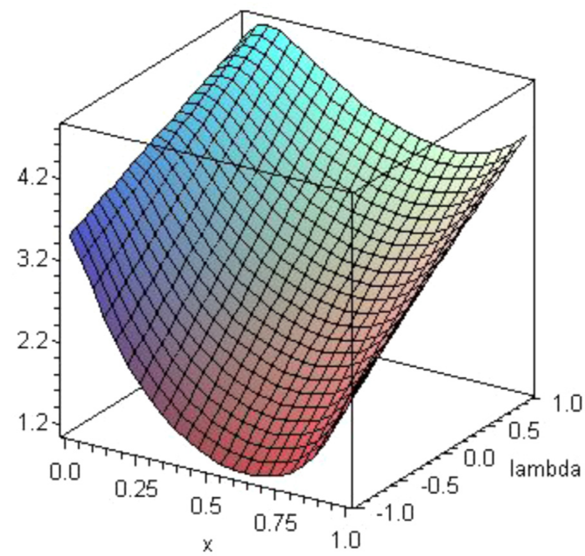

Fig. 3. Three-dimensional diagram of the generalized potential $U(x)$ versus x and λ with the other parameters taking $M = 0.03, Q = 0.1, \theta = 0.3, \tau = 0.3, c = 0.8, e = 0.2, A = 0.0$.

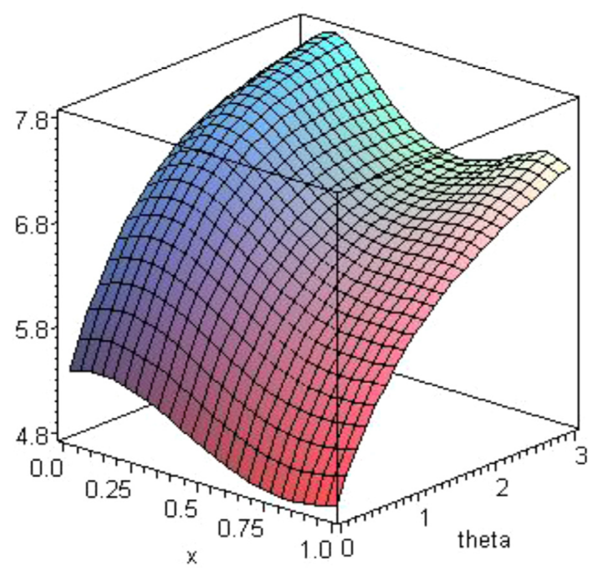

Fig. 4. Three-dimensional diagram of the generalized potential $U(x)$ versus x and θ with the other parameters taking $\lambda = 0.5, Q = 0.1, \tau = 0.3, c = 0.8, e = 0.2, M = 0.03, A = 0.0$.

In this paper, the shift behaviors between the large steady state and the extinction one, the mean extinction time and the SR phenomenon for a metapopulation system with double time delay terms which is subjected to the excitation of a multiplicative periodic signal, the correlated multiplicative and additive noises are investigated comprehensively. In Section 2, we introduce a stochastic metapopulation system disturbed by dual time delays and correlated Gaussian noises. In Section 3, we discuss in detail the biological system stability and the mean extinction time for the population due to the disturbance of different noises and time delays. In Section 4, we investigate all kinds of SR phenomena for the metapopulation system caused by the terms of time delay, the external and the internal noises. In the final section, we give a detailed summary for the above discussion on the biological dynamics of the population system.