

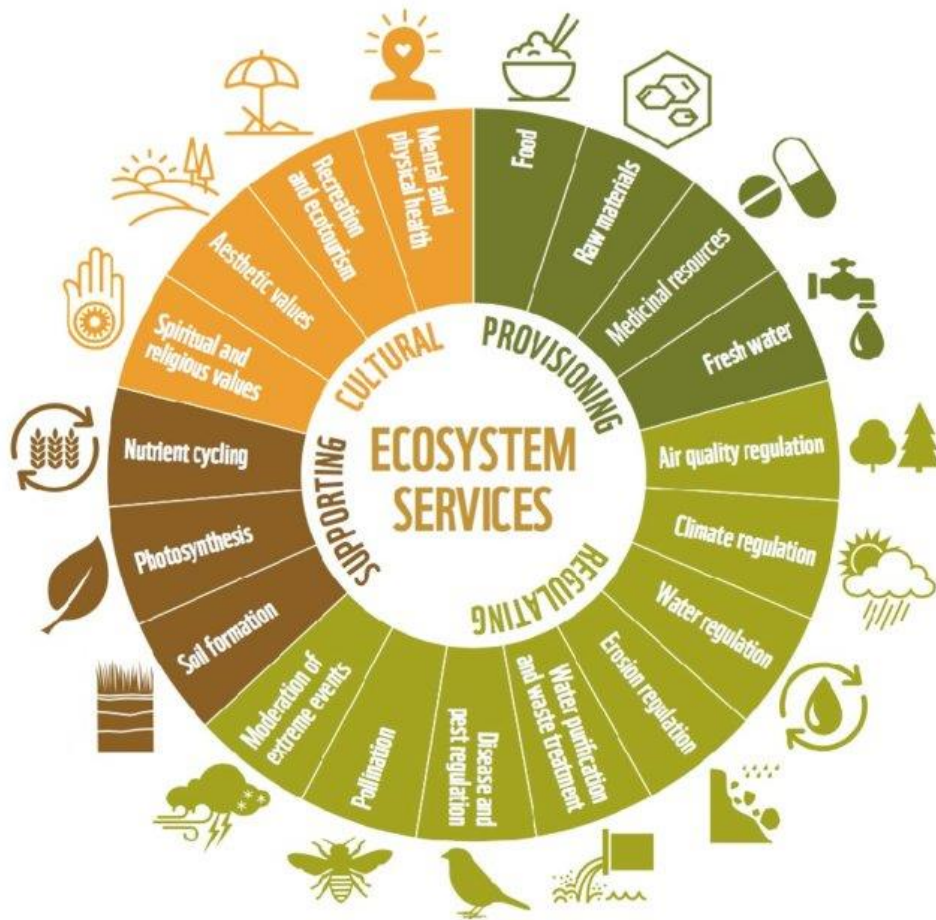
# ПОЧВЕННАЯ МАКРОФАУНА КАК ИНДИКАТОР ЭКОСИСТЕМНЫХ УСЛУГ В ШИРОТНОМ ГРАДИЕНТЕ ОМСКОЙ ОБЛАСТИ

Станислав Князев, Кирилл Бабий,  
Родион Романчук, Елена Голованова

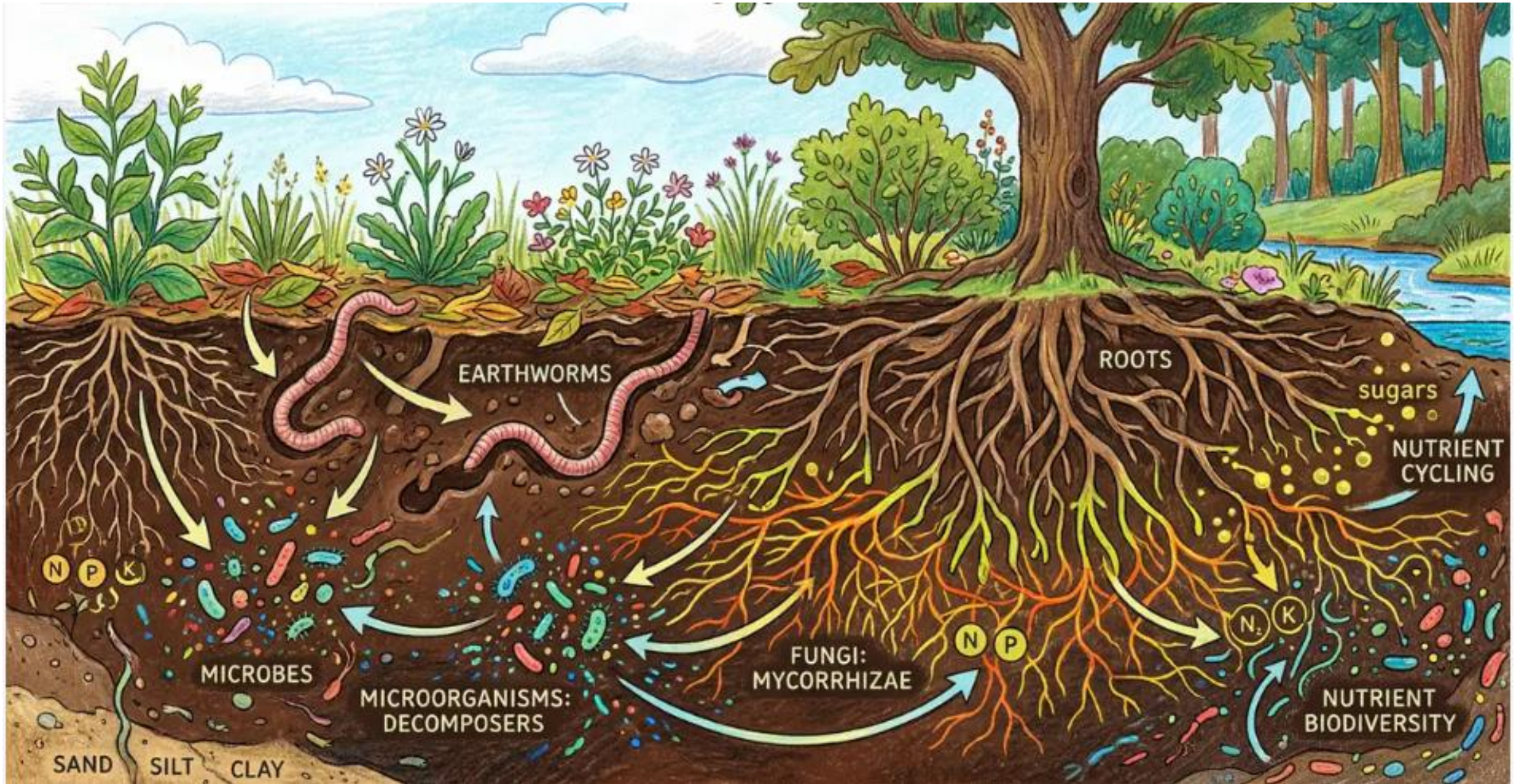
Омский государственный педагогический университет  
Лаборатория систематики и экологии беспозвоночных



# Экосистемные услуги



Экосистемные услуги – это полезные блага и функции, которые люди бесплатно получают от нормально функционирующих природных экосистем (лесов, рек, болот, полей)





## GISQ, a multifunctional indicator of soil quality

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## Abstract

We present here an indicator of soil quality that evaluates soil ecosystem services through a set of 5 subindicators, and further combines them into a single general Indicator of Soil Quality (GISQ). We used information derived from 54 properties commonly used to describe the multifaceted aspects of soil quality. The design and calculation of the indicators were based on sequences of multivariate analyses. Subindicators evaluated the physical quality, chemical fertility, organic matter stocks, aggregation and morphology of the upper 5 cm of soil and the biodiversity of soil macrofauna. A GISQ combined the different subindicators providing a global assessment of soil quality.

Research was conducted in two hillside regions of Colombia and Nicaragua, with similar types of land use and socio-economic context. However, soil and climatic conditions differed significantly. In Nicaragua, soil quality was assessed at 61 points regularly distributed 200 m apart on a regular grid across the landscape. In Colombia, 8 plots representing different types of land use were arbitrarily chosen in the landscape and intensively sampled. Indicators that were designed in the Nicaragua site were further applied to the Colombian site to test for their applicability.

In Nicaragua, coffee plantations, fallows, pastures and forest had the highest values of GISQ (1.00; 0.80; 0.78 and 0.77, respectively) while maize crops and eroded soils (0.19 and 0.10) had the lowest values. Examination of subindicator values allowed the separate evaluation of different aspects of soil quality: subindicators of organic matter, aggregation and morphology and biodiversity of macrofauna had the maximum values in coffee plantations (0.89; 0.72 and 0.56, respectively on average) while eroded soils had the lowest values for these indicators (0.10; 0.31 and 0.33, respectively).

Indicator formulae derived from information gained at the Nicaraguan sites were not applicable to the Colombian situation and site-specific constants were calculated.

This indicator allows the evaluation of soil quality and facilitates the identification of problem areas through the individual values of each subindicator. It allows monitoring of change through time and can guide the implementation of soil restoration technologies. Although GISQ formulae computed on a set of data were only valid at a regional scale, the methodology used to create these indices can be applied everywhere.

