Monitoring of biodiversity of water communities

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Abstract. Biodiversity monitoring is a process of systematic collection, analysis and evaluation of data on the diversity of living organisms, their populations, communities and ecosystems in a certain territory or area. The purpose of biodiversity monitoring is to study changes in the composition and structure of biological systems over time. Biodiversity monitoring is carried out at different levels - from global to local, and may include both long-term programs and short-term studies. It is important to take into account the scale, methods and resources required for monitoring, as well as to ensure proper processing and analysis of the data obtained. Thus, biodiversity monitoring plays a key role in assessing the state of natural systems, adapting to climate change, developing strategies for nature conservation and supporting sustainable development.

1 Introduction

Biodiversity monitoring is an important tool for assessing the state of ecosystems, identifying trends in changes in biological diversity, identifying threats and taking measures to conserve natural resources. It may include various data collection methods such as field surveys, sample collection, population monitoring, DNA analysis, use of remote sensing, and others [1].

Biodiversity monitoring data allows scientists and policy makers to understand which species are under threat, which ecosystems need protection, and what actions should be taken to conserve nature. This data can also be used to develop strategies for the sustainable use of natural resources [2], the planning of protected areas and the development of environmental policies.

Biomonitoring is a method of studying and evaluating the state of the environment and its changes by analyzing biological organisms or their parts[3].

Biomonitoring can be carried out at various levels, including [5]:

Soil biomonitoring: Animals (eg worms), plants or microorganisms are used to determine the content of contaminants such as heavy metals, pesticides or radioactive substances in the soil.

Air biomonitoring: plants (bioscoppers) [6].

Biomonitoring provides information on long-term trends in environmental pollution, allows you to determine and predict changes in ecosystems and evaluate the effectiveness

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of environmental protection programs. It is an important tool for maintaining and improving environmental quality and protecting public health.

Bioindication is the process of using biological organisms or their reactions as indicators to assess the quality and state of the environment. It allows identifying informative components of ecosystems that can serve as indicators of the ecological state and changes in the environment. Here are several approaches used in bioindication to search for informative components of ecosystems [8]:

Indicator species: Certain species of organisms can be used as indicators of specific environmental conditions or pollution. For example, some aquatic invertebrates are sensitive to pollution and may indicate the presence of certain substances in the water. Identification and monitoring of such indicator species provides information on the state of the ecosystem [9].

Biochemical indicators: The study of biochemical indicators in organisms can be a useful tool for assessing the ecological state. For example, measuring the levels of certain enzymes or biomarkers in animal or plant tissues may indicate the presence of contaminants or changes in environmental conditions.

Studying the diversity and composition of communities: Changes in the structure and diversity of biological communities can be indicative of changes in an ecosystem. An analysis of the composition of species and their relative abundances can help reveal the influence of factors such as pollution, loss of biodiversity, or changes in environmental conditions [10].

Bioaccumulation and Biomagnification: Some organisms have the ability to accumulate toxic substances in their tissues. Studying the level and type of contaminants found in organisms can provide information about the presence and distribution of contaminants in an ecosystem.

Bioindication provides valuable data on the ecological state and changes in the environment. By studying the informative components of ecosystems that respond to change, we can better understand ecological processes, evaluate the effectiveness of environmental protection measures, and develop strategies for sustainable ecosystem management [11].

The main task of bioindication is to assess the quality and state of the environment based on the reactions of biological organisms or their components. Here are some of the main tasks that are solved with the help of bioindication [10-11]:

Determining the level of pollution: bioindication allows you to assess the level of environmental pollution, including water, soil, air and other components. Biological organisms, especially indicator species, can accumulate contaminants and reflect the level of their presence.

Monitoring environmental change: Bioindication is used to detect changes in ecosystems and the environment. The study of changes in the composition of biological communities, species diversity, distribution of organisms and their behavior can indicate the impact of anthropogenic factors, climate change and other ecological processes.

Assessing the effectiveness of environmental protection measures: Bioindication can help evaluate the effectiveness of environmental protection programs and measures. Comparison of data before and after the implementation of measures allows you to determine what changes have occurred in biological organisms and ecosystems, and how successful the actions taken have been.

Prevention and prediction of environmental problems: bioindication can serve as a tool for the prevention and prediction of environmental problems. Studying the response of biological organisms to changes in the environment can help identify potential problems and risks and take appropriate measures to prevent or manage them.

