MEASUREMENT OF NON-ELECTRIC QUANTITIES

MONITORING SYSTEM FOR THE POPULATION STATUS OF RARE AND ENDANGERED FAUNA SPECIES IN UKRAINIAN NATURE RESERVES

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Abstract. The article describes the process and results of developing a model for assessing the risk and causes of extinction of rare fauna species in the reserves of the western part of Ukraine, considering specific environmental conditions of the region. An information model of the system has been developed, which includes the collection of data from GPS devices and mapping resources to create an interactive map with population indicators. The process of assessing the status of populations based on fuzzy logic is also described, which allows to take into account uncertainty in the input data and make more accurate predictions about the status of species. The system was implemented using modern technologies such as React for the frontend, Node.js for the backend, Mapbox for interactive maps, and MongoDB for data storage.

Key words: monitoring, fuzzy model, biodiversity, environmental management, system design.

1. Introduction

Endangered fauna is one of the most pressing environmental issues [1] that is constantly gaining momentum due to the impact of environmental change. Biodiversity, which is the basis of ecosystem stability, is seriously threatened by the decline in the number of species and their extinction. The decline in species diversity affects all levels of the ecosystem, from plant populations to predators, and leads to disruption of natural relationships between species, which has negative consequences for the stability of ecological processes.

The main causes of species extinction are the loss of natural habitats [2, 3, 4], which results in the disappearance of conditions for their existence and reproduction. Land urbanization and development, deforestation, water pollution, and destruction of natural areas due to agricultural activities are all factors that upset the ecological balance and reduce the area of natural habitats [5]. For some species that have limited habitats or specific environmental requirements, even minor changes in nature can be catastrophic.

In addition, human-induced climate change is becoming more and more noticeable, putting additional pressure on fauna populations. Rising temperatures, changes in precipitation patterns, flooding or drying up of water bodies create new conditions to which animals do not always have time to adapt. This leads to a shift in habitats, a reduction in the amount of food, and a lower chance of reproduction for many species.

Thus, the problems associated with the disappearance of species require a comprehensive approach to their study and constant monitoring [6]. To effectively manage populations, it is necessary to have scientifically based tools to assess the status of species and the factors that affect them. Monitoring is an important part of these measures [7], as it allows timely detection of changes in the number and condition of populations, which makes it possible to adjust strategies for the protection and restoration of biodiversity.

2. Goal

The aim of the work is to develop a system for monitoring the status of rare and endangered species in the reserves of Western Ukraine. The system is designed to ensure scientifically based biodiversity management and promote the conservation of these species through population assessment, identification of risk factors and the effectiveness of conservation measures.

To achieve the research goal, the following tasks need to be accomplished:

1) analyze existing systems for monitoring the status of populations of rare and endangered species;

2) analyze and identify the main factors that can lead to the extinction of fauna;

3) develop a model for assessing the state of populations based on fuzzy logic;

4) implement the system software to present population monitoring, management and evaluation data in a user-friendly manner.

The scientific novelty of the results obtained is the development of a model based on fuzzy logic for assessing the risk and causes of extinction of rare fauna species in the reserves of Western Ukraine, taking into account environmental conditions.

3. Information model of the research object

In order to create an effective and reliable system for monitoring the status of populations of rare and endangered species in the reserves of Western Ukraine, it is necessary to understand what input and output parameters the system will operate with.

The input data for the system comes from several sources, which are presented below.

1. Population database – data on populations of rare and endangered species, location and size of populations, as well as statistics on the distribution of species.
2. Geolocation system – mapping data on the territories of reserves and marking the location of populations with their migration routes.
3. Statistics are data about the fauna that have been obtained over a period of time, for example, for previous years. These data are essential for analyzing population dynamics and trends.
4. Data from GPS devices – uses satellite technology to determine the exact geographic position of the device. GPS devices can be attached to animals or used to determine the location of nests, foraging areas, migration areas, etc.
5. Data from topographic maps are useful for studying large areas and large mammals such as predators or migratory species. Such "topographic maps of animals" can be an effective tool in scientific research and conservation efforts.

The output of this system will be:

- general information about rare and endangered animals – information about animals in the western part of Ukraine;
- data visualization using a movement map – representation of information on animal movements in the form of a graphical representation on a map – this method makes it easy to perceive and understand the routes and movements of animals in their natural environment;
- geospatial data – the coordinates of animal detection sites obtained from GPS devices, as well as topographic data and mapping materials;
- displaying data in charts – includes the presentation of information about animals in the form of graphical charts or graphs, which allows for effective analysis and comparison of data

4. Methods of collecting and organizing data in the system

When developing a system for assessing the status of populations of rare and endangered species, it is first necessary to identify the main parameters and indicators by which this status is determined.

Animal extinction can have many causes [1, 5, 8] that interact with each other:

- loss of natural habitat – the destruction of natural habitats due to construction, deforestation, agricultural activities and other anthropogenic interventions can lead to the loss of the necessary environment for survival and reproduction;
- climate change – global climate change caused by human activity can affect the distribution of animals, their access to food and shelter, which can lead to the extinction of some species;
- lack of protection – illegal hunting, animal trafficking, and lack of effective protection can lead to population decline and species extinction;
- overpopulation – an increase in the human population leads to an increase in the use of natural resources and competition for space and resources, which can lead to the displacement of animals and loss of biodiversity.