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**Keywords:** Macrofauna; Multivariate analyses; Soil quality; Organic fractions; Respirometry; Morphology

## 1. Introduction

While concerns grow worldwide in face of the extensive degradation of soils and alarming reduction in the biodiversity that sustains their function, the identification

and implementation of sustainable land use practices gains priority every day (MEA, 2005). The European Union, for example, is about to propose a legal framework to enhance soil protection, while systems for soil quality monitoring are developing rather rapidly (Arrouays et al., 2003). There is a growing need for methods to evaluate soil quality and its changes as new practices are implemented and favoured by alternative policies.

No synthetic index has been proposed so far that would combine all these variables into a single formula and allow

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## Soil macrofauna as an indicator for evaluating soil based ecosystem services in agricultural landscapes

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## ARTICLE INFO

**Keywords:**  
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## ABSTRACT

Soils participate in the provision of numerous ecosystem services of great importance for the maintenance of ecosystems and human societies. Physical and chemical soil properties sustain supporting ecosystem services like plant production and the infiltration and provision of clean water. Carbon sequestration is a regulating ecosystem service important for climate regulation. Soils are also home of a large biodiversity whose participation in soil processes is critical for their sustainable use. Evaluating these functions to assess the provision of ecosystem services is an important challenge for which simple and accurate tools and methodologies are requested.

In this work, the relationship of the soil macro-fauna with some soil-based ecosystem services was evaluated in three different regions of Colombia, Brazil and Nicaragua with rather contrasted conditions of soils and management options. In each country, we calculated a set of sub-indicators of physical quality, chemical fertility, organic matter accumulation, soil macro aggregation and macro-invertebrate communities abundance and diversity. The combination of these sub indicators in a General Indicator of Soil Quality (GISQ) provided an overall assessment of the quality of the soil and associated ecosystem services. The strong relationship observed between macrofauna indicators and soil physical, chemical and organic matter characteristics makes it a powerful tool for evaluating and monitoring soil quality.

## 1. Introduction

Ecosystems provide a wide range of benefits to humanity, from food, drinking water and protection against floods to cultural heritage. However, many of these benefits, known as 'ecosystem services', are under severe threat due to human pressures (Science for Environment Policy, 2015; Sukhdev et al., 2014). Changes in biodiversity and plant covers due to human activities have been faster in the last 50 years than at any other time in the history of mankind. The drivers of change that led to the loss of biodiversity either do not show any signs of decline over time, or increase in intensity (Millennium Ecosystem Assessment, MEA, 2005).

The Earth planet has already lost a large part of its biodiversity and a simple look at the rising prices of raw materials and food shows the consequences of this loss for society. The extinction of species and the deterioration of ecosystems are inevitably linked to human well-being and, therefore, it is urgent that corrective actions be taken (TEEB, 2008).

Population and economic growth and the conversion of natural ecosystems for agricultural exploitation will continue and this significantly affects ecosystem services, especially the ones that depend on soil quality. Soils are deteriorating rapidly due to erosion, indiscriminate use of fertilizers and pesticides, natural depletion of nutrients, loss of organic carbon

and biodiversity, compaction and other threats. The increase in soil erosion, desertification, salinity and the expansion of urban areas over natural areas are increasing this problem.

Soils provide ecosystems with key services such as climate regulation through C sequestration nutrient cycling operated via decomposition of soil organic matter (SOM), flood and erosion control (Brussaard et al., 1997; Swift et al., 2004). Most of these services derive from closely related ecological processes. However, although several frameworks have been proposed for their evaluation, they are generally not sufficient and clear in their interpretation.

Several authors affirm that these services are still poorly recognized by policy-makers or by societies in general (Sukhdev et al., 2014) and that tools are needed to evaluate in a holistic way the contribution of soils to ecosystem services, to limit their use and management within acceptable ecological limits (Costanza et al., 1997; Dominati, 2013; De Groot et al., 2012).

The soil hosts a quarter of the planet's biodiversity and the invertebrate communities of the soil are highly sensitive to changes in the ecosystems. Their effects on soil processes - for example, decomposition of organic matter, formation of biogenic structures, nutrient cycling and disease control - have been extensively reviewed (Lee and Foster, 1991;

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# Глобальный индикатор качества почвы Imac



A global indicator of soil macroinvertebrate community composition, abundance and diversity

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## ABSTRACT

Macroinvertebrate communities are highly sensitive indicators of physical and chemical soil qualities. Their evaluation in field conditions is rather simple and could serve as proxy for soil-based ecosystem services that farmers and field technicians could use. We tested the hypothesis that an indicator of soil macroinvertebrate communities, with 14 taxonomic groups characterized at the order level, could be used in any region of the world to assess these communities. A synthetic indicator was calculated using data from 9 reference sites from tropical, subtropical and temperate regions, a set of 3694 data of the open access Macrofauna database and a new site for validation. Invertebrates were extracted with the standard ISO/TS89 methodology and characterized with a set of 14 large taxonomic units, plus an index of taxonomic richness and total density. At each of the 9 reference sites, 27 to 252 sample points, representing different types of plant covers and/or soil management options, were considered and compared with their respective local synthetic GISQ indicator values. These indicators, elaborated from Principal Component Analysis of the sample points data, are set to vary from 0.1 to 1.0 according to the composition, diversity and abundance of the community. Analyses showed great similarities among sites, with Factors 1 (from 21.9 to 36.9 % variance explained) expressing the overall abundance and diversity of the communities and Factors 2 (8.9 to 15.83 %) opposing sites with dominant soil ecosystem engineer populations (Earthworms, Ants, Termites and some Coleoptera) to sites dominated by litter transformer populations (Diplopoda, Isopoda and others). Indicator formulae were designed based on PCA analyses of each data set and a global formula was established with the Macrofauna database. Very high correlations (>0.95) were obtained among values calculated with local data set and the general formula calculated with data of the Macrofauna database, in 8 of 9 sites and in the validation site. We discuss the importance of having a single formula to transform data obtained with a simple standard field method in the building of public policies for soil-based ecosystem services payment.

## 1. Introduction

Soils are the basis for 16 of the 24 ecosystem services listed in the Millennium Ecosystem Assessment (MEA, 2005; Adhikari and Hartemink, 2016; Luján Soto et al., 2020). They are self-organized systems in which organisms interact with the physical, chemical and microbiological environment and determine pathways and intensity of ecosystem processes (Lavelle et al., 2016b). These interactions span over a suite of spatial and temporal scales ranging from microbial microsites and the micro aggregates that they build, to the next scale of intermediate aggregates where micro food web processes operate. At the next scales up, macroaggregated structures built by roots and macroinvertebrate ecosystem engineers are created in their respective functional domains. These structures are further accumulated and diversified at the upper ecosystem and landscape scales, linking the basic biological functions to the delivery of ecosystem services, at the largest spatial and temporal scales.

Macroinvertebrate communities shaped by general soil and climate conditions, operate at a strategic intermediate scale, driving microbial

processes in their functional domains. They are key components of the soil that contribute to the formation of aggregates and the creation and maintenance of the pore space that determine water infiltration and storage, plant health and growth stimulation and C storage (Lavelle and Spain, 2001; Blouin et al., 2013).

Different synthetic indicators of their composition and abundance have been proposed and linked to a wide range of soil conditions (Velasquez et al., 2007; Ruiz et al., 2011; Menta et al., 2017; Fusaro et al., 2018; Velasquez and Lavelle, 2019). These indicators generally have local validity and allow measuring the local impact on their communities, of natural differences in soil and vegetation, or the effect of soil management options (Lavelle et al., 2014, 2016a; Yang et al., 2020; Velasquez and Lavelle, 2019; Rodriguez et al., 2021). While the abundance and diversity of soil macroinvertebrate communities have been repeatedly statistically related to a number of other synthetic indicators of soil physical, chemical or morphological conditions, and associated ecosystem services, general processes recommended for the evaluation of soil quality still largely ignore them (Filsøer et al., 2016; Bünnemann et al., 2018; Thoumazeau et al., 2019). They propose instead lists of

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## Расчет формулы:

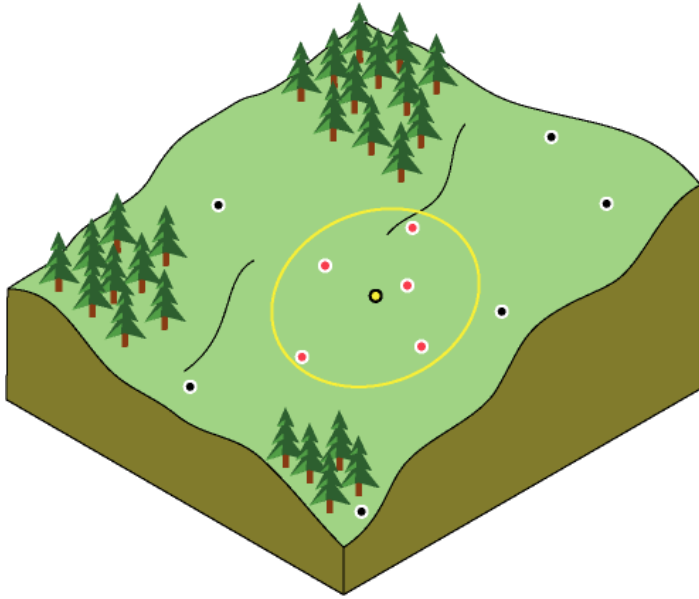
$$I_i = (0.9 * \text{Raw } I_i / 643) + 0.1 \text{ that is } I_i = 0.0014 * \text{Raw } I_i + 0.1$$

$$\begin{aligned} \text{Raw } I = & 18.30 * \text{EW} + 16.83 * \text{AN} + 9.20 * \text{TE} + 7.69 * \text{BL} + 19.62 * \text{CO} + 15.09 * \text{AR} \\ & + 18.78 * \text{DO} + 20.12 * \text{CH} + 16.31 * \text{DL} + 11.29 * \text{HM} + 7.58 * \text{DR} \\ & + 9.15 * \text{LE} + 15.08 * \text{GA} + 19.82 * \text{OT} + 24.74 * \text{DN} + 27.88 * \text{TR} \end{aligned}$$

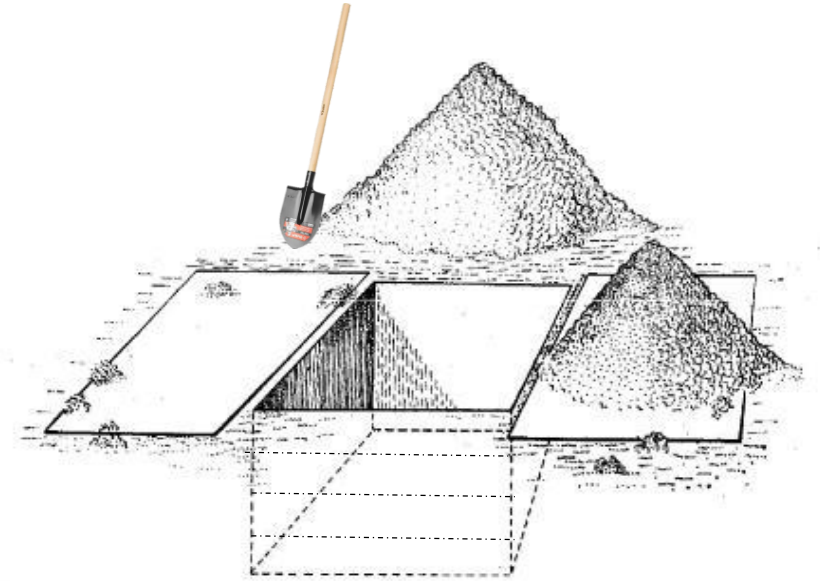
где EW= log10 (плотность особей на м2 Earthworm+ 1); AN= log10 (плотность особей на м2 Formicinae+ 1); DO= log10 (плотность Diplopoda+ 1); CO: Coleoptera (имаго+личинки); CH: Chilopoda; DL: Diptera личинки; HM: Hemiptera; DR: Dermaptera; LE: Lepidoptera гусеницы; GA: Gastropoda; OT: Прочие; DN: общая плотность; TR: таксономическое богатство.

**Интерпретация:** Показатель Imac варьируется от 0,1 до 1,0. Значение, приближающееся к 1, свидетельствует о максимальном богатстве и разнообразии сообщества.

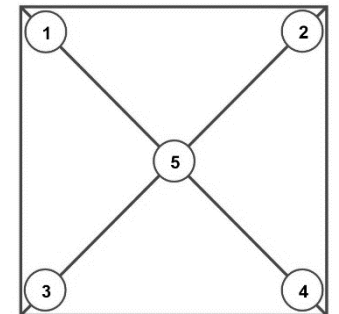
# Материалы и методы



## Метод обратных взвешенных расстояний (IDW)



Общий вид стандартной почвенной  
пробы, взятой методом раскопок (по  
Гилярову, 1975)



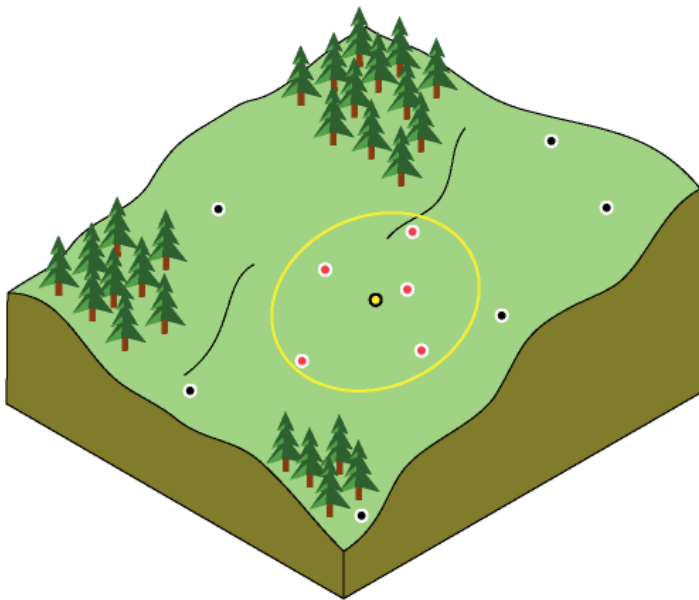
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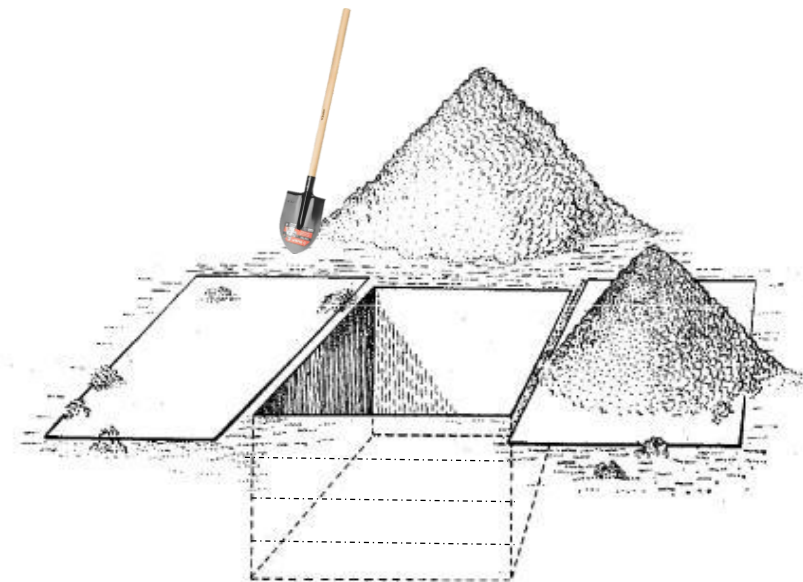
# Зональные луга Омской области



