Model of interaction between different populations of organisms for the conservation of biodiversity

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Abstract. This paper presents land management strategies and adaptation measures aimed at mitigating the impacts of climate change and conserving biodiversity. Proposed measures include the development of efficient farming methods, such as drip irrigation and optimizing the use of water resources, which helps reduce soil degradation and reduce water consumption. In addition, measures to protect and restore ecosystems are being considered, including planting trees, creating nature reserves and protected areas, and controlling pollution and deforestation. It also emphasizes the need to develop and implement strategies for the sustainable use of natural resources, such as solar and wind energy, to reduce pressure on ecosystems and reduce greenhouse gas emissions. Particular attention is paid to educational campaigns and information activities to increase public awareness of climate change and its impact on ecosystems, thereby promoting public involvement in decision-making and promoting sustainable behavior at home and community levels. In this work, the Lotka-Volterra model was used to simulate the impact of climate change on populations of plants and insect parasites in the dry regions of Uzbekistan. The model presented in this work allows us to predict changes in populations in response to climatic factors and develop adaptation strategies for the conservation of biodiversity. The work highlights the importance of scientific and innovative initiatives in the field of climate change research and sustainable development, which will create infrastructure for sustainable development and the implementation of environmentally sustainable technologies.

1 Introduction

Climate change has become increasingly evident in recent decades, having significant impacts on ecosystems and biodiversity around the world. Dry regions, where natural resources are already limited, are especially vulnerable to such changes. Uzbekistan, much of which is arid, is no exception. Rapidly changing climate conditions, including rising temperatures and decreasing precipitation, increase the risk of soil degradation, decreased water resources and, as a result, threaten the sustainability of ecosystems and the well-being

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of people. In an environment of increasing environmental instability, the importance of developing strategies for sustainable land use management and adaptation to changing climate conditions is becoming a priority. Efficient use of water resources, the introduction of modern agricultural technologies such as drip irrigation, and the creation of protected natural areas play a key role in maintaining ecological balance and sustainable development of agriculture. One of the important tasks in conserving biodiversity and protecting ecosystems is to study the interactions between different populations of organisms, such as plants and parasitic insects, in a changing climate. Mathematical modeling allows us to gain a deeper understanding of these processes and develop effective measures to regulate them. In this paper, we use the Lotka-Volterra model to investigate the impact of climate change on the population dynamics of plants and insect parasites in the dry regions of Uzbekistan. This study is aimed at developing an integrated approach to land use management, including the introduction of sustainable agricultural technologies , measures for the protection and restoration of ecosystems, and raising public awareness of the significance of climate change. Particular attention is paid to analyzing the effectiveness of environmental protection measures and developing strategies for their optimal application in dry regions. This article aims to provide scientific justification and practical recommendations for sustainable land use development in Uzbekistan, taking into account modern challenges associated with climate change.

The relevance of the study is related to the growing challenges that climate change poses for agriculture and ecosystems in dry regions, including Uzbekistan. These changes include rising temperatures, decreased precipitation, and an increase in the frequency of extreme weather events such as droughts and floods. In dry regions where access to water resources is limited, climate change is having a serious impact on agriculture, ecosystems and the lives of local people. Decreased soil moisture and deteriorating conditions for growing crops lead to lower yields and increased vulnerability of agricultural systems.

In this context, the development and implementation of sustainable land use strategies, as well as adaptation measures, becomes a necessity to ensure food security, preserve biodiversity and maintain ecological balance. Research into modeling interactions between different ecosystem components, such as plants and insect pests, plays an important role in understanding these processes and developing effective management strategies. Thus, this study is relevant for practical work in the field of agriculture, ecology and sustainable development, as well as for decision-making at the public policy level in a changing climate.

