Conceptual model of beaver population system dynamics

Maxim Logachev[1*]

[1]Moscow Polytechnic University, 107023 Moscow, Russia

Abstract. All living organisms affect the environment and the livelihoods of their neighboring populations. Such neighborhood can have both positive and negative consequences. The paper presents a simulation model that determines the number of beavers in a limited area depending on external factors. Such factors include natural conditions, anthropogenic influence on their habitat, peculiarities of beaver's life activity and conditions regulating the population (possibilities of trapping or hunting). The developed model corresponds to the system dynamics model, which allows to predict the changes of the beaver population in the given time interval depending on the given conditions, which can change. The obtained model can be used in intelligent systems providing environmental monitoring, ecosystem biodiversity and effective management of various types of resources.

1 Introduction

Certain biological populations pose a serious threat to humans and their livelihoods [1, 2]. For instance, a health threat is posed by ticks infected with borreliosis or encephalitis, or mosquitoes that carry malaria; an economic threat is posed by damage to agriculture (destruction of crops, infestation of animals, accelerated degradation of the surface layer of soil, etc.). [Invertebrate Zoology: https://biocpm.ru/paraziticheskie-prosteyshie]).

In addition, there may be cases of negative impact of populations on biodiversity. In scientific literature, such organisms are called invasive [3]. They are characterized by aggressive behavior in the environment, affecting trophic networks and disturbing the balance of the ecosystem. All this becomes the cause of extinction of specific species and the emergence of ecological disasters. For instance, the boxwood firefly has no natural enemies in Europe, so it made it possible for it to spread quickly in the new area and cause significant damage to European boxwoods [4].

There are various ways to make it possible to limit populations that are harmful and dangerous. Breeders create parasite-resistant crop species, develop chemicals to control insects and rodents, capture or shoot large animals, add natural predators to the ecosystem, etc.

According to Russian legislation, the regulation of the number of specific wildlife species should be carried out in ways that prevent harm to other wildlife species and ensure the preservation of their habitat, taking into account the conclusions of scientific organizations

* Corresponding author: logachevmaxim@gmail.com

solving problems in this area, and in coordination with specially authorized state bodies responsible for the protection of land, water and forest resources [Regulation of the number of wildlife species: https://www.consultant.ru/document/cons_doc_LAW_6542/ca9fa5f334d4dde9a6c26fd7cad4d9ec96fbd2f0].

For many decades, data on the number of animals on the territory of Russia have been obtained using the method of route counts, the most common type of which is counting tracks in the snow cover [5]. The accuracy of its results depends on the adequacy of methods for assessing the distribution of individuals in natural habitats and the volume of survey routes [Monitoring of Game Animals: https://adm-nems.gosuslugi.ru/dlya-zhiteley/novosti-i-reportazhi/novosti-193_311.html]. Improvements in methods and technology have provided accurate data for analysis, for instance, monitoring of territories by unmanned aerial vehicles [Rossiyskaya Gazeta: https://rg.ru/2019/10/01/bespilotniki-pomogut-poschitat-dikih-zhivotnyh.html], Installation of camera traps in habitats [Ministry of Natural Resources and Ecology of the Kaliningrad Oblast: https://minprirody.gov39.ru/news/236864], chipping [6], etc. The use of information technologies and artificial intelligence technologies made it possible to quickly and accurately process large volumes of heterogeneous data, to carry out objective and continuous monitoring of the state of the environment and animal or plant populations [7, 8].

Purpose. The present work is the development of a numerical model for forecasting changes in the number of animal individuals in a natural area.

Theoretical significance. The work is carried out to systematize and formalize the factors influencing changes in wildlife populations. The results obtained can be used in research related to biodiversity conservation, climate change and other ecological and anthropogenic interactions. In addition, the model can be part of an intelligent resource management system used to develop strategies and methodologies to protect wildlife populations and restore ecosystems. This is the practical significance of the development.

For the accomplishment of the set goal, it is required to perform **objective** to identify key aspects of the subject area, including qualitative and quantitative characteristics of its objects and processes, establishing relationships between changes in their states and rules of interactions; to select a methodology for formalizing the results obtained; to develop a formal model that meets the requirements of digital transformation.