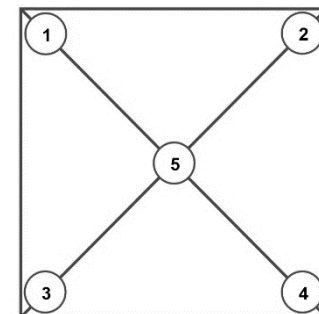
# МАТЕРИАЛЫ И МЕТОДЫ



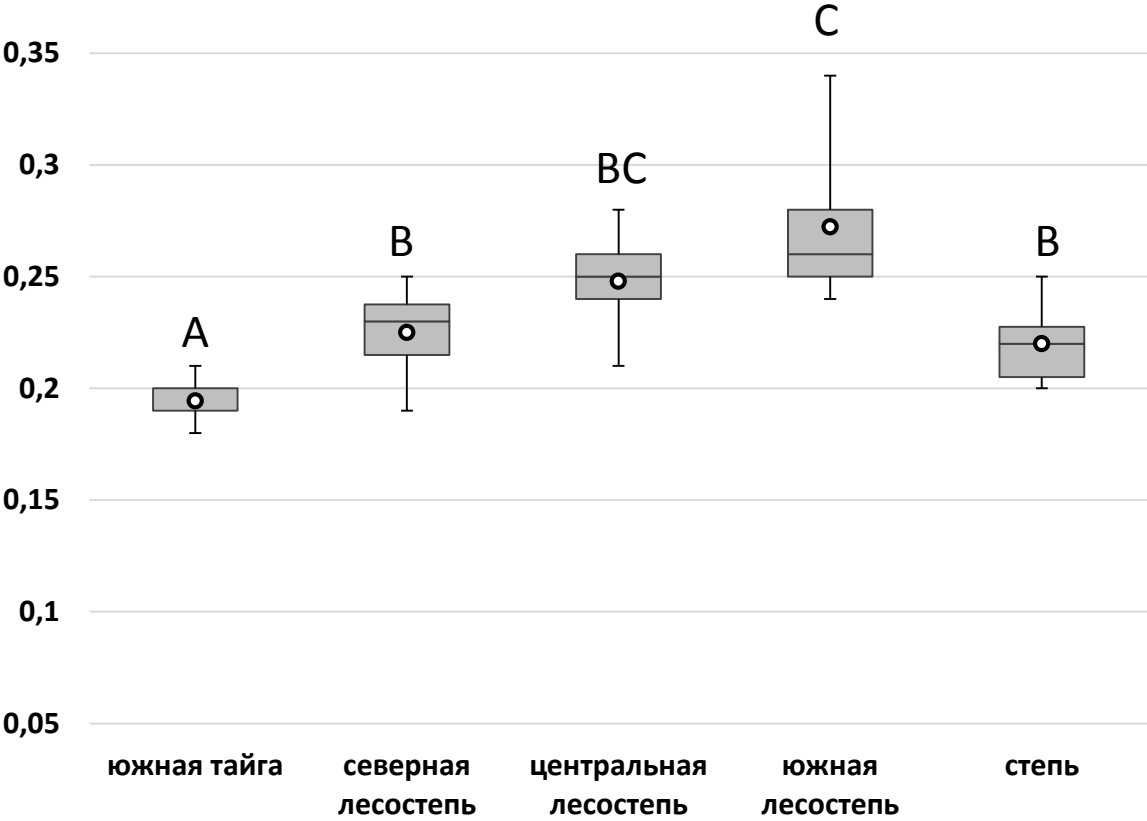
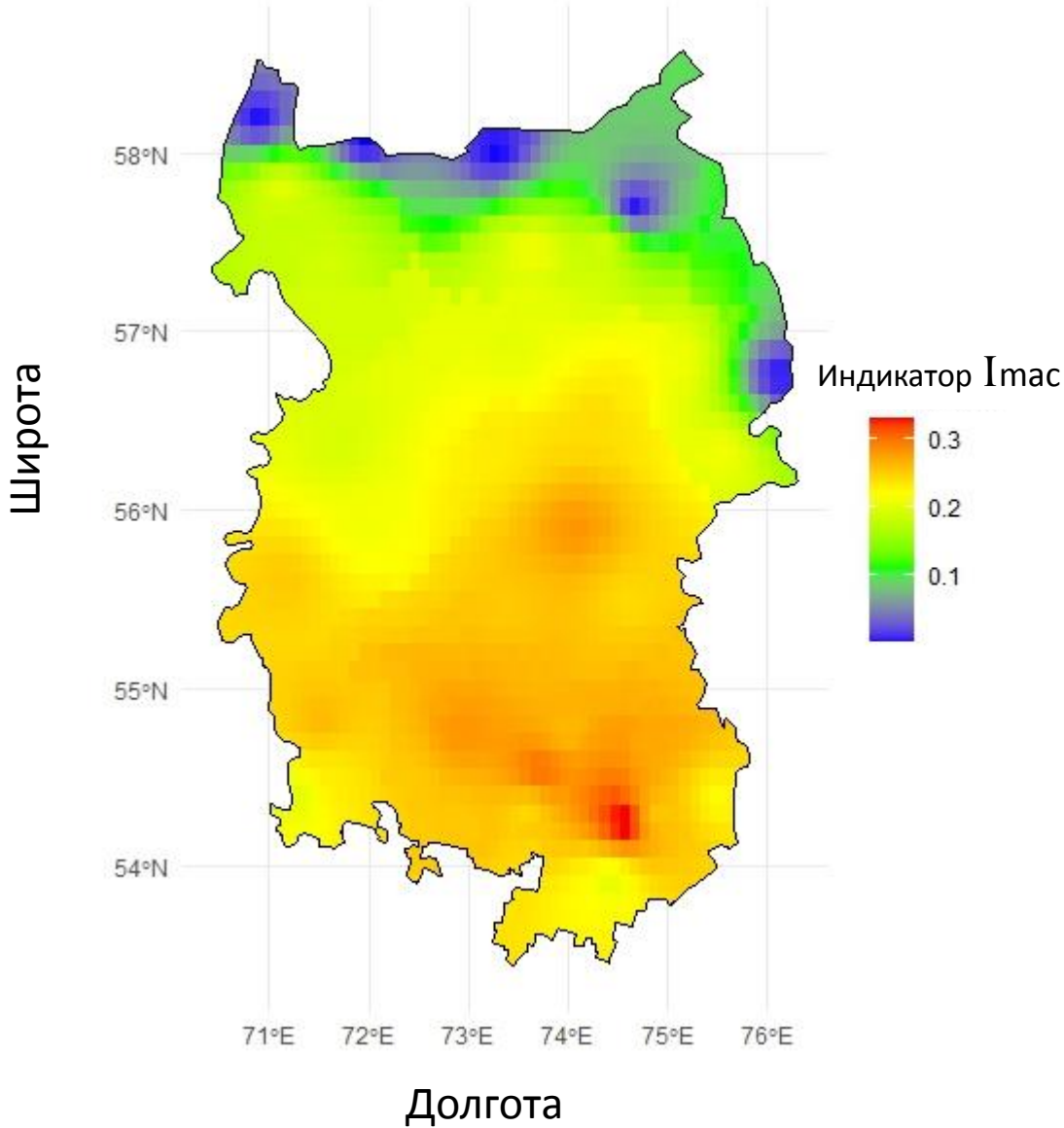
Метод обратных взвешенных расстояний (IDW)



Общий вид стандартной почвенной пробы, взятой методом раскопок (по Гилярову, 1975)

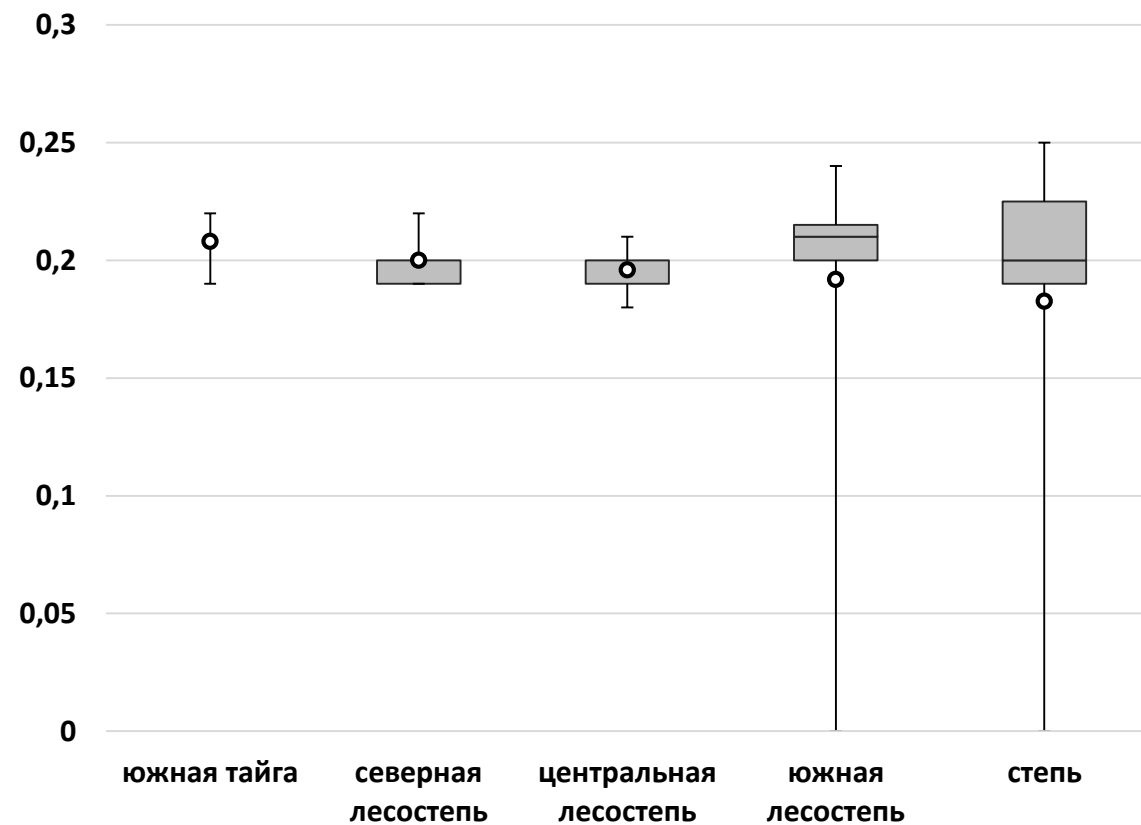
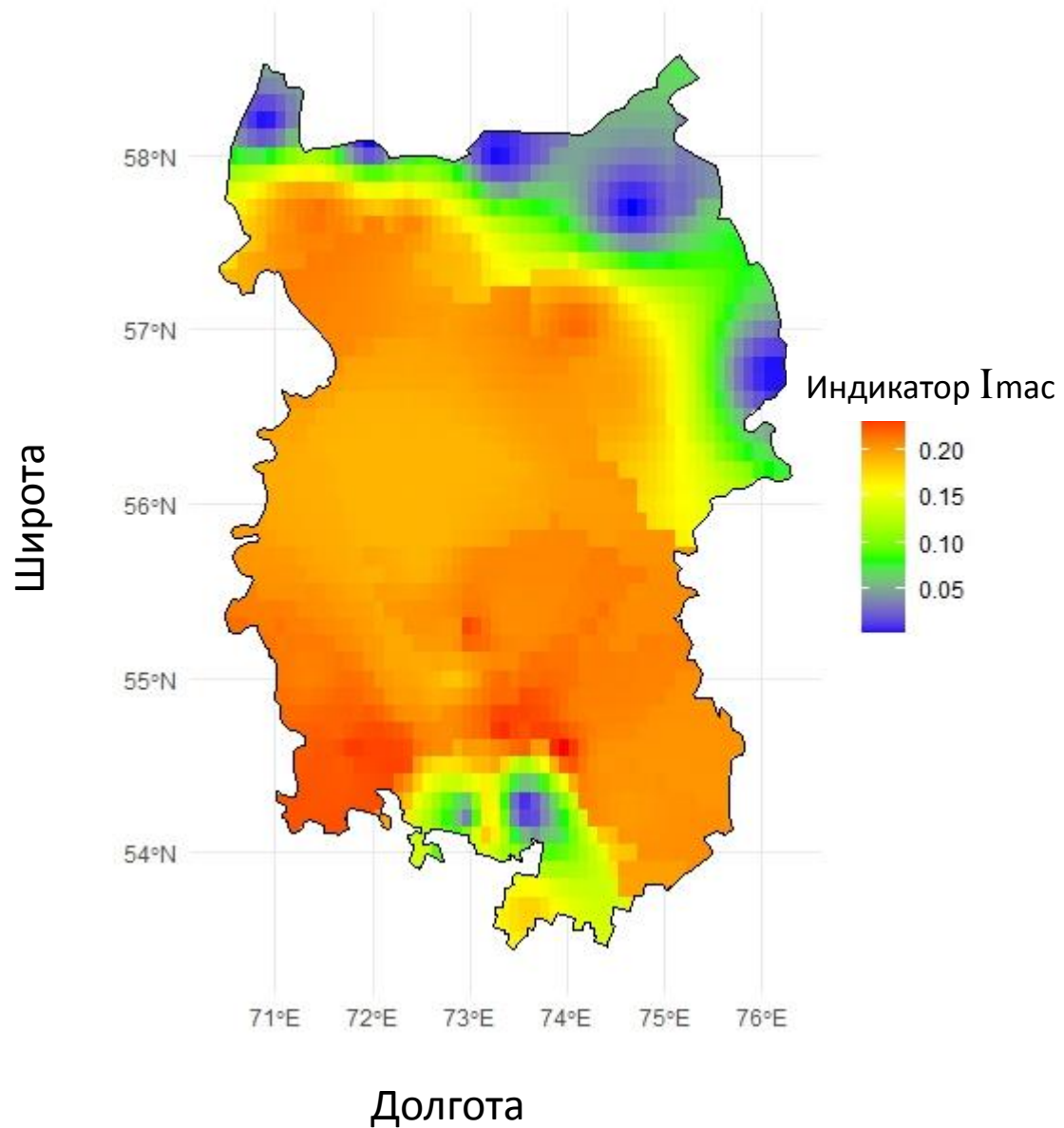


