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Integrative model of a population distribution in a habitat

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Abstract

This paper is devoted to an explanation of the mathematical model of a population distribution in a habitat. The spatial distribution is considered as a function of factors affecting a population. The model includes both linear and non-linear modeling mechanisms, which allow description of a variety of environmental situations observed in nature. All components of the model are conceptually connected with one another and based on one methodological basis. This allows development of the integrative picture of mathematical modeling of spatial population dynamics. The theoretical portion of the paper presents logical structures and mathematical equations for numeric modeling of a population distribution in a habitat. The practical portion describes the application of the integrative model to the study of the spatial distribution of fry of Brown trout (*Salmon trutta* L.) in the experimental conditions. The integrative model represents a standardized and reliable method for studying spatial population dynamics applicable to a variety of populations of different species. This method offers a comprehensive algorithm of steps which one should take in order to predict spatial distribution of organisms. It also outlines the information necessary for mathematical modeling of spatial population dynamics. Through systematization of the modeling process, the integrative model aims to enhance the understanding and use of mathematical modeling in environmental sciences and ecology in general.

Keywords: Population; Spatial distribution; Mathematical model; Preferendum; Behavioral response

1. Introduction

The study of spatial distribution of a population in a habitat for a long time has been one of the central topics in ecology (Odum, 1971; Fedorov and Gilmanov, 1980; Krebs, 2001; Guisan and Zimmermann, 2000). There have been many attempts to explain how climate along with other environmental factors determine the spatial preferences of organisms within their biotope and, thus, define their distribution. Investigations of spatial distribution of populations were started almost a century ago by researchers such as Grinnell (1917) and Elton (1927). Their pioneering studies, however, had a primarily descriptive, intuitive character, that made

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it difficult to interpret and apply their ideas in practice. Quantitative research in population distribution began with Hutchinson (1957), when he introduced and described the concept of multi-dimensional fundamental and realized niches, the areas occupied by a population as a response to abiotic and biotic factors in their habitat. Hutchinson's ideas initiated further quantitative research in population distribution (MacArthur, 1972; Charnov, 1975; Pianka, 1981). This research, however, was evolutionary in nature and aimed to outline the niche that a population can occupy in its habitat. Niche theory with its broad scale and theoretical nature, was not able to address distributional questions at finer ecological, rather than evolutionary, scale related to instantaneous measurements and predictions of organisms' location in response to short- and medium-term variations in their environment. At the same time, these measurements are extremely important for our understanding of what drives spatial population dynamics and how population distribution will change under the effect of various natural and anthropogenic factors.

Recently, the modeling of spatial distribution of a population in response to environmental variability have received significant research attention since they have been recognized as an important component of conservation planning and other management efforts (Austin, 2002; Franklin, 1995; Guisan and Zimmermann, 2000). As a result, a variety of computational techniques, especially statistical methods, as well as geographic information system (GIS) have been developed to address the questions of population distribution. These methods, very useful in some situations, often neglect the functional relationships between the organisms and their environment (Austin, 2002). At the same time, these very relationships ultimately determine the behavioral locomotory response of organisms and distributional preferences of a population within a habitat.

It our previous research we have made attempts to develop an analytical mechanism to predict a population distribution in its habitat based on the functional relationships between organisms in a population and their environment (Gertsev et al., 1996; Gertsev and Gertseva, 1999; Gertseva and Gertsev, 2002). These attempts were successfully applied to manage commercially important fish species, including Caspian sturgeon. However, we have always wanted to combine our ideas in this area into a unified, integral and, perhaps, complete picture, illustrated by fundamentally new results. Such a picture would undoubtedly contribute to both theoretical ecology and applied environmental sciences by offering an analytical method for prediction of a population distribution under various set of environmental factors. Motivated by this desire, we developed an integrative model of a population distribution in a habitat. This paper is devoted to the explanation of this model.

2. Model background

Let us assume that a population inhabits a particular space V with the coordinates x, y, z. In the general case, organisms in a population are not evenly distributed in their habitat $V(x, y, z)$, but concentrated in particular, more favorable areas. The totality of the points N, which belong to these areas, constitute a population distribution $Q(x, y, z)$. Thus, we can write

$$Q(x, y, z) \subset V(x, y, z)$$

and

$$Q(x, y, z) = \{(x_1, y_1, z_1), \ldots, (x_j, y_j, z_j), \ldots, (x_N, y_N, z_N)\} \quad (1)$$

A population distribution $Q(x, y, z)$ is formed by behavioral responses of organisms in a population to the affecting factors $g_i (i = 1, 2, \ldots, n)$. Therefore, we can write

$$Q(x, y, z) = f(g_i), \qquad (i = 1, 2, \ldots, n) \quad (2)$$

Formula (2) is a basic equation that represents that the spatial distribution of organisms in a habitat is shaped by environmental factors affecting a population. Within the scope of this paper, we will elaborate this equation in detail to be able to predict the distribution of organisms under various environmental conditions.

Two questions might appear on the first stage of our reasoning. First, the distribution $Q(x, y, z)$ in expression (2) is presented as a stationary function, independent from time t. However, the values of factors g_i may change over time and, therefore, a population distribution should be presented as time-dependent function when $Q = Q(x, y, z, t)$. How can stationary function (2) take into account temporal variations in affecting