2 Objects and Methods

The object of the research is the beaver population. Its number on the territory of Russia is estimated at about 730 thousand individuals, most of which live in the Central and Volga Federal Districts [Wildlife of Russia: http://nature.kremlin.ru/animals/21]. The beaver population represents scattered pockets of habitat concentrated in the upper Yenisei, Kuzbass, Pribaikalye, Khabarovsk Krai, Kamchatka, regions of Siberia and Altai Krai; its wide distribution is represented in the forest and forest-steppe zones of the European part of Russia and Northern Trans-Urals. Two subspecies of the river beaver are listed in the Red Data Book of the Russian Federation, namely the West Siberian beaver (except for the Altai population) and the Tuva beaver [Ministry of Natural Resources and Ecology of the Russian Federation: https://www.mnr.gov.ru/activity/red_book].

The beaver poses a threat to humans only if they meet directly, as the beaver's jaw has a serious grip and the presence of incisors that successfully work with wood [Gazeta.Ru, INPO “Green Civilization”: https://www.gazeta.ru/social/news/2024/04/13/22777406.shtml]. However, beaver populations can create problems for economic and other human activities. The beaver, through its activities, forms a new environment, changing the current ecosystem by creating dams or ponds. All this entails waterlogging of the area, destruction of land reclamation networks, flooding of roads or railroads. Creation of a model predicting changes in the beaver population size from the point of view of observing the natural balance and reducing the negative impact on the objects of human economic activity is a topical objective.

The creation of the digital model was carried out in several stages, each of which used a specific set of methods.

Requirements gathering phase. Modern scientific sources of information were studied to make it possible to determine the peculiarities of beaver populations and their impact on ecosystems and human economic activity. For this purpose, the methods of systematization, abstraction, systematization and synthesis were used.

Analysis phase. Made it possible to establish the key processes affecting the rate of spread of beaver population and their characteristics. As noted in research that analyzes the problem domain in order to create digital twins, such data make it possible to form a set of input parameters and rules for the simulation model [9-11]. For this purpose, the methods of structural analysis, systematization, abstraction, synthesis, and step-by-step refinement are used.

Conceptual model development phase. Simulation modeling methods were applied to the results obtained during the implementation of the analysis stage. As a result of such methods, the behavior of the system under study is recreated in a digital environment, i.e., changes in its properties and characteristics are generated to the extent provided by the system boundaries [12-14]. To create a model corresponding to the research goal, the system dynamics method was used.

3 Results

Consecutive fulfillment of the mentioned stages and application of appropriate methods made it possible to obtain a system dynamics model corresponding to the purpose of the work. Fig. 1 shows the corresponding model that makes it possible to simulate the dynamics of beaver population changes in a certain territory.

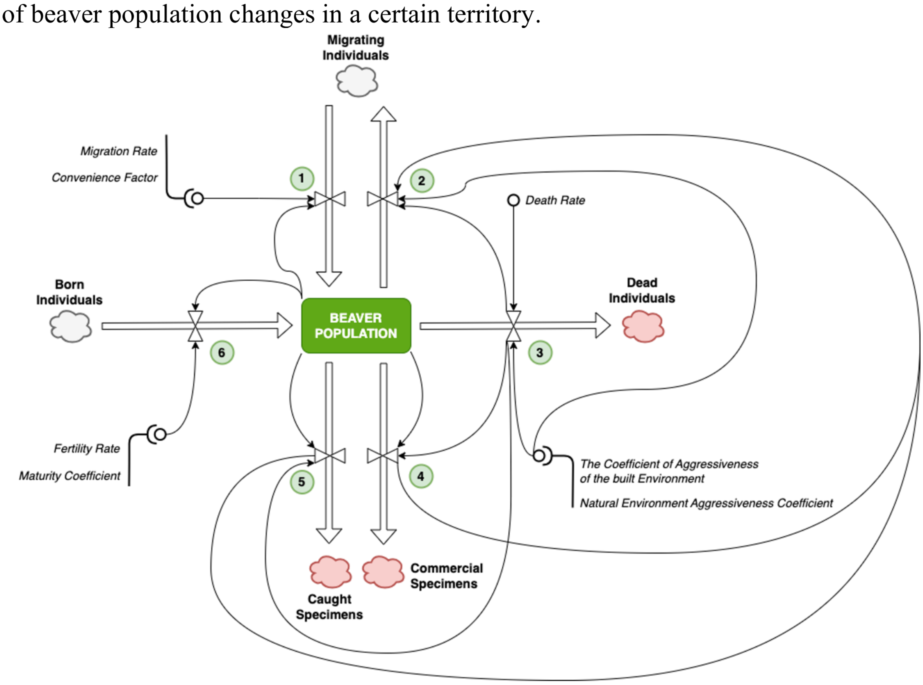
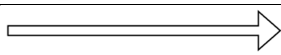
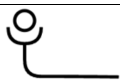
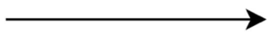


Fig. 1. Beaver population system dynamics model

Table 1 presents the characterization of notation adopted in the model.

