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The Main Factor Determining the Dynamics of the Lake Ecosystem under Excessive Nutrient Loading (A Case Study of the Naroch Lakes)

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Abstract—The system of the Naroch lakes, which includes the eutrophic Lake Batorino, the mesotrophic Lake Myastro, and the oligo-mesotrophic Lake Naroch, serves as a model object for the study of the factors initially influencing the state of a particular lake ecosystem affected by variable nutrient loading. Throughout the 1970s–2000s, these lakes have been going through the stages of anthropogenic eutrophication, deeutrophication, and benthification. A set of continuous data based on the seasonal means of the eight parameters from each lake for the period 1978–2015 has been analyzed by Principal Component and Singular Spectrum Analysis (SSA, or Caterpillar). In addition, we consider the dynamics of the trophic index of each lake, which had been calculated earlier at the same data set. The first main component is the stability of the lake ecosystem under variable nutrient loading, which is inversely related to the trophic state of the water body. This component determines the condition of the Batorino, Myastro and Naroch lakes by 63, 65, and 43% respectively.

Keywords: lake ecosystems, multiannual dynamics, ecological stability, trophic state, Principal Components Analysis, Singular Spectrum Analysis, main factor interpretation, Naroch lakes

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INTRODUCTION

The analysis of long-term series of various characteristics of ecosystems is currently becoming one of the main ways to identify general ecological patterns (Krogius et al., 1987; Anneville et al., 2002; George et al., 2007; Ostapenya et al., 2012; *Lake Kinneret*..., 2014; *Oneida Lake*..., 2016; Adamovich et al., 2017; Kovalenko et al., 2018). In addition to relatively clearly visible trends with long-term tendencies in changes of individual characteristics of a community or ecosystem, the observed dynamics of these characteristics reflects the effects of various cyclic processes occurring in the ecosystem.

Now, as a result of many years of monitoring, data on the dynamics of the main hydrochemical and hydrobiological indices of the ecosystems of some water bodies have been accumulated (Ostapenya et al., 2012; *Lake Kinneret*..., 2014; *Oneida Lake*..., 2016; Burlakova et al., 2018). This allows moving on to identifying the basic laws of the development of the aquatic ecosystem using more subtle methods of analyzing sufficiently long continuous series of values of the measured parameters. In particular, the Singular Spectrum Analysis (SSA, or Caterpillar) method can be used to decompose a time series into a long-term trend, cyclical components of different periods and amplitudes, and a remainder that cannot be decomposed (Zhigljavsky and Golyandina, 2013). This decomposition allows comparing the detected trends and cycles in the dynamics of various parameters and thus more effectively discuss the influence of specific factors on the ecosystem. Another useful method is principal component analysis (Aivazyan et al., 1989; Jolliffe, 2002). This analysis allows reducing the dynamics of the totality of any number of real ecosystem parameters to the dynamics of several new conditional variables (main components), which almost completely describe the behavior of the initial series. In accordance with the construction logic (Jolliffe, 2002), the principal component analysis automatically creates orthogonal, i.e. statistically independent variables, which allows them to be interpreted independently of each other. The problem is to find the correct interpretation of the main components and thereby establish those phenomena or circumstances (main factors) on which the change in the state of the