ECOLOGICAL MODELLING 200 (2007) 183–188

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Measuring q-bits in three-trophic level systems

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ARTICLE INFO

Article history:
Received 2 August 2005
Received in revised form
29 May 2006
Accepted 4 July 2006
Published on line 22 August 2006

Keywords:
Herbivores
Information
Population
Predator
q-Bits
Three-trophic system

ABSTRACT

The use of quantum information has been proposed as an approach to deal with biological data (Piqueira, J.R.C., Serboncini, F.A., Monteiro, L.H.A., 2006. Biological models: measuring variability with classical and quantum information. J. Theor. Biol. 242 (2), 309–313). Using three-trophic level systems as examples, we show how to model population data by expressing the system states with q-bits. The system time evolution is given by the state transition matrices which relate the states to successive time intervals. It is a complementary way of looking at the problem which is usually modeled with deterministic differential equations. This is possible because the dynamics of interacting populations in three-trophic level systems is a problem with several coupled variables and, consequently, complex dynamical behaviors seem to result. The non deterministic dynamics generated by the state transition matrices is supposed to model the biological system as a whole, with real data expressing even the global effects of small disturbances in the ecological parameters.

1. Introduction

A discussion with long tradition in ecology is one of population dynamics in three-trophic systems, i.e., systems composed of plant, herbivores and predator (Hunter and Price, 1992; Halaj and Wise, 2001).

Modeling population problems with the use of deterministic ordinary differential equations is an approach inspired by Classical Mechanics and successfully applied to Biology (Murray, 2002). For trophic structures in ecosystem models, there have been several well conducted studies in such a way (Pahl-Wostl, 1997; Sazykina et al., 2000).

This work meant to be an alternative methodological idea to deal with biological data considering the Quantum Mechanics formalism, while it describes a system under study as a whole. Population data are converted in probabilities and the state of the system in each time interval can be expressed by a linear combination of orthogonal states $|0\rangle$ and $|1\rangle$. The time evolution between two successive states is expressed by state transition matrices, which capture the variability of the system, including effects of small disturbances on parameters that appear as fluctuations in the state transition matrices (Piqueira et al., 2006).

In order to elucidate the procedures, we have used data collected from two systems that, in a simplified version composed of plants, their main herbivores and the main predators found in the plants, are supposed to be three-trophic. They occur in a tropical ecosystem, a mesophytic semi-deciduous forest at Japi Mountain, in São Paulo State,

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doi:10.1016/j.ecolmodel.2006.07.006

South-East Brazil. This ecosystem has a well-defined climatic variability: there is a wet and hot season from November to March, and a dry and cold season from April to September, with a transition season between September and October.

The former system consists of plant *Desmodium discolor* Vog. (Fabaceae: Papilionoideae), herbivores *Urbanus* spp. (Lepidoptera: Hesperiidae), and predator *Runcinioides argenteus* (Araneae: Thomisidae). The latter is composed of plant *Desmodium uncinatum* (Jacg.) DC. (Fabaceae: Papilionoideae) and the same herbivores and predator of the former one.

Actually, the diet of spider *R. argenteus* is not restricted to herbivores *Urbanus* spp. but, as it is the main predator in the system considered here, its abundance plays a relevant role in the larvae dynamics,which allows us to consider the plant–larvae–spider as a tri-trophic system.

A common feature of both plants, *D. discolor* and *D. uncinatum*, is the presence of hooked trichomes: in *D. discolor*, these trichomes are located in the leaves, while in *D. uncinatum* they are concentrated in the stems. These hooked trichomes act as a mechanical defense against herbivores since trichomes make it difficult for herbivores to move through the plant or even trap some of them, and this effect is stronger in *D. uncinatum*. Herbivores caught by trichomes die of starvation or are eaten by predators that can walk along the plant without being caught by trichomes.

By using concepts from Quantum Information Theory (Bennett and Di Vincenzo, 2000; Hirvensalo, 2001; Piqueira, 2004; Piqueira et al., 2006) we have expressed the data as states of the systems in q-bit notation, i.e., linear combinations of orthogonal states $|0\rangle$ and $|1\rangle$. Adjusting the data with evolution algorithms, we have estimated the transition state matrices that express the dynamical behavior of plants, herbivores and spiders for each given system.

When we examine the theoretical evolution of the systems described by the calculated transition matrices and compare the results with the measured data, we conclude that the use of dynamics in a Quantum Mechanics way is a good strategy to model this type of ecological systems. Furthermore, the calculated state transition matrices could be used to evaluate the linear part of the vector field representing the Dynamical System (Guckenheimer and Holmes, 1983) if deterministic differential equations approach is chosen.

2. Methods

The study of the two tri-trophic systems was carried out for 20 months (from May, 2000 to December, 2001). Monthly, around 50 plants of each system were analyzed; and the amount of mature leaves, as well as the populations of eggs and herbivores larvae *Urbanus* spp., and predators *Runcinioides argenteus* were measured.

The plants were examined once a month, for 20 and 13 months, for *D. discolor* and *D. uncinatum*, respectively. We counted the number of plants with herbivores (eggs and larvae), the amount of plants with predators (spiders), the total number of leaves and the total number of mature leaves. Table 1 shows the data for *D. discolor* and Table 2 those for *D. uncinatum*.

Usually, information is obtained with the use of binary digits (bits); and a state of each plant in stage *i* could be represented by strings of zeros (0) and ones (1) (Reza, 1961), with each position indicating, for instance, the presence of herbivores (eggs and larvae) and predators (spiders). This is an individual approach for modeling the system and, therefore, an individual string should be associated to each leaf.

In order to present a description for the whole set of leaves, we have used the Quantum Information idea of each state of

Table 1 – *Desmodium discolor* data

Index (i)	Month	Number of plants (N_p)	Plants with eggs (N_e)	Plants with larvae (N_l)	Plants with spiders (N_s)	Number of leaves (N_{le})	Mature leaves (N_m)
1	05/00	44	6	9	0	745	513
2	06/00	65	9	7	0	679	228
3	07/00	55	3	0	0	394	33
4	08/00	45	3	0	1	287	6
5	09/00	62	3	1	1	464	44
6	10/00	42	0	1	1	744	400
7	11/00	46	1	2	6	1097	754
8	12/00	44	1	0	3	911	721
9	01/01	45	1	1	6	1192	910
10	02/01	58	12	3	3	1433	1198
11	03/01	50	7	6	4	1321	1151
12	04/01	51	9	6	1	922	728
13	05/01	50	6	7	0	712	489
14	06/01	50	1	0	2	447	162
15	07/01	61	0	0	0	581	209
16	08/01	47	2	1	1	599	333
17	09/01	54	3	0	2	841	600
18	10/01	50	0	0	2	1013	692
19	11/01	51	1	0	2	750	579
20	12/01	50	0	0	1	887	691