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GENERAL BIOLOGY

A Mathematical Model of the Temperature Conditions of Mammalian Burrows as Exemplified by the Burrow of the Marmot *Marmota bobak* Müll., 1776

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Recent studies [1] on the temperature conditions in the burrows of the marmot *Marmota bobak* have showed that (1) air convection is practically absent in the burrows and (2) the temperature conditions in the burrows depend on the properties of the soil in which the burrows had been burrowed. Thus, on the basis of the temperature and thermal physical soil properties, it is possible to estimate the temperature in the burrows without direct measurements of the temperature [2]. This task becomes easier because temperature measurements on the soil surface are much simpler than inside the burrows, the algorithm and software for assessment of the soil temperature have been developed [3], and the data necessary for determining the boundary conditions of the thermal conductivity equation in the model used are available.

In this work, we studied the fit of the model to the simulated object using marmot burrows as an example.

Both the temperature directly in the marmot burrow itself and the temperature of the soil surface in the vicinity of the burrow were used as objects of simulation.

The model is based on the numerical solution of the thermal conductivity equation [4]

$$\frac{\partial U(z, t)}{\partial t} = a^2 \frac{\partial^2 U(z, t)}{\partial z^2}, \qquad (1)$$

where $U(z, t)$ is temperature as a function of depth (z) and time (t), and a is the coefficient of thermal conductivity. The average temperature of the soil surface and the temperature of the thermoneutral soil layer were used as boundary conditions. The thermoneutral soil layer is the layer whose temperature is constant throughout the year [3]. In our case, the layer whose temperature oscillations throughout the year did not exceed accuracy of the model (1 K) was used as a thermoneutral layer. In the region of our studies (the Kharkov oblast, Ukraine) it begins at a depth of 8 m. The initial conditions may be excluded, because changes in the boundary conditions are cyclic [4]. The thermal conductivity coefficient was assumed to be constant and to be the same at different depths (3.4×10^{-7} m^2/s) [5]. This value is usually used for clay soil in this region.

The field studies were performed in the vicinity of the Nesterivka village (Velikoburlukskii raion, Kharkov oblast, Ukraine) [6]. The temperature in the marmot burrow was measured from March to September 2000 at a depth of 1.9 m. The results of these observations and details of the method were described earlier [7].

The soil temperature (within the radius of 20 m around the burrow in which temperature was measured earlier) was measured from November 2003 to May 2004 at a depth of 3 m. It is known that the hibernacula of bobak marmot is located at a depth about 3 m. The soil temperature was measured by a RTV–2 autonomous thermosensor (KARAT). Its diameter was 17 mm, and the thickness was 6 mm. The diameter of the bore for placing the thermosensor into the burrow was 30 mm. The bore was covered with turf about 40 cm thick.

In both cases, the thermometer indications were read 4 times a day: at 8 a.m., 12 noon, 4 p.m., and 8 p.m.

The average monthly temperature at 12 noon was calculated for the use in direct measurements and the model. This temperature was used as a parameter to describe the temperature chganges with the use of the quadratic equation

$$U(t) = at^2 + bt + c, \qquad (2)$$

where $U(t)$ is temperature; t is time (the ordinal number of the month); a, b, and c are the coefficients of the regression equation. The regression curves for all cases are shown in Figs. 1 and 2. The regression equations

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