The main task of bioindication is to use biological organisms as indicators to obtain information about the state of the environment and its changes. This allows you to make decisions based on reliable data and implement sustainable management of ecosystems [12].

The essence of environmental regulation is the development of criteria and standards that allow assessing the degree of influence of anthropogenic (human) factors on the sustainability and biodiversity of ecosystems. Environmental regulation is one of the tools of environmental management and allows you to assess and control the impact of human activity on the environment.

In the process of environmental regulation, certain criteria and indicators are established that allow assessing the quality and condition of ecosystems. These criteria and indicators may include aspects such as water quality, air pollution, noise levels, levels of radiation pollution, loss of biodiversity and other factors affecting ecosystems.

Assessment of the degree of influence of anthropogenic factors on the sustainability and biodiversity of ecosystems is carried out using scientific methods and data collected in the process of monitoring and research. Based on these data, maximum permissible levels of pollution and other standards are developed that regulate the impact of human activity on the environment [12-13].

Environmental regulation is essential for protecting the environment and preserving biodiversity. It helps to determine an acceptable level of human impact, prevents negative impacts on ecosystems, and helps ensure the sustainable use of natural resources.

The population approach is used to assess the species richness and biodiversity of aquatic communities using simple "indices". With this approach, the main attention is paid to the study of populations of individual species of aquatic organisms, such as fish, invertebrates, aquatic plants, and others [14].

2 Materials and methods

On the basis of data obtained from population monitoring, various "biodiversity indices" are built, which allow assessing the richness of species and the state of aquatic communities. These indices may include such indicators as the number of species, species richness indices, species distribution uniformity indices, and others [14].

The population approach is especially useful for assessing the state and health of aquatic ecosystems, as it allows you to identify changes in the populations of aquatic organisms that may be associated with water pollution, changing environmental conditions, changing water regimes, and other factors. It can also be used to assess the effectiveness of measures to restore and conserve aquatic ecosystems.

In general, the population approach is an important tool for assessing the biodiversity of aquatic communities and taking measures for their conservation and sustainable use. It complements other biodiversity monitoring and research methods, such as biodiversity monitoring at the species and ecosystem levels, and contributes to a better understanding of the state of aquatic ecosystems [15].

Building a fuzzy model based on experimental data and improving the Sugeno fuzzy logic model can be an important task for monitoring the biodiversity of aquatic communities and predicting the causes and development of the water pollution process.

To build a fuzzy model for monitoring the biodiversity of aquatic communities based on experimental data, you need data related to the species composition and distribution of organisms in aquatic ecosystems. To build a model for assessing water salinity, a sample (X_r, y_r), $r = \overline{1,M}$ was received from experts, where $X_r = (x_{r,1}, x_{r,2}, ..., x_{r,n})$ is the input vector of the r-pair and y_r is the corresponding output vector. These data will help define fuzzy variables and fuzzy rules that describe the relationships between input and output variables in the model, such as pollutant concentrations, water quality, and other parameters that affect biodiversity [16].

Our task is to build a fuzzy model as follows:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} - w_{jp} \quad \text{with weight}\right) \rightarrow y_j = b_{j,0} + b_{j,1}x_1 + \ldots + b_{j,n}x_n + \\ + b_{j,n+1}x_1^2 + \ldots + b_{j,2n}x_n^2 + \ldots + b_{j,n+l-1}x_1^l + \ldots + b_{j,ln}x_n^l. \tag{1}$$

Improving the construction of the Sugeno fuzzy logic model for monitoring the biodiversity of aquatic communities can include various methods and approaches. For example, you can analyze and pre-process data to extract the most significant input variables and model rules. You can also use optimization and adaptive learning techniques to tune model parameters based on new data and update the model over time.