Table 1. Symbols of the model of system dynamics of the beaver population

No.	Graphic designation	Characterization
1		A container identifying the total number of beaver individuals at the current point in time
2		Levels characterizing quantitative growth or loss from the total number of individuals depending on the name of the element
3		Flow characterizing the rate of change of levels
4		Function corresponding to the rate of change of flows
5		Groups of variables included in one function
6		Variable included in the functions
7		Channel identifying the relationship of levels and variables to functions
8		Identification number of flows

The model considers the area where a beaver family is located as well as families that are located nearby within the same natural area (for instance, forestry) as a territory. Accordingly, beavers are affected by factors related to the state of the natural environment (availability of a forage base, which includes soft deciduous woody and shrub vegetation and riparian vegetation; water bodies that are not frozen to the bottom; slow-flowing, not wide rivers, ponds, lakes or irrigation canals; presence of predators, etc.), anthropogenic human activities (activities that create noise or destroy beaver dwellings). The following situations are possible, which are related to beaver migration relative to the study area:

- the area is beaver-free, then its settlement is affected by the *stream 1* (accordingly, the values of the variables should correspond to favorable conditions for active settlement);
- the area is occupied by beavers, there may be an exodus of individuals (*stream 2*) for the following reasons:
  - conditions have become unfavorable for the continuation of life activity (for instance, the forage base has run out, dwelling has been destroyed due to unfavorable weather conditions, anthropogenic human activity or purposeful human activity to evict beavers);
  - separation of young individuals from their parents (most often, after reaching sexual maturity at 2-3 years of age, the young go in search of a mate and a suitable place to live);
  - the death of a partner may trigger a search for a new place to live.

Stream 3 implies beaver mortality not only due to natural causes due to age, but also mortality associated with accidental environmental factors or weather conditions (floods, drought, forest fires); from human activities unrelated to hunting; beavers themselves (for instance, a tree falling on an individual); and the presence of predators.

Streams 4-5 have a targeted reduction in beaver population associated with ensuring the natural balance or reducing the negative impact on infrastructure facilities. The quota for trapping or hunting is set depending on the current beaver population and coefficients determining the rates of change of associated flows.

Stream 6 characterizes the growth of beaver population due to the appearance of new offspring. Most often, beavers begin to reproduce in the third year of life and offspring in such a family appear in April-May. For instance, the offspring of the Tuva beaver can reach only three individuals, whose life expectancy is about seven years [Ministry of Forestry and Nature Management of the Republic of Tyva: https://mpr.rtyva.ru/events/12485]. The common beaver is characterized by the presence of one to six cubs in a brood, whose life expectancy under favorable conditions can reach several tens of years.

4 Discussion

Modeling is one of the methods that make it possible to represent data, processes and events at the current moment of time or how they will change over a given time interval [15, 16]. This approach is actively used to model the behavior of complex systems where, for instance, there are numerous heterogeneous objects, processes whose state may change from random events, and it is required to determine strategies for effective control or qualitative change before their implementation with real objects or processes. This is justified by irreversible changes that can incur at least economic losses, and at most - catastrophic consequences (up to the destruction of the object). Digital simulation models are actively created and used in the field of sustainable transportation [17, 18], economic development of different industries [8, 9, 11, 19], environmental sustainability [5-7], etc.

The analysis of the studied works on simulation modeling makes it possible to conclude that the stated research methods are correctly applied and the results obtained are correct, valid for the problem area and the purpose of the work. The authors have established key characteristics that determine the nature of process states of complex systems, on the basis of which formal models have been developed [12, 14, 16]. Such models correspond to generally accepted methodologies in the field of modeling and are suitable not only for stand-alone use, but also for their integration into complex information or intelligent systems [2, 10, 15].

5 Conclusions

The development of environmental management methods ensures accurate and, in some cases, humane intervention in ecological processes. In this way, it is possible to effectively influence the variable attribute and reduce the negative impact on related processes or objects. This not only ensures a balance between anthropogenic and ecosystem processes, but also makes it possible to assess the state and possible changes in the biodiversity of the ecosystem.

Ecological management is a complex process that requires constant data collection and processing, identification of patterns, development and implementation of various measures aimed at preserving ecosystems, etc. Digital transformation of such processes at the current stage of development of digital systems and technologies provides accurate and timely results. The software solutions used in this process become an effective tool to support the decision-making of relevant specialists.

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