When we talk about the problem of habitat loss, it is usually driven by specific indicators [1, 4, 6]. Below are some general examples of metrics that can be taken into account when setting the maximum permissible loss of natural habitat for animals:

- preservation of the natural environment for breeding – at least 90 % of the natural environment necessary for breeding and reproduction of populations;
- Ensuring access to water resources – maintaining access to natural water bodies on at least 80 % of the territory inhabited by a particular species;
- Preventing fragmentation of natural areas – the maximum size of infrastructure projects that may cause fragmentation of natural habitats should not exceed 5 % of the total area of the territory;
- preservation of food resources – ensuring access to natural food sources in the amount of at least 70 % of the area of the animals' living space.

As for the climate change problem, there are maximum permissible temperature limits, namely:

- air temperature – the minimum temperature should not be less than –20 degrees Celsius. In turn, there should not be high temperatures, should not exceed 40–45 degrees Celsius;
- water temperature – the minimum water temperature should be approximately 5 degrees Celsius. The maximum water temperature should not be more than 30–35 degrees Celsius.

To understand some parameters, you need to know how animals move and change their location. Animal movements can be tracked using various methods [9, 10, 11], such as GPS tags, radio telemetry, microchip markings, as well as modern technologies like satellite systems, camera traps, surveillance cameras, and mobile app-based monitoring technologies. The parameters such as habitat loss and overpopulation are determined using GPS devices [12, 13].

Fig. 1. GPS tracker

The GPS tracker (Fig. 1) is designed to track the movement and location of an object in real time. It is used to track animals and any moving objects in general. The GPS tracker actively monitors and transmits data on the object's movement in real time.

Fig. 2. GPS receiver

The GPS receiver (Fig. 2) is designed to receive signals from satellites and determine the location at a specific point in time. It is commonly used for location, positioning, and navigation. GPS receivers are also used as components in more complex systems or devices, such as smartphones, car navigators, etc.

5. Development of a system model based on fuzzy logic

Fuzzy logic is an extension of classical logic, where truth is considered as a linguistic variable that can take on values such as "very true", "more or less true", "not very false", etc. These linguistic values are expressed as fuzzy sets. Unlike classical logic, where "True" and "False" have two possible states, fuzzy logic uses a degree of truth ranging from 0 (False) to 1 (True). Thus, logical operations are no longer represented by truth tables, but are defined by functions that take into account the uncertainty in the values. Only in some cases, when the values of variables are 0 or 1, these functions can be reduced to the truth table of classical logic [14, 15].

The following parameters will be used to assess the state of populations of rare and endangered species of fauna based on the construction of a fuzzy model:

- an indicator of preserving the natural environment for breeding;
- an indicator of access to water resources;
- an indicator of food resource conservation;
- air temperature;
- water temperature.

For all parameters, the terms will be set as low, moderate, and high.

The general scheme of the data structure for the fuzzy model is shown in Fig. 3.

This diagram illustrates that the assessment of the ecological safety of fauna in western Ukraine will be calculated according to the values of these input parameters using fuzzy logic tools.

The output parameter will be defined using the terms "healthy", "moderate", and "harmful".

Development of a model for a fuzzy logic controller

The system is designed to assess the ecological safety of fauna in Western Ukraine using fuzzy logic methods. The system takes into account five key input parameters and provides an assessment of the ecological state using three output terms.

Triangular membership functions were chosen to represent the input and output parameters of the fuzzy model.

Membership functions:

1. An indicator of the preservation of the natural environment for reproduction (Fig. 5).

The function reflects the quality of the breeding environment for animals, where a high level is represented by a wider range of values to ensure population stability.

2. An indicator of access to water resources (Fig. 6).

The graph shows a smooth transition between terms, which reflects the real situation with the availability of water for animals.

3. An indicator of food resource conservation (Fig. 7).

The function takes into account seasonal fluctuations in the availability of food resources.

4. Air temperature (Fig. 8).

Takes into account the comfortable temperature range for most species of fauna in the region. Low temperatures (below 5 °C) force animals to spend more energy to maintain their body's heat balance and can lead to migration or hibernation for some species. Normal temperature (5–25 °C) creates optimal conditions for the activity of most species of fauna, providing an efficient metabolism and favorable conditions for reproduction and feeding of offspring. High temperatures (above 25 °C) can cause heat stress in animals, forcing them to seek shaded areas and water bodies for cooling, and can also negatively affect the availability of food due to drying out of vegetation.