Пространственное распределение индикатора  
**I**мас лугов в Омской области в 2009-2012



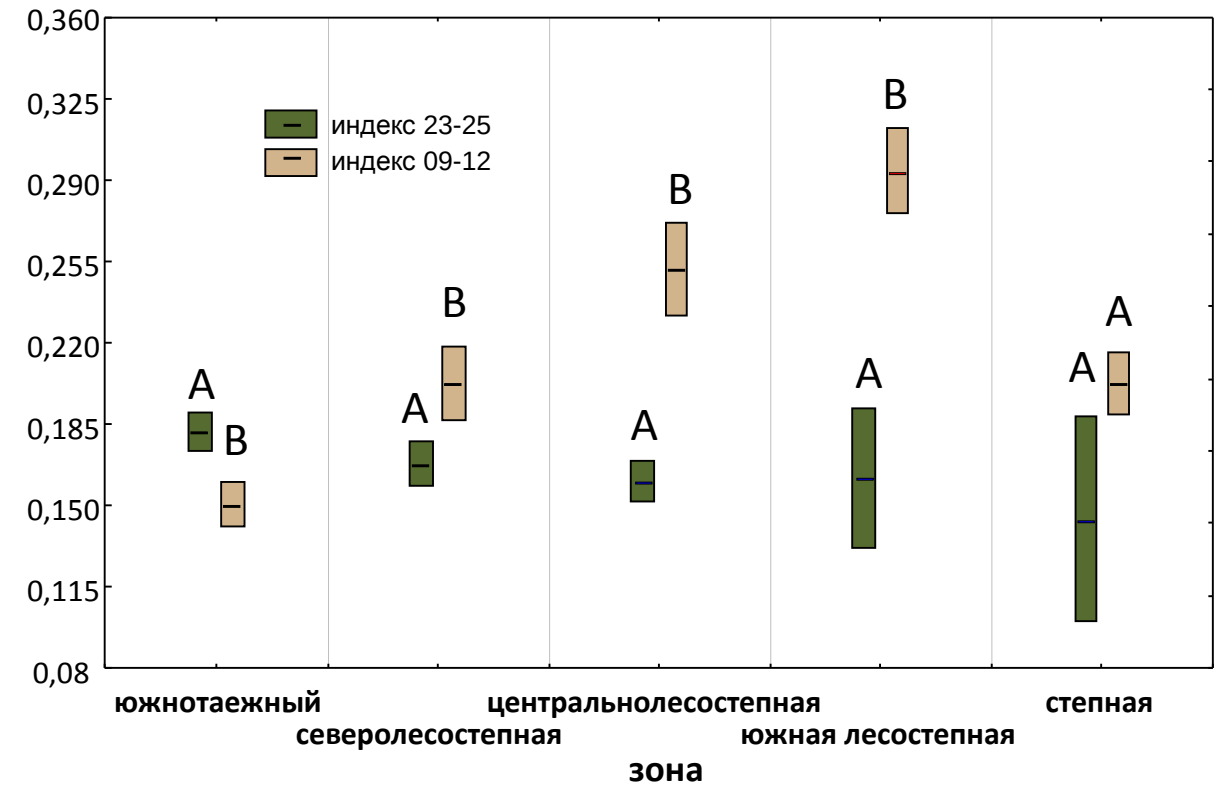
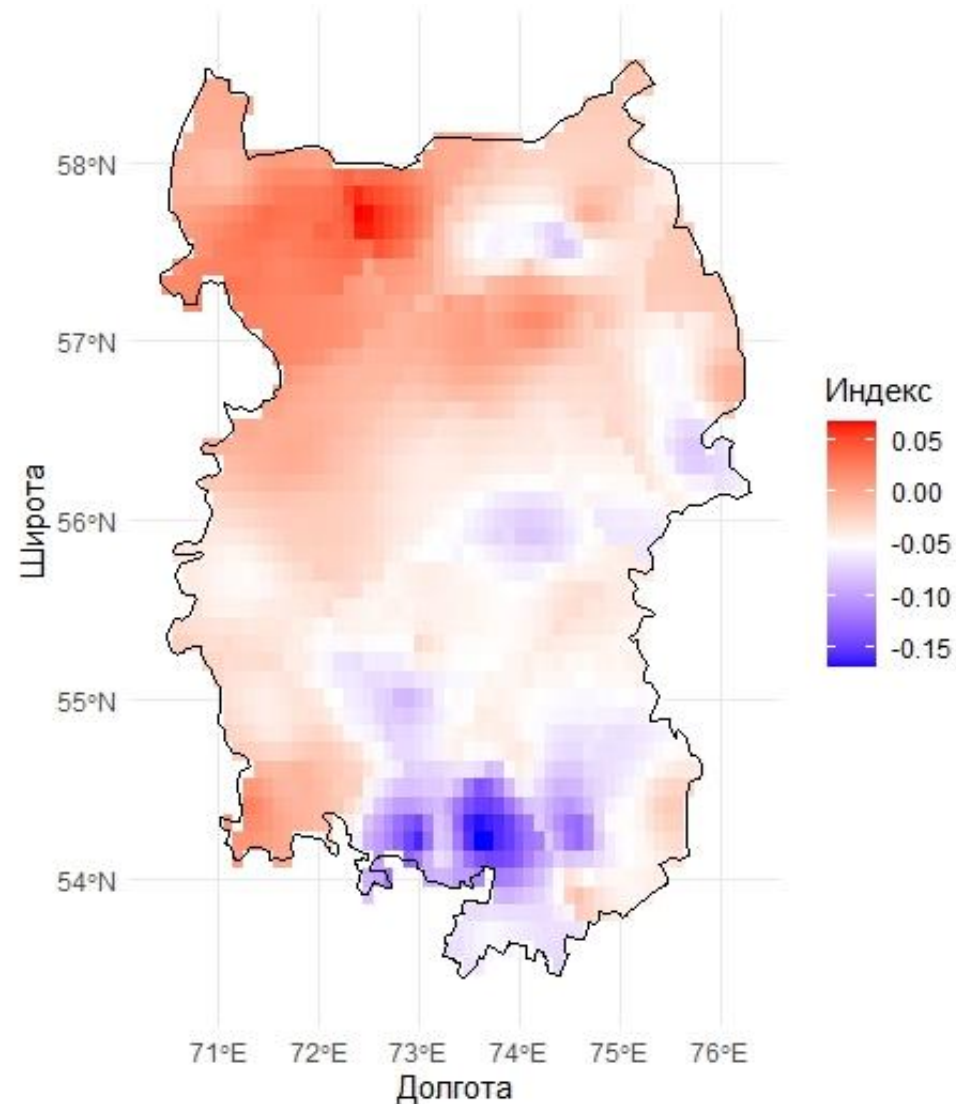
Зональное распределение значений индикатора I<sub>мас</sub> (среднее, медиана, 1Q-3Q и выбросы) лугов Омской области с 2009-2012 гг. Большими буквами показаны различия между зонами ( $p < 0,05$ , PERMANOVA).

