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ScienceDirect
BioSystems 93 (2008) 211–217
Bio Systems
www.elsevier.com/locate/biosystems

Monitoring environmental change in an ecosystem

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Received 25 February 2008; received in revised form 21 April 2008; accepted 25 April 2008

Abstract

The monitoring and analysis of the processes taking place in an ecosystem is a key issue for a sustainable human activity. A system of populations, as the biotic component of a complex ecosystem is usually affected by the variation of its abiotic environment. Even in nearly natural ecosystems an abiotic effect like climatic implications of global warming may cause important changes in the dynamics of the population system. In ecosystems involving field cultivation or any industrial activity; the abiotic parameter in question may be the concentration of a substance, changing, e.g. as a result of pollution, application of a pesticide, or a fertilizer, etc. In many cases the observation of the densities of each population may be technically complicated or expensive, therefore the question arises whether from the observation of the densities of certain (indicator) populations, the whole state process of the population system can be uniquely recovered. The paper is aimed at a methodological development of the state monitoring, under the conditions of a changing environment. It is shown, how the technique of mathematical systems theory can be applied not only for the approximate calculation of the state process on the basis of the observed data, even under the effect of an exogene abiotic change with known dynamics; but in certain cases, also for the estimation of the unknown biological effect of the change of an abiotic parameter. The proposed methodology is applied to simple illustrative examples concerning a three-species predator–prey system.

Keywords: Environmental monitoring; Observer system; Ecosystem

1. Introduction

Detection of the effect of human activities (e.g. pollution) and environmental change such as climatic variation, is an important part in the analysis of a *composite system*, *including ecological, human and environmental subsystems*. The effect of such factors on the parameters of population system models has been studied by several authors, see e.g. Gragnani (2002) and Xia (2007). The problem we consider is the following: suppose we know that an abiotic change has an effect on the parameters of a population system, we want to estimate, at the same time both the whole state process and the change of the mentioned parameters, observing the densities of certain indicator populations.

For the solution of this problem a constructive method is proposed. Mathematical systems theory offers appropriate concepts and technique for the development of such a methodology. The methodological foundations of the application of controllability and observability to frequency-dependent population models (described by systems with invariant manifold), have been set in Varga (1989) and Varga (1992), see also Scarelli and Varga (2002). The original problem of state monitoring of a population system as formulated in Varga et al. (2003) is that, from the observation of the time-dependent densities of certain species, the whole state process of the population system is to be recovered. An important concept for the solution of this problem is *observability*. The latter in this context means that *from the observation of one or several (but not all) state variables, it is possible to recover the whole state process of the populations system, in a unique way* (without determining, however, a constructive method to obtain this process). Observability has been analysed in different population system models in Varga et al. (2002, 2003) and Shamandy (2005), see also López (2003) and López et al. (2004). In order to prove observability, we use a general sufficient condition for local observability of nonlinear observation systems, published in Lee and Markus (1971). For a general review on the application of mathematical systems theory in population biology, see Varga (2008).

Once local observability near an existing equilibrium is proved, we also need a constructive method for the estimation

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doi:10.1016/j.biosystems.2008.04.012