In the process of building a model, it is necessary to find the values of the coefficients of the fuzzy inference rule as follows [17]

$$B = (b_{1,0}, b_{2,0}, \ldots, b_{m,0}, b_{1,1}, b_{2,1}, \ldots, b_{m,1}, \ldots, \\ \ldots, b_{1,n} b_{2,n}, \ldots, b_{m,n}, \ldots, b_{1,ln} b_{2,ln}, \ldots, b_{m,ln}), \\ i = \overline{1,n},\ j = \overline{1,m} \tag{2}$$

And minimize the following function:

$$r = \sum_{1,M}\left(y_r - y_r^f\right)^2 \rightarrow \min \tag{3}$$

The solution of problem (1) corresponds to the solution of the following equation:

$$\boldsymbol{Y} = \boldsymbol{A} \cdot \boldsymbol{B}, \tag{4}$$

Where:

$$A = \begin{bmatrix} \beta_{1,1}, \ldots, \beta_{1,m}, \ x_{1,1} \cdot \beta_{1,1}, \ldots, x_{1,1} \cdot \beta_{1,m}, \ \ldots, \ x_{1,n} \cdot \beta_{1,1}, \ldots, \\ \quad \ldots, x_{1,n} \cdot \beta_{1,m}, \ldots, \ x^l_{1,1} \cdot \beta_{1,1}, \ldots, x^l_{1,1} \cdot \beta_{1,m}, \ \ldots, \ x^l_{1,n} \cdot \beta_{1,1}, \ldots, x^l_{1,n} \cdot \beta_{1,m} \\ \vdots \\ \beta_{M,1}, \ldots, \beta_{M,m}, x_{M,1} \cdot \beta_{1,1}, \ldots, x_{M,1} \cdot \beta_{1,m}, \ldots, \\ \quad \ldots, x_{M,n} \cdot \beta_{M,1}, \ldots, x_{M,n} \cdot \beta_{M,m}, \ldots, x^l_{M,1} \cdot \beta_{1,1}, \ldots, x^l_{M,1} \cdot \beta_{1,m}, \ldots, x^l_{M,n} \cdot \beta_{M,1}, \ldots, x^l_{M,n} \cdot \beta_{M,m} \end{bmatrix}. \tag{5}$$

Fuzzy logic allows you to take into account the ambiguity and fuzziness in the data, and the Sugeno fuzzy algorithm can be used to make conclusions based on fuzzy rules and logic [18].

3 Results and Discussion

A fuzzy logical Sugeno model for assessing the ecological state of a reservoir based on biological indicators has been constructed [19-23].

If:

$$\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{11}^j)a_{11}^j}{\sum_{j=1}^{q}\mu(a_{11}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{12}^j)a_{12}^j}{\sum_{j=1}^{q}\mu(a_{12}^j)}\wedge\ldots\wedge x_6=\frac{\sum_{j=1}^{q}\mu(a_{16}^j)a_{16}^j}{\sum_{j=1}^{q}\mu(a_{16}^j)}\right)\vee$$
$$\vee\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{21}^j)a_{21}^j}{\sum_{j=1}^{q}\mu(a_{21}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{22}^j)a_{22}^j}{\sum_{j=1}^{q}\mu(a_{22}^j)}\wedge\ldots\wedge x_6=\frac{\sum_{j=1}^{q}\mu(a_{26}^j)a_{26}^j}{\sum_{j=1}^{q}\mu(a_{26}^j)}\right) \tag{6}$$

Then:

$$y=b_{10}+b_{11}\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})}+b_{12}\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})}+b_{13}\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})}+$$
$$+b_{14}\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})}+b_{15}\frac{\sum_{j=1}^{n}\mu(x_5^{1j})x_5^{1j}}{\sum_{j=1}^{n}\mu(x_5^{1j})}+b_{16}\frac{\sum_{j=1}^{n}\mu(x_6^{1j})x_6^{1j}}{\sum_{j=1}^{n}\mu(x_6^{1j})}. \tag{7}$$

If:

$$\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{31}^j)a_{31}^j}{\sum_{j=1}^{q}\mu(a_{31}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{32}^j)a_{32}^j}{\sum_{j=1}^{q}\mu(a_{32}^j)}\wedge\ldots\wedge x_6=\frac{\sum_{j=1}^{q}\mu(a_{36}^j)a_{36}^j}{\sum_{j=1}^{q}\mu(a_{36}^j)}\right)\vee$$
$$\vee\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{41}^j)a_{41}^j}{\sum_{j=1}^{q}\mu(a_{41}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{42}^j)a_{42}^j}{\sum_{j=1}^{q}\mu(a_{42}^j)}\wedge\ldots\wedge x_6=\frac{\sum_{j=1}^{q}\mu(a_{46}^j)a_{46}^j}{\sum_{j=1}^{q}\mu(a_{46}^j)}\right) \tag{8}$$