## Пространственное распределение индикатора $I_{\text{мас}}$ лугов в Омской области в 2023-2025



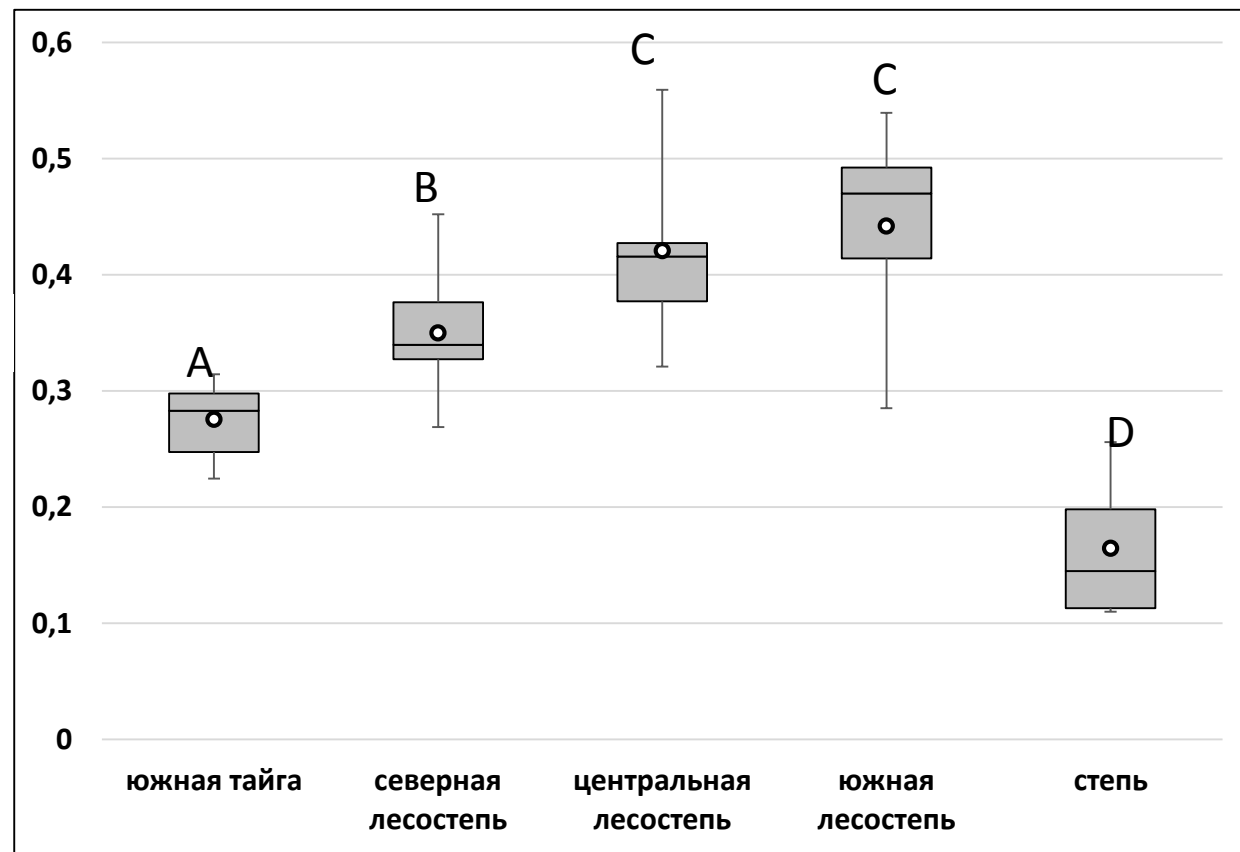
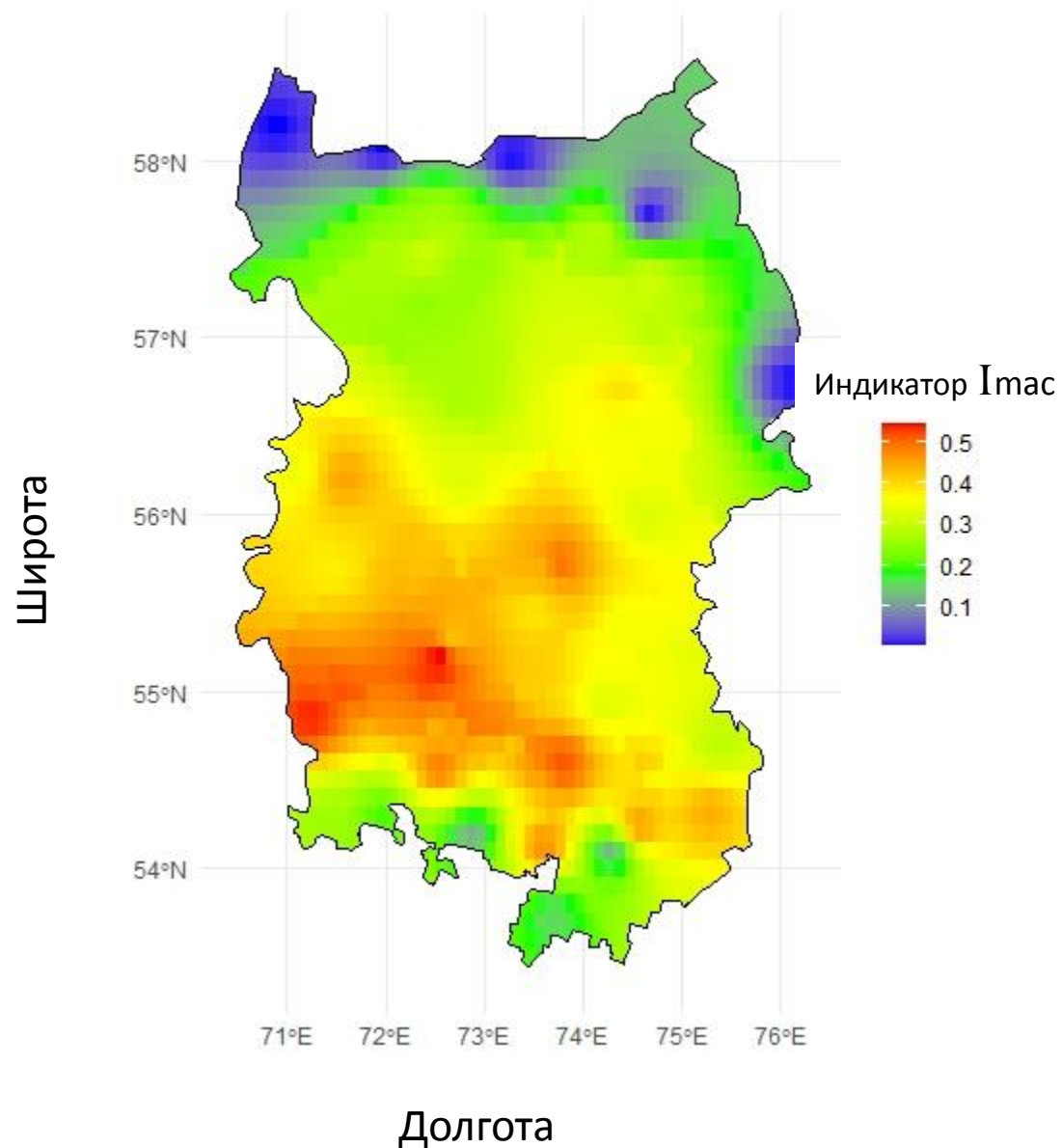
Зональное распределение значений индикатора  $I_{\text{мас}}$  (среднее, медиана, 1Q-3Q и выбросы) лугов Омской области с 2023-2025 гг. Большими буквами показаны различия между зонами ( $p < 0,05$ , PERMANOVA).