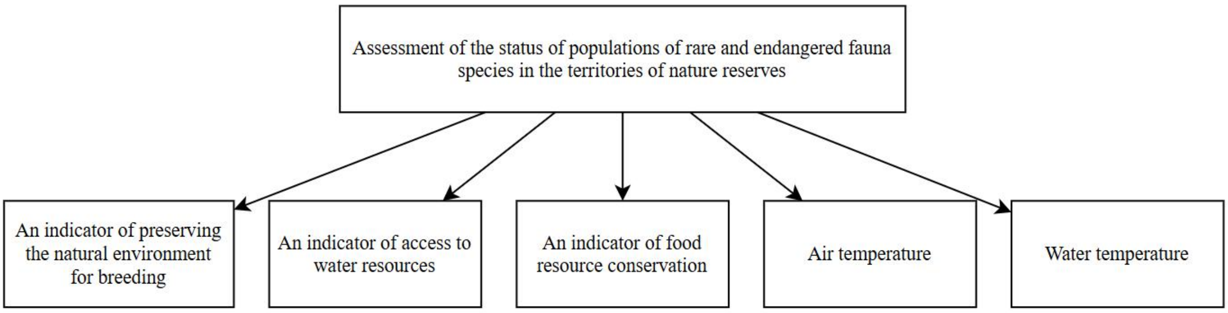

Fig. 3. General data structure system for a fuzzy model

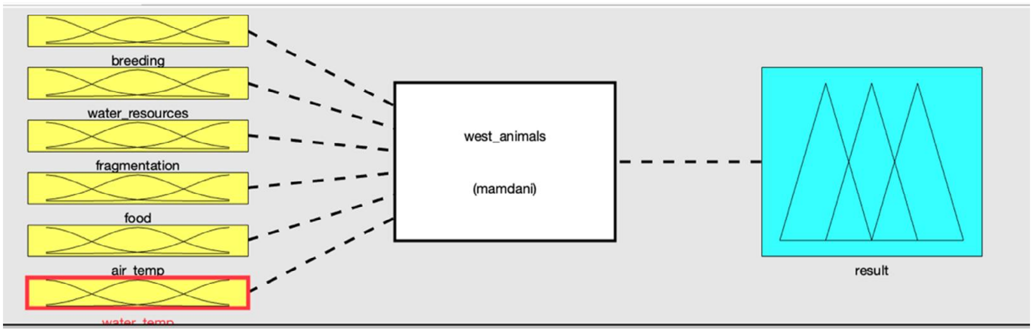

Fig. 4. Input and output parameters of the system

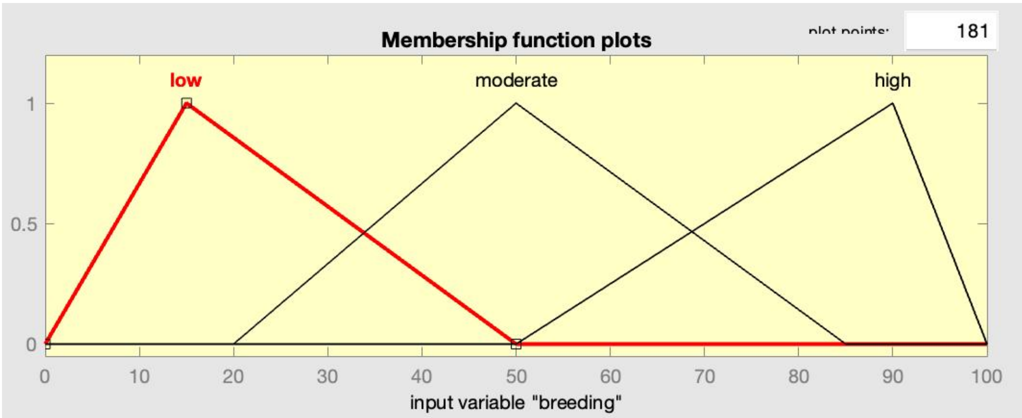

Fig. 5. The membership function of the parameter "preservation of the natural environment for reproduction"

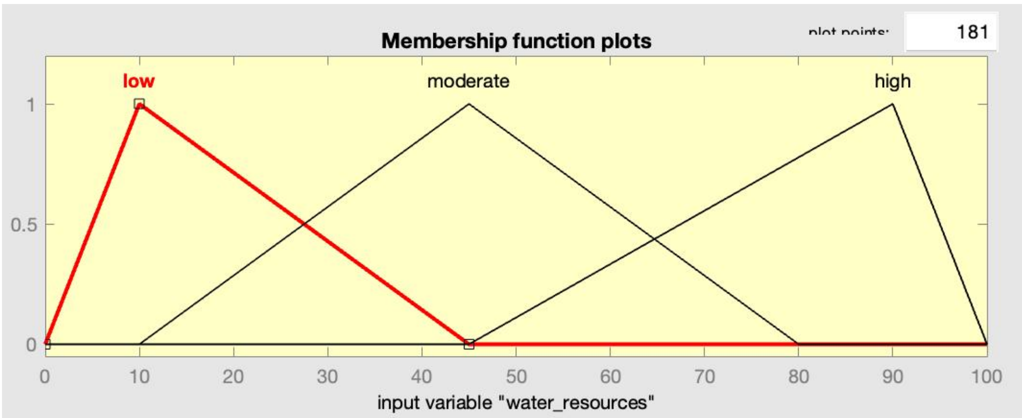

Fig. 6. The membership function of the parameter "ensuring access to water resources"

