Ecological Complexity 23 (2015) 61–67

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

Original research article

Chaos far away from the edge of chaos: A recurrence quantification analysis of plankton time series

Alexander B. Medvinsky [a,*], Boris V. Adamovich [b], Amit Chakraborty [c], Elena V. Lukyanova [b], Tamara M. Mikheyeva [b], Nailya I. Nurieva [a], Natalia P. Radchikova [d], Alexey V. Rusakov [a], Tatyana V. Zhukova [e]

[a] Institute of Theoretical and Experimental Biophysics, Pushchino 142290, Russia
[b] Biology Faculty, Belarussian State University, Minsk 220030, Belarus
[c] School of Mathematics, Statistics and Computational Sciences, Central University of Rajasthan, NH-8, Bandar Sindri, Ajmer 305801, Rajasthan, India
[d] Belarussian State Pedagogical University, Minsk 220050, Belarus
[e] Naroch Biological Station, Belarussian State University, Naroch 222395, Belarus

ARTICLE INFO

Article history:
Received 25 January 2015
Received in revised form 25 June 2015
Accepted 2 July 2015
Available online

Keywords:
Plankton communities
Predictability
Chaos
Chaoticity level
Recurrence quantification

ABSTRACT

Population abundance exhibits large fluctuations over time. Whether these irregular oscillations are driven by random environmental factors or a suite of deterministic mechanisms is an unsettled question in theoretical ecology. In this connection, one prevalent view is that at least part of the apparent disorder, which is known as deterministic chaos, is caused by deterministic interactions between species and/or some external periodic forcing. Disentangling this chaotic dynamics from environmental noise in field data remains problematic, however. Recent attempts to find chaos in the wild resulted in the conclusion that a great majority of populations live at a boundary between chaotic and regular dynamics, *i.e.* on the edge of chaos. Parallel to that result, we report here that chaos is an inherent dynamic phenomenon, which can emerge far away from the edge of chaos in a natural population. We have observed that the plankton dynamics in the Naroch Lakes, Belarus, exhibit chaos with the horizon of predictability of around 2.5 months, and the corresponding dominant Lyapunov exponent equals approximately 0.4, thus laying out of the narrow interval between −0.1 and +0.1 characteristic of living at the edge of chaos. Furthermore, we have found that the second order Renyi entropy can be considerably greater than the values of the dominant Lyapunov exponents. It implies that the plankton dynamics can be characterized by at least two physical degrees of freedom, and the qualitative description of irregular changes in plankton abundance requires a four- or higher-dimensional phase space. In other words, interspecific interactions across trophic levels can significantly contribute to the emergence of chaos far away from the edge of chaos.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

"Is chaos a mathematical artifact or ecological reality?"—A prevalent unresolved question in ecology is weakening the link between non-linear dynamics and population ecology (Sherratt et al., 1997). Detection and characterization of chaotic dynamics or near-to-chaos dynamics in natural populations is, therefore, a thriving area of contemporary ecological research. Many attempts have been made to identify chaotic oscillations (see Turchin, 2003; Solé and Bascompte, 2006 and references therein). Chaotic population dynamics specifically characterized by positive values of the dominant Lyapunov exponent, which quantifies the sensitivity of the dynamics to initial conditions (Ott, 2002), were found to be rare in nature (Berryman and Milstein, 1989; Thomas et al., 1980; Ellner and Turchin, 1995; Higgins et al., 1997). Analysis of a large number of population time series allowed hypothesizing that the majority of wild populations live at the edge of chaos, *i.e.* at a boundary between chaotic and regular dynamics (Ellner and Turchin, 1995). The boundary is characterized by the values of the dominant Lyapunov exponent close to zero. Living at the edge of chaos implies that small changes in parameters can cause the population dynamics to switch between regular and chaotic behavior. Alternatively, continual transitions in and out of chaos may also arise as a result of competition between coexisting regular and chaotic attractors at the same set of parameter values (Kaitala et al., 2000; Medvinsky et al., 2001). Switching between

* Corresponding author. Tel.:+7 9099005438.
E-mail address: alexander_medvinsky@yahoo.com (A.B. Medvinsky).

http://dx.doi.org/10.1016/j.ecocom.2015.07.001
1476-945X/© 2015 Elsevier B.V. All rights reserved.