Разница значений индикатора **I**<sub>мас</sub> (луга) между 2023-25 и 2009-12 гг. на территории Омской области



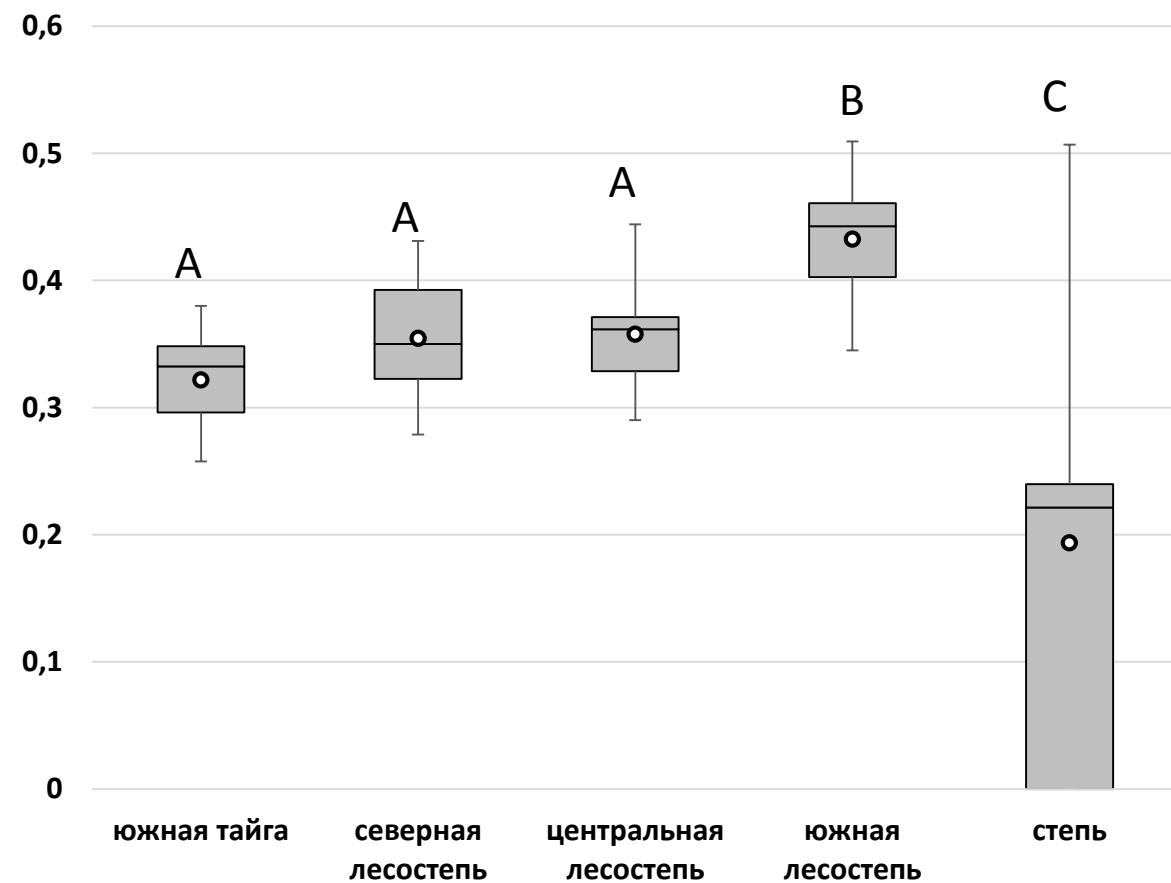
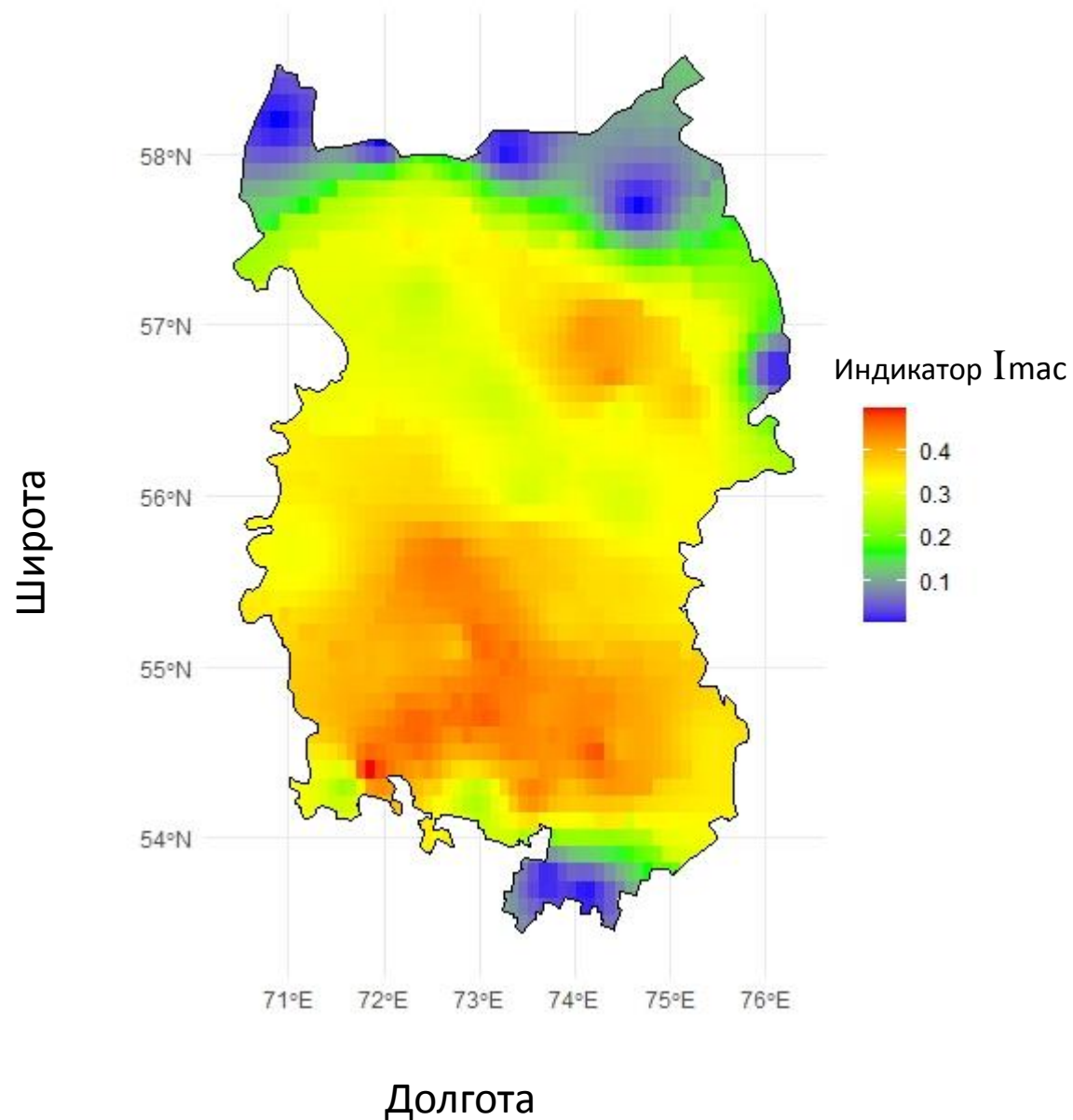
Зональные различия индикатора **I**<sub>мас</sub> лугов между периодами 2009-2012 гг. и 2023-2025 гг. Варианты с разными буквами значительно различаются ( $p < 0,05$ , тест Mann-Whitney U Test). Вертикальные столбцы обозначают  $\pm$  стандартную ошибку, значок в центре столбца – среднее значение.