Then:

$$y=b_{20}+b_{21}\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})}+b_{22}\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})}+b_{23}\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})}+$$
$$+b_{24}\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})}+b_{25}\frac{\sum_{j=1}^{n}\mu(x_5^{1j})x_5^{1j}}{\sum_{j=1}^{n}\mu(x_5^{1j})}+b_{26}\frac{\sum_{j=1}^{n}\mu(x_6^{1j})x_6^{1j}}{\sum_{j=1}^{n}\mu(x_6^{1j})}. \tag{9}$$

If:

$$\left(x_1 = \frac{\sum_{j=1}^{q} \mu(a_{51}^j) a_{51}^j}{\sum_{j=1}^{q} \mu(a_{51}^j)} \wedge x_2 = \frac{\sum_{j=1}^{q} \mu(a_{52}^j) a_{52}^j}{\sum_{j=1}^{q} \mu(a_{52}^j)} \wedge \ldots \wedge x_6 = \frac{\sum_{j=1}^{q} \mu(a_{56}^j) a_{56}^j}{\sum_{j=1}^{q} \mu(a_{56}^j)} \right) \vee$$
$$\vee \left(x_1 = \frac{\sum_{j=1}^{q} \mu(a_{61}^j) a_{61}^j}{\sum_{j=1}^{q} \mu(a_{61}^j)} \wedge x_2 = \frac{\sum_{j=1}^{q} \mu(a_{62}^j) a_{62}^j}{\sum_{j=1}^{q} \mu(a_{62}^j)} \wedge \ldots \wedge x_6 = \frac{\sum_{j=1}^{q} \mu(a_{66}^j) a_{66}^j}{\sum_{j=1}^{q} \mu(a_{66}^j)} \right) \quad (10)$$

Then:

$$y = b_{30} + b_{31} \frac{\sum_{j=1}^{n} \mu(x_1^{1j}) x_1^{1j}}{\sum_{j=1}^{n} \mu(x_1^{1j})} + b_{32} \frac{\sum_{j=1}^{n} \mu(x_2^{1j}) x_2^{1j}}{\sum_{j=1}^{n} \mu(x_2^{1j})} + b_{33} \frac{\sum_{j=1}^{n} \mu(x_3^{1j}) x_3^{1j}}{\sum_{j=1}^{n} \mu(x_3^{1j})} +$$
$$+ b_{34} \frac{\sum_{j=1}^{n} \mu(x_4^{1j}) x_4^{1j}}{\sum_{j=1}^{n} \mu(x_4^{1j})} + b_{35} \frac{\sum_{j=1}^{n} \mu(x_5^{1j}) x_5^{1j}}{\sum_{j=1}^{n} \mu(x_5^{1j})} + b_{36} \frac{\sum_{j=1}^{n} \mu(x_6^{1j}) x_6^{1j}}{\sum_{j=1}^{n} \mu(x_6^{1j})}. \quad (11)$$

Here: x_1 - Abundance, thousand ind./m^2; x_2 - Biomass, g/m^2; x_3 - Number of species; x_4 - Shannon diversity index, bit/spec.; x_5 - Biotic index Woodiwiss; x_6 - Parele index.

The statement "Biomass, g/m^2 should be close to 24.3" can be represented as follows:

$$\mu(a_{12}^j) = \left[1 + \frac{(a_{12} - 23)^2}{7} \right]^{-1}. \quad (12)$$

The statement "Parele index should be close to 0.55" can be represented as follows:

$$\mu(a_{14}^j) = \left[1 + 400(a_{14} - 0{,}55)^2 \right]^{-1}. \quad (13)$$

Evaluation of functions based on partial redundant fuzzy logic. It allows you to work with limited data and approximate the shape of a fuzzy type, which may be associated with the construction of fuzzy models and choose solutions based on fuzzy logic.

4 Conclusion

As a result, building a fuzzy model and using the Sugeno fuzzy algorithm to monitor the biodiversity of aquatic communities and predict the causes and development of the water pollution process can help in a more accurate and comprehensive assessment of the state of ecosystems.

The use of Sugeno's fuzzy algorithm for predicting the causes and features of the development of the water pollution process can help in determining the relationships between various pollution factors and predicting the consequences of changes in these factors on the biodiversity of aquatic communities.

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