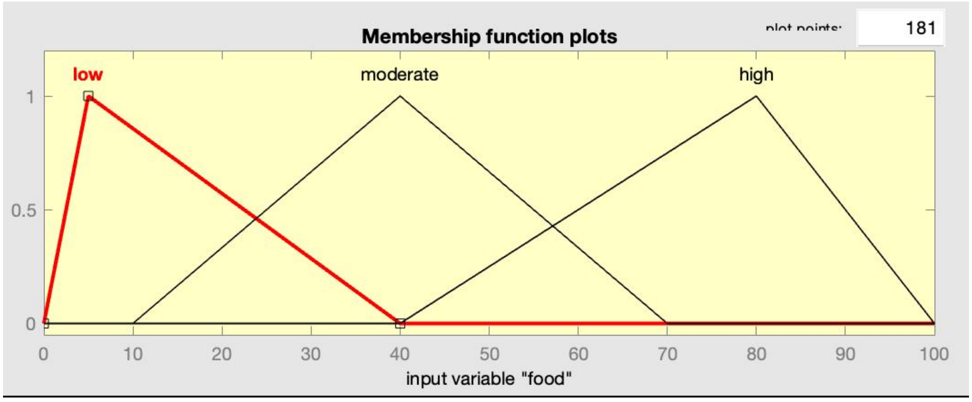

Fig. 7. The membership function of the parameter "food resources conservation"

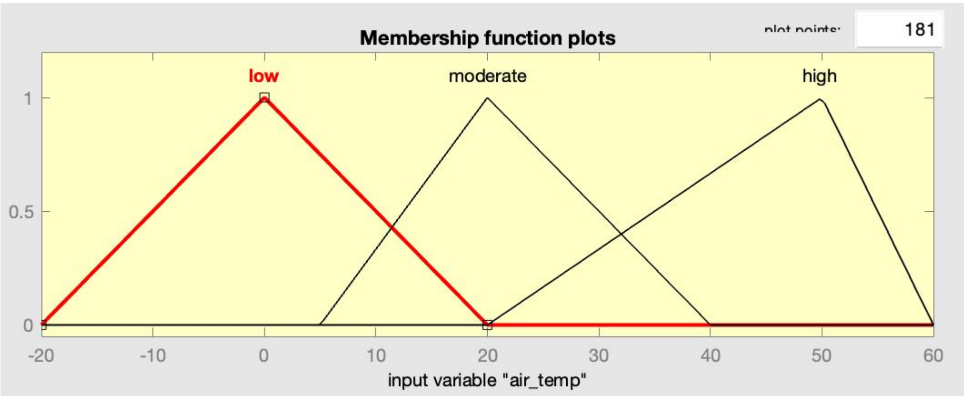

Fig. 8. The function of the "air temperature" parameter membership

5. Water temperature (Fig. 9).

Reflects the optimal temperature conditions of water bodies for aquatic and semi-aquatic species. Cold water (below 10 °C) can slow down the metabolism of aquatic organisms and reduce their activity, especially during the breeding season. Moderate temperatures (10–20 °C) provide optimal conditions for most fish and amphibian species, contributing to their normal development and vital activity. Warm water (above 20 °C) can lead to a decrease in dissolved oxygen in the water and create stressful conditions for cold-loving species, although some species may prefer such temperatures.

After fuzzification (definition of the term set and dependency function), we formed the rules of logical inference taking into account all the defined term sets, input linguistic variables for each term of the output variable (Fig. 10).

The system uses a comprehensive set of rules that take into account the relationships between all input parameters. The rules are designed to ensure that:

− accurate assessment of the environmental situation;

− taking into account critical combinations of parameters;

− balanced influence of various factors.