[1] provides an extensive overview of current knowledge about the importance of biodiversity for human well-being and proposes management strategies for conserving ecosystems and their services to support viable societies. Article [2] describes a study of the antibacterial activity of four fractions from Heracleum plants persicum and Cinnamomum zeylanicum . The study's findings highlight the potential importance of plants in treating infections, confirming the importance of biodiversity conservation for medical research and development. These works highlight not only the importance of biodiversity for ecosystem services and human well-being, but also its potential importance in the fields of health sciences and biotechnology. They support research into the conservation and management of biodiversity to achieve sustainable development and preserve human health. [3] discusses the importance of understanding agriculture for conservation. The authors highlight key aspects that should be taken into account when developing strategies for conserving biodiversity in agricultural landscapes. In [4], the author discusses methods for partitioning beta diversity components, which can be useful for assessing changes in biodiversity in response to anthropogenic impacts. [5] examines the impact of organic farming on biodiversity and abundance, which may be important for the development of sustainable agricultural practices. These articles present diverse aspects

of the relationship between agriculture and biodiversity, which emphasizes the relevance of studying this problem and developing strategies for the sustainable use of natural resources. [6] analyzes the factors influencing the participation of Puerto Rican coffee farmers in conservation programs. Understanding these factors can be helpful in developing effective strategies to encourage farmer participation in conservation programs. [7] explores farmers' perceptions and knowledge about insects in Gobardikha village in Nepal. Understanding local knowledge and perceptions can help develop more effective pest management practices in agricultural systems. The study [8] compared agroforests and protected forests in the Eastern Usambara Mountains of Tanzania. The results may help understand the impact of agricultural practices on biodiversity and forest conservation. Article [9] discusses the inevitable conflicts between food production, ecosystem services and biodiversity. Understanding these conflicts can help develop sustainable agricultural practices.

The book [10] examines the concept of " Climate Smart Agriculture " and its role in building climate resilience in agriculture. It offers strategies and practical recommendations for agricultural systems that promote adaptation to changing climate conditions. The study [11] analyzes the number, size and distribution of farms, small family farms and family farms around the world. Understanding this framework helps to better understand agricultural systems and their role in food security. [12] explores farmers' perceptions and knowledge of natural enemies as providers of biological control in apple orchards. Understanding these aspects can help develop more sustainable ones. practitioners in pest management. Research by [13] analyzes society's preferences for “packages” of ecosystem services. Understanding these preferences can help guide ecosystem management and conservation policy development. [14] explores the role of knowledge, attitudes and perceptions in the adoption of agricultural and agroforestry innovations . among smallholder farmers in sub-Saharan Africa. Understanding these aspects helps improve the adoption of new practices in agriculture. This study discusses how agroecological practices contribute to improving the welfare of farmers in the agricultural corridor in Tanzania. Understanding the impact of such practices on farmers' well-being can help develop strategies for sustainable development in agriculture. [15] discusses how agroecological practices contribute to improving the welfare of farmers in the agricultural corridor in Tanzania. Understanding the impact of such practices on farmers' well-being can help develop strategies for sustainable development in agriculture.

The article [16] discusses how insufficient environmental knowledge can deepen farmers' dependence on pesticides. The study points to the need to improve environmental awareness among farmers to develop more sustainable pest management practices. [17] explores the global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. The results highlight the need to consider such factors when developing sustainable agriculture strategies. Climate change and the quest for carbon neutrality have become major topics in the modern world. International and national efforts are aimed at reducing greenhouse gas emissions and adapting to the impacts of climate change. This review examines key studies and reports related to decarbonization strategies, the current state of climate change, and plans to achieve carbon neutrality [18–24].

[25-30] demonstrates a wide range of studies and reports related to various aspects of energy and climate science. These works highlight the importance of an integrated approach to solving problems of sustainable development, including both theoretical models and practical solutions. Achieving carbon neutrality requires a collaborative effort between scientists, policymakers and industry to develop innovative technologies and use resources efficiently.

Let's look at some land management strategies and adaptation measures that can help conserve biodiversity and mitigate the impacts of climate change in the dry regions of

Uzbekistan. Developing efficient farming methods, such as drip irrigation and efficient use of water resources, will help reduce negative impacts on ecosystems in dry regions. It will also reduce soil degradation and reduce water consumption, promoting more sustainable use of natural resources. It is important to carry out measures to protect and restore ecosystems in dry regions, such as planting trees and shrubs, establishing nature reserves and protected areas, as well as controlling pollution and deforestation. This will help preserve biodiversity and strengthen the regulatory role of ecosystems in maintaining environmental health. Developing and implementing strategies for the sustainable use of natural resources, such as solar and wind energy, will help reduce pressure on ecosystems and mitigate the impact of climate change. It also helps diversify energy sources and reduce greenhouse gas emissions. It is important to conduct educational campaigns and information activities aimed at increasing public awareness of climate change and its impact on ecosystems. This will help involve the community in decision-making and encourage sustainable behavior at home and community levels. Research on climate change and sustainable development must be supported by scientific and innovation initiatives aimed at developing new technologies and methods to adapt to changing conditions. This will help create infrastructure for sustainable development and promote the development of environmentally sustainable technologies [31-34].

