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Deterministic Chaos and the Problem of Predictability in Population Dynamics

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Abstract—The studies of the processes that can significantly influence the predictability in population dynamics are reviewed and the results of mathematical simulations of population dynamics are compared to the time series obtained in field observations. Considerable attention is given to the chaotic changes in population abundance. Some methods of numerical analysis of chaoticity and predictability of the time series are considered. The importance of comparing the results of mathematical simulation and observation data is tightly linked to problems in detecting chaos in the dynamics of natural populations and estimating the prevalence of chaotic regimes in nature. Insight into these problems can allow identification of the functional role of chaotic regimes in population dynamics.

Keywords: deterministic chaos, predictability, population dynamics

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Deterministic chaos is usually defined (see, for example, [1]) as a dynamic functional regime of a studied system characteristic, which includes (a) determinacy and (b) limited predictability. Determinacy implies that a time-related change in the state of a system is unambiguously determined by dynamic laws; this is also characteristic of nonchaotic regular deterministic regimes. The limited predictability of deterministic chaos is a consequence of the sensitivity of deterministic chaotic systems to the initial conditions, namely, a consequence of the exponentially rapid divergence of the initially close trajectories within a limited region of phase space.

The concept of deterministic chaos dates back to the end of the 19th century when Poincare [2] demonstrated that the evolution of a system consisting of three gravitationally interacting bodies displayed signs of chaos in the sense that a small perturbation of the initial position of one body can radically change the overall system state relative to its unperturbed state. If the introduced perturbation is so small that it cannot be detected by measurement it is impossible to predict the future states of the perturbed system. Thus, the results of Poincare demonstrate that determinism does not necessarily imply predictability (see [3] for the history of research into the problem of n bodies). It took scientists over half a century to grasp the limitations in the predictability of the dynamics of natural systems imposed by deterministic chaos (it is likely that the term chaos was used for the first time in [4]). This brought about the concept of the predictability horizon [5]: the time interval within which the trajectories fail to considerably diverge and, consequently, the corresponding natural chaotic process remains predictable (to an acceptable accuracy).

The predictability of natural processes depends on a number of factors, such as the effect of noise, i.e., random and unpredictable factors external to the studied system [6, 7]; accuracy of measurements [8, 9]; and, finally, the inherent instability and chaoticity that occur even in the absence of significant external impacts [10, 11]. Some of these factors are not independent. In particular, even a small inaccuracy in measurements can lead to almost unpredictable consequences if the studied system is chaotic [12]. Another example is that a drastic and almost unpredictable change in the dynamic pattern of a system caused by even weak external impacts can be significantly determined by a strong dependence of the "choice" of a particular dynamic regime made by the system on a small fluctuation in the system parameters [13].

The goal of this work was to provide an overview of the data on the factors that significantly influence the predictability in population dynamics. The focus of this review is deterministic chaos in the context of comparison of the mathematically simulated oscillation of the population size in time and the data (time