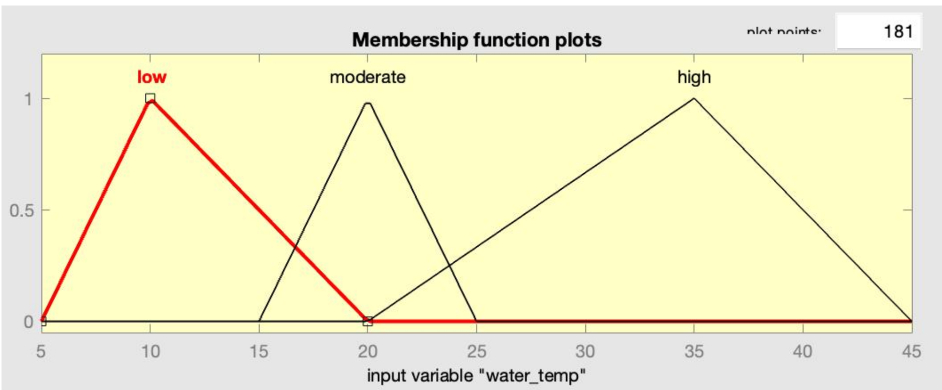

Fig. 9. The function of the "water temperature" parameter membership

Fig. 10. Rules of logical inference

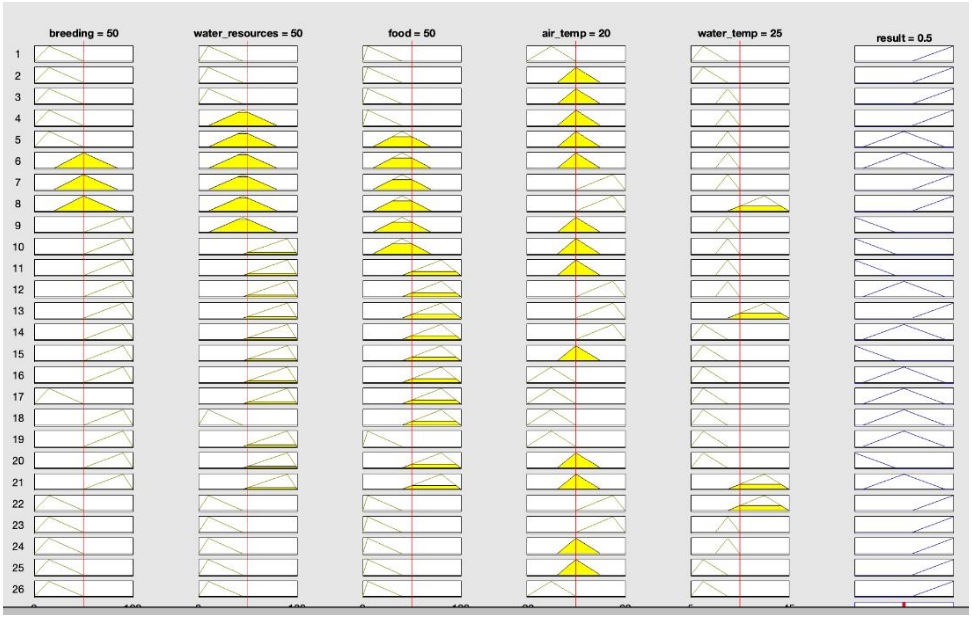

Fig. 11. Graphical representation of the rules

The graphical representation of the rules demonstrates the relationships between input parameters and their impact on the final environmental safety assessment. This allows you to visually assess the system's performance and check the correctness of the established dependencies (Fig. 11).

The developed system of fuzzy logic rules allows for a comprehensive assessment of the environmental state, taking into account the relationships between parameters and their critical combinations. The graphical representation of the rules provides visual control of the correctness of the established dependencies and facilitates the process of system configuration.

6. Components of the developed system

The created fuzzy model is a component of the implemented system for monitoring and assessing the state of populations of rare and endangered species of fauna in the reserves of the western part of Ukraine. Fig. 12 shows the use case diagram for this system, which depicts the actions an actor (user) can perform in the system. The description of actors and the specification of use cases are presented in the tables.

The data in the system is stored using the document-oriented database management system MongoDB. It is a database that provides flexibility and scalability when working with data. Unlike traditional relational databases, MongoDB stores data in BSON (Binary JSON) format, which allows you to work with complex data structures and easily adapt to changes in the data schema without the need to predefine the structure [16].

The database of the system for monitoring the status of populations of rare and endangered species of fauna in the reserves of Western Ukraine consists of a single table containing information about animals and their movements.

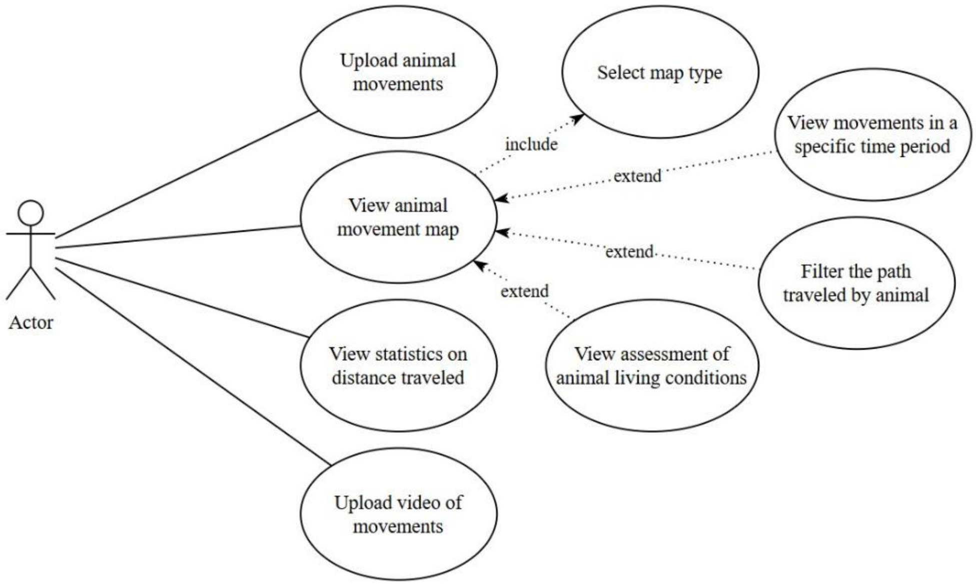

Fig. 12. Diagram of use cases

Table 1. Actor specification

Actor	Description
User	User of the system for monitoring the status of populations of rare and endangered species of fauna in the territory of nature reserves. The user can be: – educational institutions and students: The system can serve as a learning platform for universities and educational institutions to conduct research and educate students; Citizens and tourists: The general public and tourists can also be users, receiving information about the status and diversity of fauna in the reserves

Table 2. Specification of use cases

Option for use	Description
Upload animal movements	Users can upload their own data on animal movement
View animal movement map	The user can view a map with the movements of animals. It includes the ability to change the map view and is expanded by viewing movements in a specific time period and filtering the path traveled by the animal, as well as the ability to assess the state of the animal's living conditions
View statistics on distance traveled	The user can view statistics on the distance traveled by the animal. This includes a graph with the distance traveled in kilometers depending on the time
Upload video of movements	The user can upload the movement of animals on the map in video format and share it

This table is enough to store all the necessary information about animal movements. It contains the following attributes:

- animal_id – table identifier of integer type, contains a unique numeric value;
- species – a type of animal of type varchar;
- timestamp – the time when the animal was spotted on the map, of the timestamp type and must be in the format – 2025-01-01 12:00:00;
- lon – the location of the animal in longitude, decimal type;
- lat – location of the animal by latitude, decimal type;
- alt – animal location by altitude, decimal type;
- image_url – a web link to the image of the animal, type varchar;
- breeding – the value of preserving the natural environment for breeding at a particular location (used in a fuzzy model; decimal type);
- water_resources – an indicator of access to water resources at a particular location (used in the fuzzy model; decimal type);

– food – an indicator of food resource conservation at a particular location (used in the fuzzy model; decimal type);

– air_temperature – an indicator of air temperature at a specific location (used in a fuzzy model; decimal type);

– water_temperature – an indicator of water temperature at a specific location (used in a fuzzy model; decimal type).

Animal	
PK	animal_id (INT)
	species (varchar)
	timestamp (timestamp)
	lon (decimal)
	lat (decimal)
	alt (decimal)
	image_url (varchar)
	breeding (decimal)
	water_resources (decimal)
	food (decimal)
	air_temperature (decimal)
	water_temperature (decimal)

Fig. 13. Animal table

The system's user interface is developed using the React JavaScript library. React divides the interface into small components. A component is an independent unit that has its own state and can display content.

The initial interface (Fig. 14) displays the first data point of animal movements, for example, the Bison's initial location. The map shows the first starting point of animal movements, in our case it is the Bison and its start of movement.

When you hover over a point on the map (Fig. 14), you can see a window that displays brief information about the point, namely:

– the type of animal;
– tag, or identifier;
– the time the animal was at this point;
– latitude coordinate;
– longitude coordinate;
– height coordinate;
– the importance of preserving the natural environment for reproduction;
– indicator of habitat preservation for breeding;
– indicator of food resource conservation;
– air temperature indicator;
– water temperature indicator.

At the bottom of this window is an important indicator, namely, the value of the conditions in which the animal was at this coordinate. It is determined through complex algorithmic calculations that are embedded in the fuzzy model. This indicator can contain three values – harmful, moderate, and healthy, which means harmful, moderate, and healthy conditions for the animal, respectively (Fig. 15).