2 Materials and methods

Let's create a mathematical model that will take into account the impact of climate change on populations of plants and parasitic insects in the dry regions of Uzbekistan. To do this, we can use the Lotka-Volterra model, which describes the dynamics of interaction between two species.

Let be: $R(t)$ - plant population at a point in time t; $P(t)$ - population of parasitic insects at a point in time t; d_R and d_P are the diffusion coefficients for plants and insects, respectively; r - growth rate of plant population (without taking into account the impact of insects); K_R and K_P - medium containers for plants and insects, respectively; β_{RP} and β_{PR} are the coefficients of interaction between plant and insect populations.

Then the Lotka-Volterra system of differential equations will take the form:

$$\begin{cases} \dfrac{\partial R}{\partial t} = d_R \nabla^2 R + rR\left(1 - \dfrac{R + \beta_{RP} P}{K_R}\right), \\ \dfrac{\partial P}{\partial t} = d_P \nabla^2 P\left(1 - \dfrac{P + \beta_{PR} R}{K_P}\right). \end{cases} \quad (1)$$

This model describes changes in plant and insect population densities over space and time, taking into account diffusion and interactions between species. The first equation describes the change in the plant population depending on the rate of their growth and the influence of insects, and the second equation describes the change in the insect population depending on the rate of their decline and the availability of food in the form of plants. It takes into account both internal dynamic processes (growth, decline and interaction of populations) and the spatial distribution of plants and insects. Such a model can analyze spatial population dynamics and explore how changes in climate and land use affect the distribution and abundance of plants and insects in dry regions and can be used to predict the dynamics of plant and insect populations in a changing climate and to evaluate the effectiveness of different land use management strategies and protection of biodiversity.

3 Results and Discussion

The study tested various farming methods aimed at optimizing the use of water resources and reducing soil degradation in the dry regions of Uzbekistan. Algorithm for solving the Lotka-Volterra equations with diffusion:

1. Setting task parameters:

- Area L size .
- Number of nodes in x and y: N_x, N_y.
- Simulation T time.
- Number of time steps N_t.
- Spatial steps: $\Delta x = \frac{L}{N_x - 1}$, $\Delta y = \frac{L}{N_y - 1}$.
- Time step $\Delta t = \frac{T}{N_t}$.

2. Setting model parameters for populations N_1 and N_2:

- For a population N_1:
- Growth rate r_{1N_1}.
- Environment capacity K_{1N_1}.
- Competition β_{12N_1} coefficient.
- Diffusion D_{1N_1} coefficient.
- For a population N_2.
- Growth rate r_{1N_2}, r_{2N_2}.
- Capacity of the environment K_{1N_2}, K_{1N_2}.
- Competition coefficient β_{12N_2}, β_{21N_2}.
- Diffusion coefficient D_{1N_2}, D_{2N_2}.

3. Initialization of initial conditions for populations N_1 and N_2:
The initial values of population numbers are set in the central region of the grid.
4. Iterative process for solving equations:
For each time step nnn from 0 to N_t-1.
a. Calculation of diffusion terms:
For each grid point *i* and *j* within the area (excluding borders):

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$$\frac{\partial^2 N_1}{\partial x^2} \approx \frac{N_1[i+1, j] - 2N_1[i, j] + N_1[i-1, j]}{\Delta x^2}.$$
$$\frac{\partial^2 N_1}{\partial y^2} \approx \frac{N_1[i, j+1] - 2N_1[i, j] + N_1[i, j-1]}{\Delta y^2}.$$
$$\frac{\partial^2 N_2}{\partial x^2} \approx \frac{N_2[i+1, j] - 2N_2[i, j] + N_2[i-1, j]}{\Delta x^2}.$$
$$\frac{\partial^2 N_2}{\partial y^2} \approx \frac{N_2[i, j+1] - 2N_2[i, j] + N_2[i, j-1]}{\Delta y^2}. \tag{2}$$

b. Update population numbers to account for diffusion and interaction:

$$N_1^{new} = N_1 + \Delta t\left(D_{1N_1}\left(\frac{\partial^2 N_1}{\partial x^2} + \frac{\partial^2 N_1}{\partial y^2}\right)\right) - r_{1N_1} N_1\left(1 - \frac{N_1 + \beta_{12N_1} N_2}{K_{1N_1}}\right).$$
$$N_2^{new} = N_2 + \Delta t\left(D_{2N_2}\left(\frac{\partial^2 N_2}{\partial x^2} + \frac{\partial^2 N_2}{\partial y^2}\right)\right) - r_{2N_2} N_2\left(1 - \frac{N_2 + \beta_{21N_2} N_1}{K_{2N_2}}\right). \tag{3}$$

c. Updating N_1 and values N_2:

$$N_1 = N_1^{new}.$$
$$N_2 = N_2^{new}. \tag{4}$$

5. Saving data for graphic display:
At each time step nnn we save the current values N_1 and N_2.
6. Construction of 3D graphs of population numbers (Figure 1).

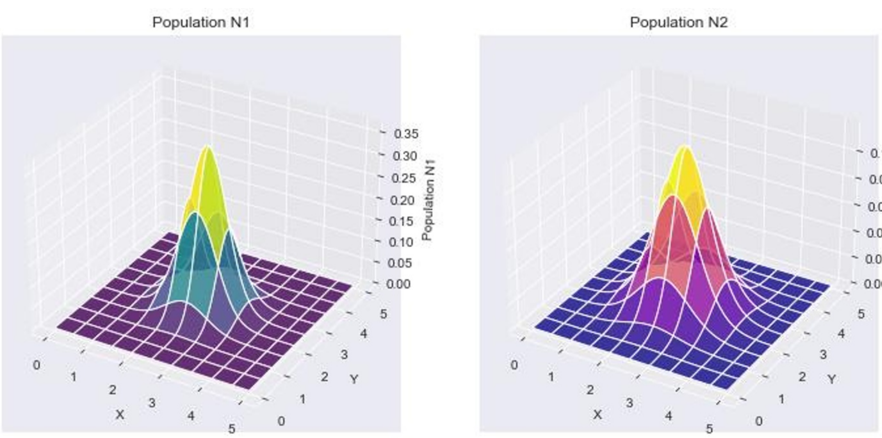

Fig. 1. Construction of 3D graphs of population numbers.

Interactions between plant and parasitic insect populations varied depending on climatic conditions. With increasing temperatures and decreasing precipitation, the number of parasitic insects increased, which required strengthening measures for biological plant protection. The introduction of drought-resistant plant varieties and the use of biological control methods have made agricultural systems more resilient to climate change. The development of green areas and infrastructure for the sustainable use of natural resources has improved the ecological condition of regions and increased their ability to adapt to climate change. The study results highlight the importance of an integrated approach to natural resource management and adaptation to climate change in the dry regions of Uzbekistan. Implementation of efficient farming methods, protection and restoration of ecosystems, sustainable use of resources and educational initiatives contribute to mitigating the negative impacts of climate change and preserving biodiversity. The Lotka-Volterra model has proven to be a useful tool for predicting population changes and developing adaptation strategies.

4 Conclusion

In the context of a changing climate and increasing aridity, biodiversity conservation and sustainable management of natural resources in the dry regions of Uzbekistan are critical challenges. This article examines various land management strategies and adaptation measures aimed at mitigating the impacts of climate change and conserving biodiversity. The main results of the study showed that the introduction of efficient farming methods, such as drip irrigation and optimization of water resource use, can significantly reduce soil degradation and reduce water consumption. Ecosystem conservation and restoration measures, including tree planting and protected areas, help improve the environment and increase biodiversity. The use of renewable energy sources, such as solar and wind energy, has also been found to help reduce pressure on ecosystems and reduce greenhouse gas emissions. Educational campaigns and information events have increased public awareness of climate change and contributed to public involvement in decision-making. The Lotka-Volterra model, used to predict the impact of climate change on plant and insect populations, has been shown to be effective in analyzing population dynamics and developing adaptation strategies. Predicting population changes in response to climate factors allows for the development of more accurate and effective measures for the conservation of biodiversity and sustainable management of natural resources. It is important to integrate scientific and innovative initiatives in the field of climate change research and sustainable development. An integrated approach, including the introduction of new technologies, protection of ecosystems, sustainable use of resources and raising public awareness, allows creating conditions for sustainable development of regions and improving their ability to adapt to changing climatic conditions.

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