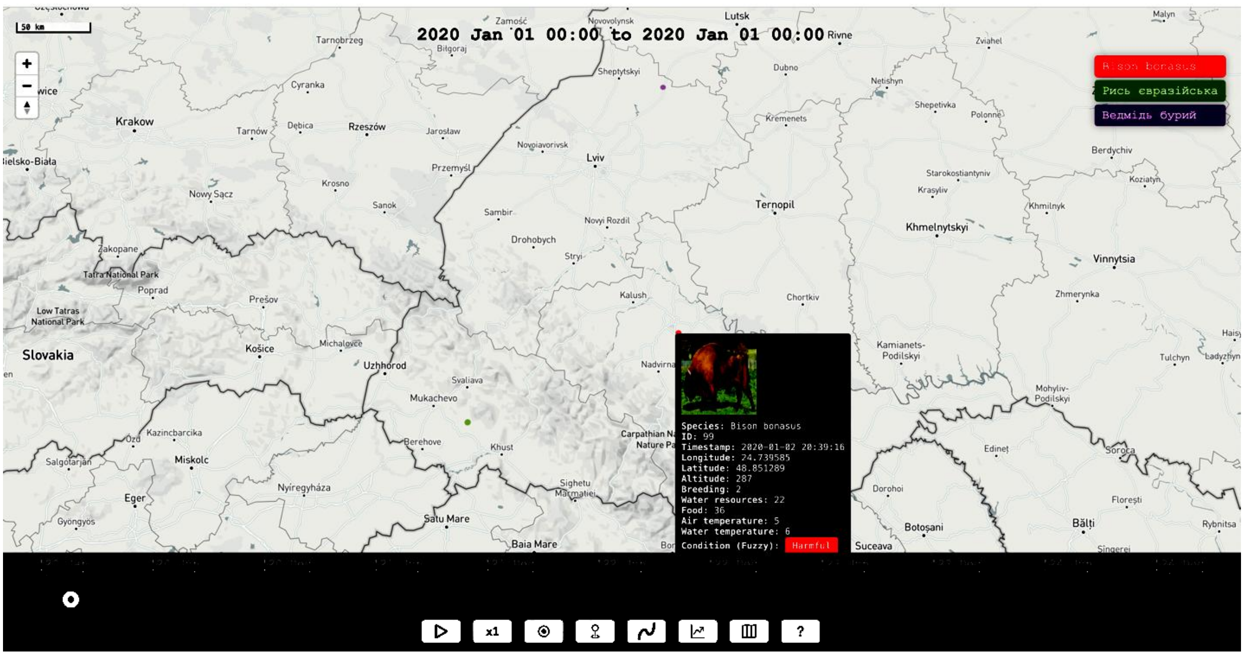

Fig. 14. Information about a point on the map

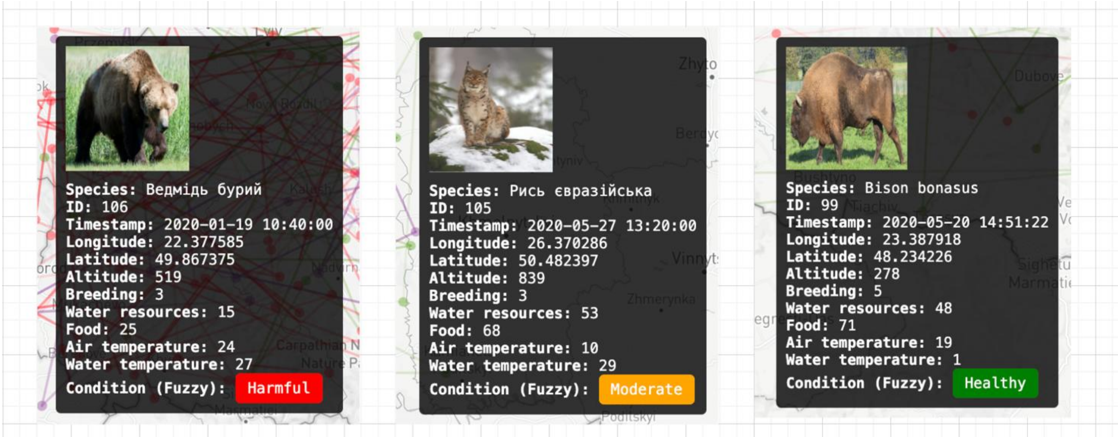

Fig. 15. Three different indicators of animal welfare

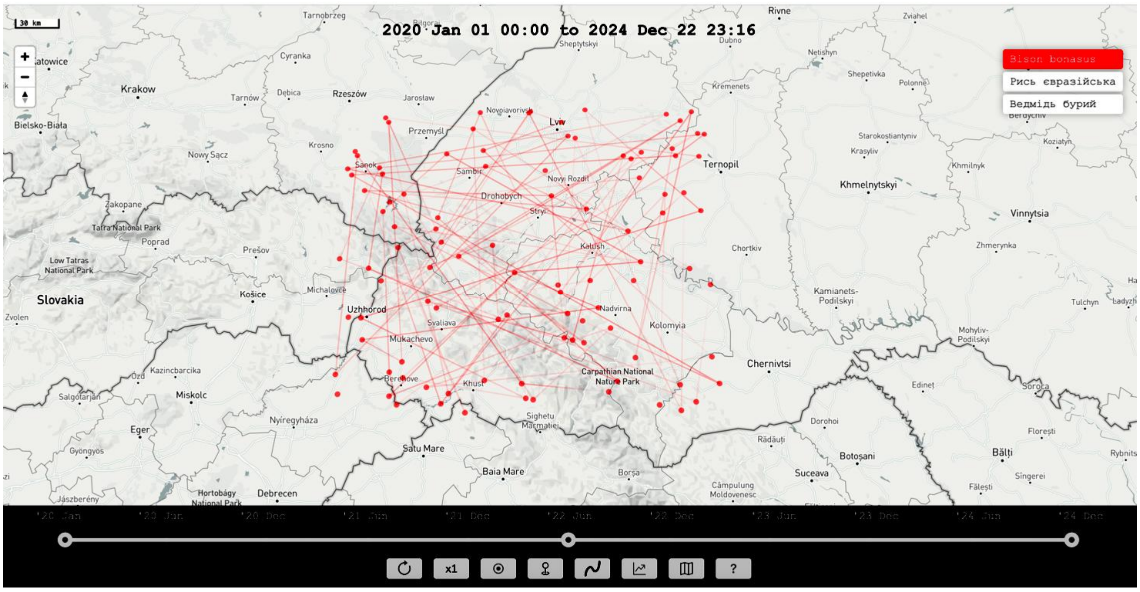

Fig. 16. Movement of the Bison for the entire period of time

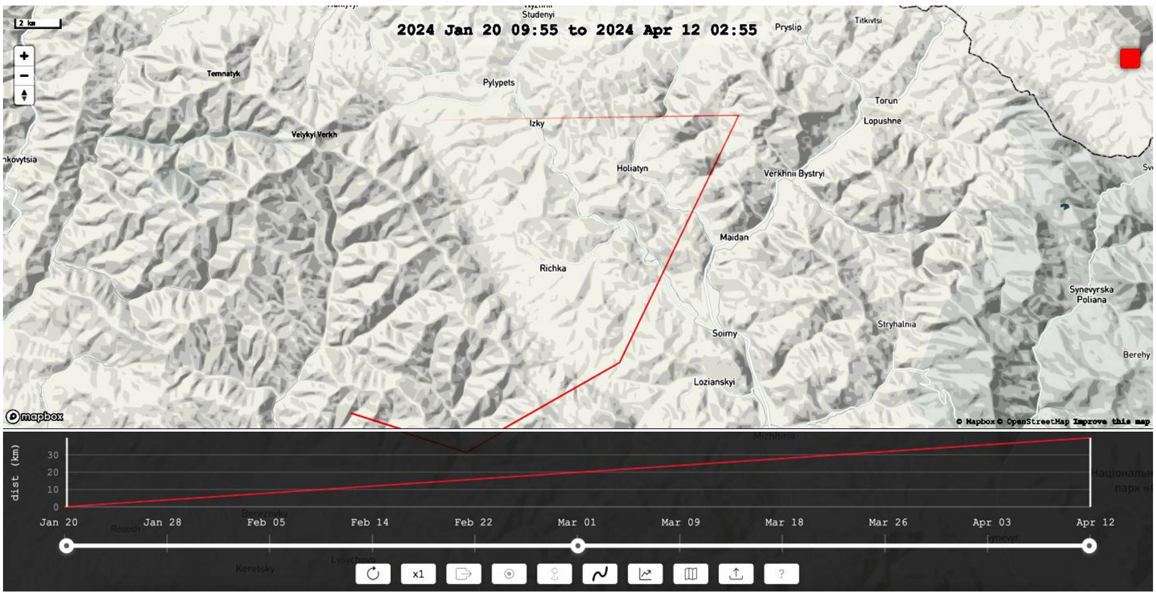

Fig. 17. Graph with animal movement

At the bottom of the screen (Fig. 14), there is a progress bar above which the dates of Bison's movements are displayed. We can drag this scale and thus update our map with new points. Also, by dragging this scale, you can clearly see how the location of the animal changes relative to a certain period of time. Let's drag this scale to the end (Fig. 15) and see how our map has changed.

The map (Fig. 17) shows the red line marking the animal's movements over the entire period of time. We can also see this information in the form of a graph, which shows how the distance traveled by the bison changed over a certain period of time.

You can change the map view to a dark style (Fig. 18) and a satellite view. This is done using the "map styles" button from the button section at the bottom of the screen.

You can also display the movement of several animals at once on the map. For example, let's add the movements of a bear and a lynx. Now, the map will contain red, green, and purple lines (Fig. 19).

Fig. 18. Dark view of the map

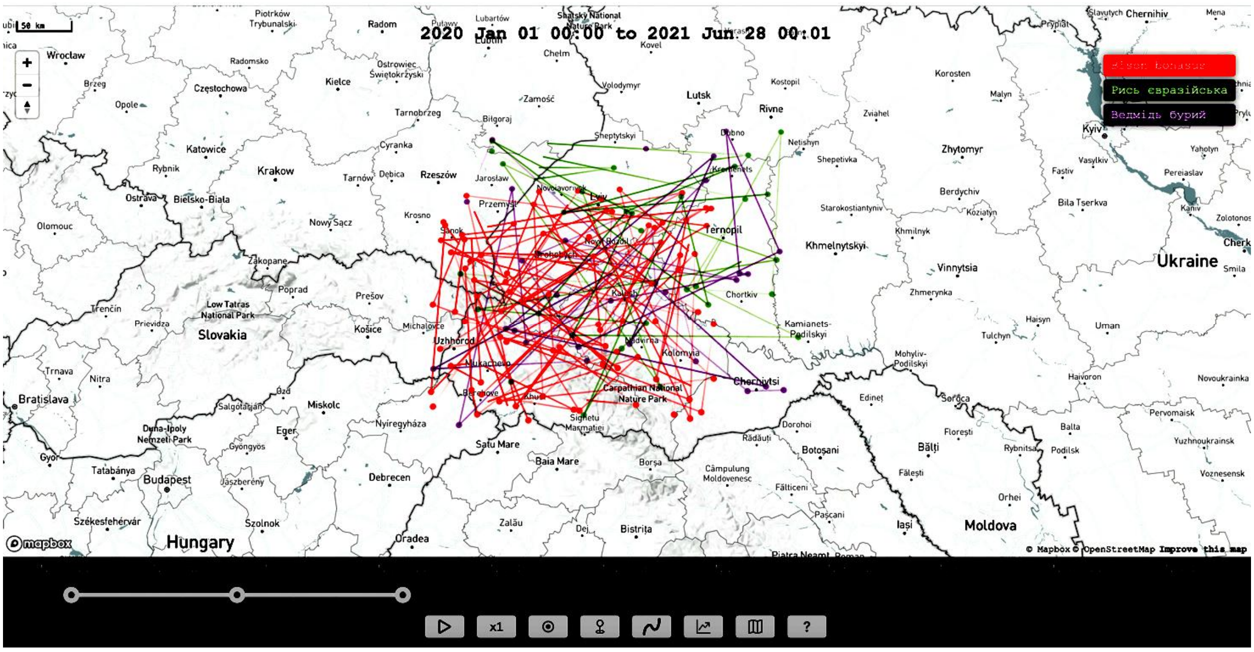

Fig. 19. Moving several animals

In the right corner of the screen (Fig. 19), there are three buttons of red, green, and purple colors, by clicking on which you can hide or show the movement of an animal. The buttons also display the names of the animals.

7. Conclusions

The developed system is a response to modern challenges in biodiversity conservation and allows integrating advanced technological solutions to assess the ecological status of species. The use of fuzzy logic became the basis for developing a model that takes into account the multifactorial impact of the environment and allows assessing the state of populations by critical environmental parameters.

The practical application of this system expands the capabilities of conservation organizations to effectively manage and monitor populations of endangered species. Thanks to the available analytical tools, the system is able to provide data for making informed decisions on species conservation, as well as for adapting conservation strategies depending on environmental conditions.

Overall, the established monitoring system is an important tool for ecological research, reserve management, as well as educational and awareness initiatives aimed at protecting the biodiversity of Western Ukraine

Conflict of Interest

The authors state that there are no financial or other potential conflicts regarding this work.

Gratitude

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