# Пространственное распределение индикатора **I**мас лесов в Омской области в 2009-2012



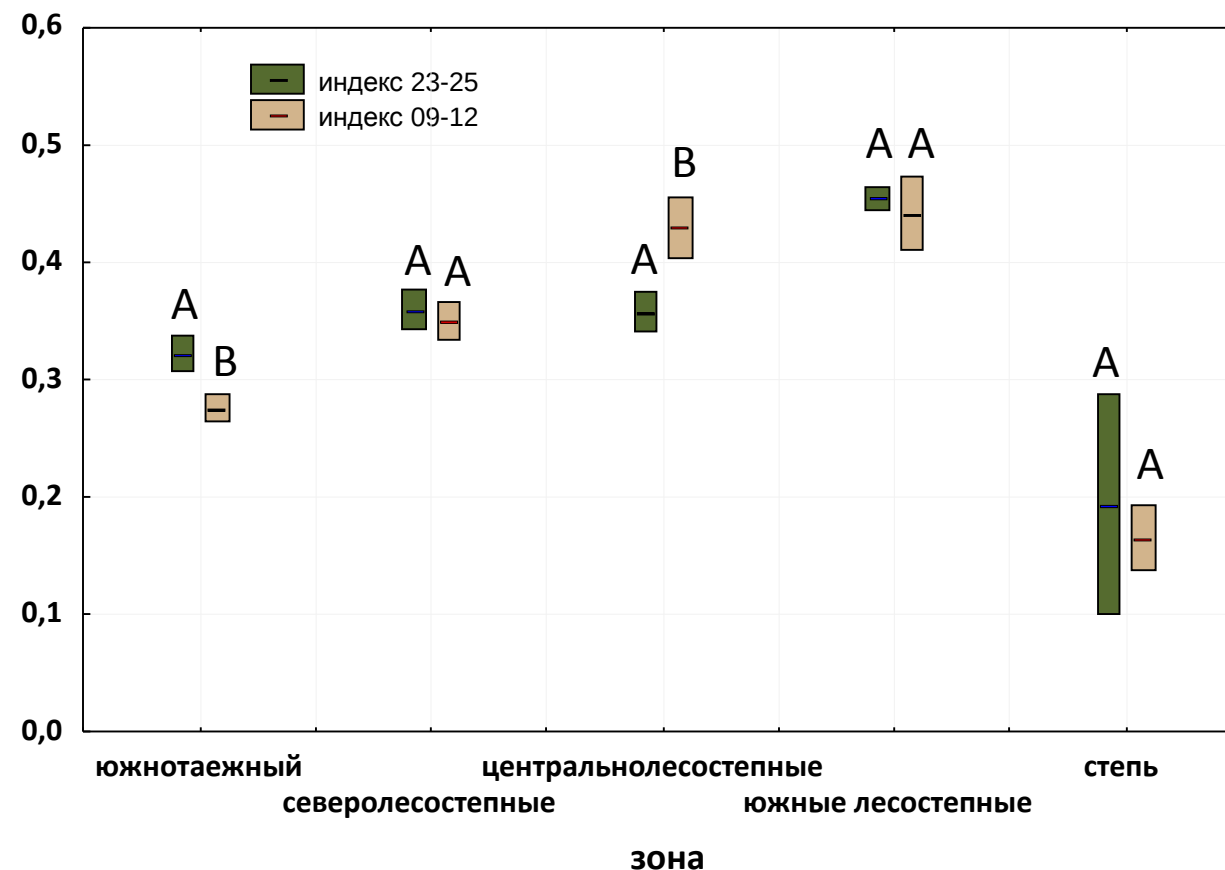
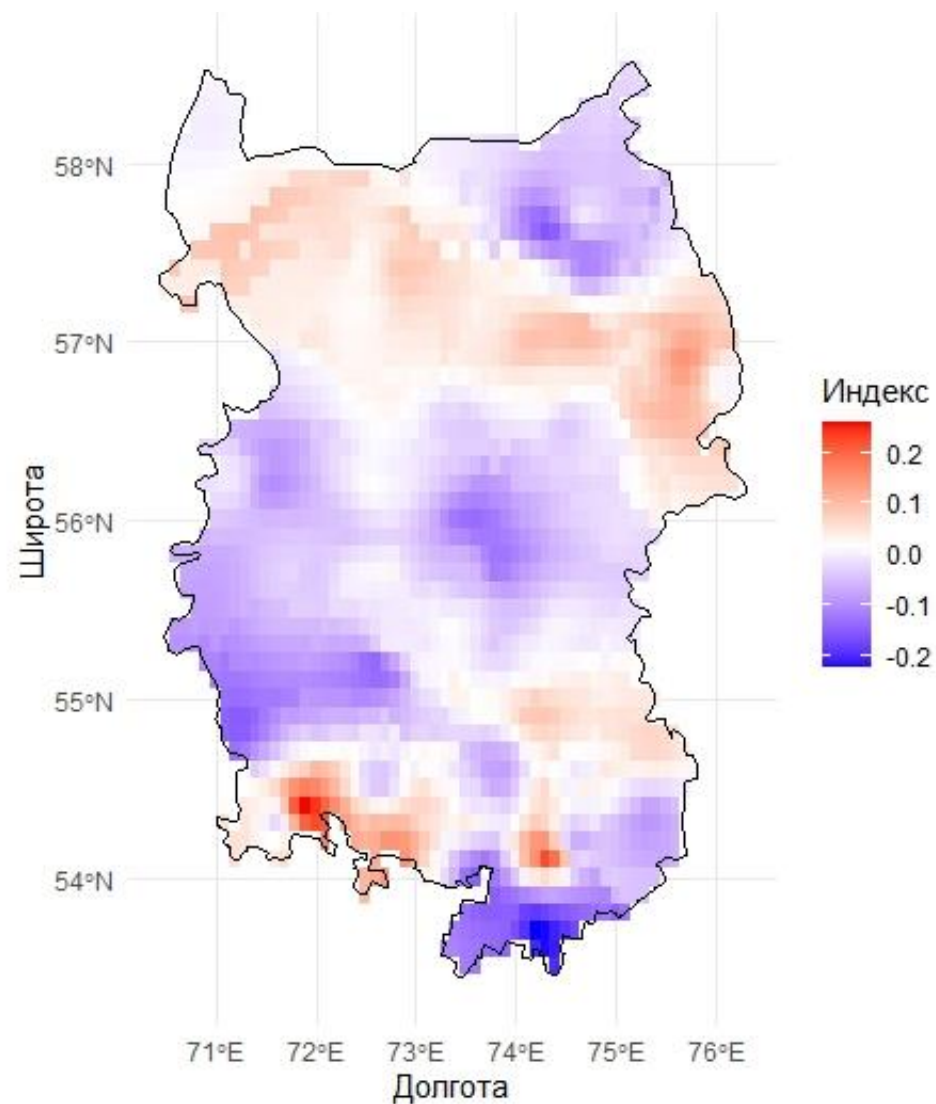
Зональное распределение значений индикатора **I**мас (среднее, медиана, 1Q-3Q и выбросы) лесов Омской области с 2009-2012 гг. Большими буквами показаны различия между зонами ( $p < 0,05$ , PERMANOVA).

## Пространственное распределение индикатора I<sub>мас</sub> лесов в Омской области в 2023-2025



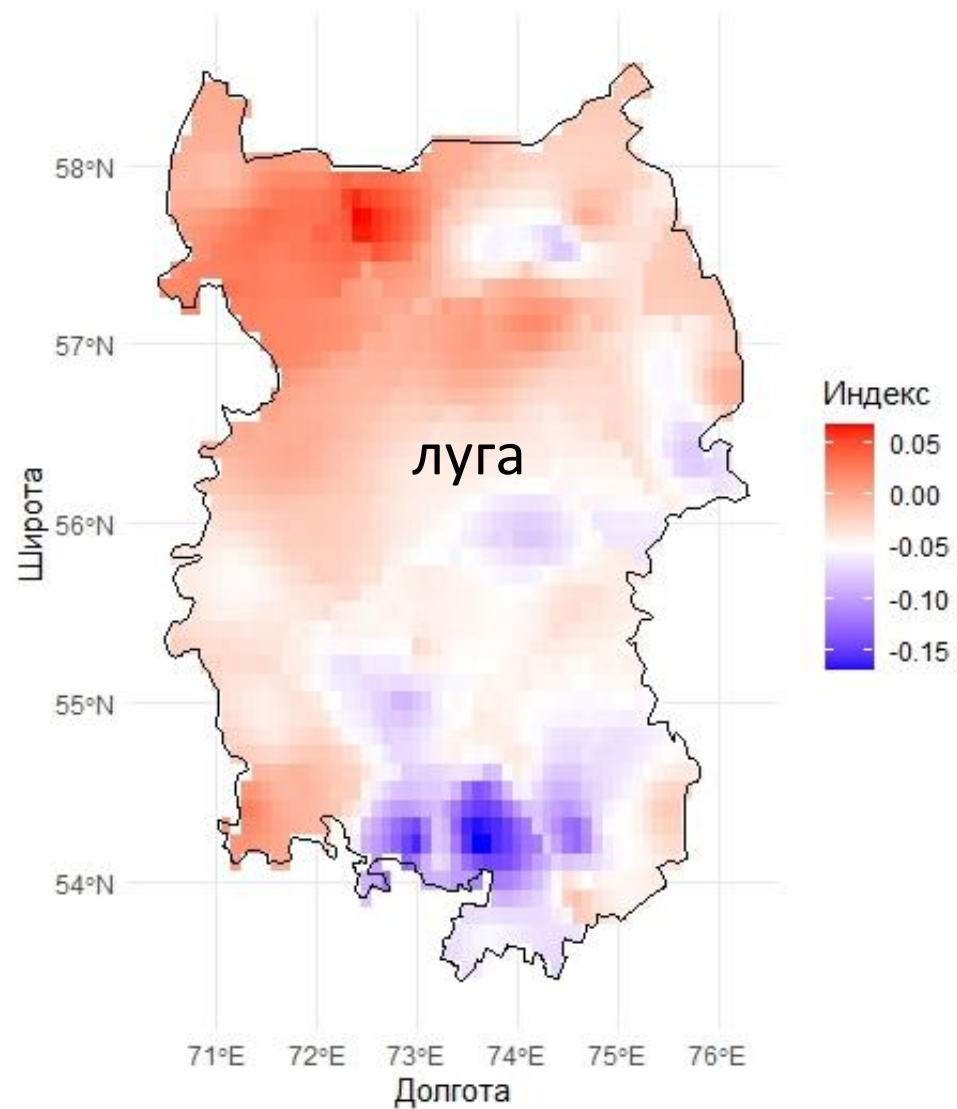
Зональное распределение значений индикатора I<sub>мас</sub> (среднее, медиана, 1Q-3Q и выбросы) лесов Омской области с 2023-2025 гг. Большими буквами показаны различия между зонами ( $p < 0,05$ , PERMANOVA).

# Разница значений индикатора I<sub>мас</sub> (леса) между 2023-25 и 2009-12 гг. на территории Омской области

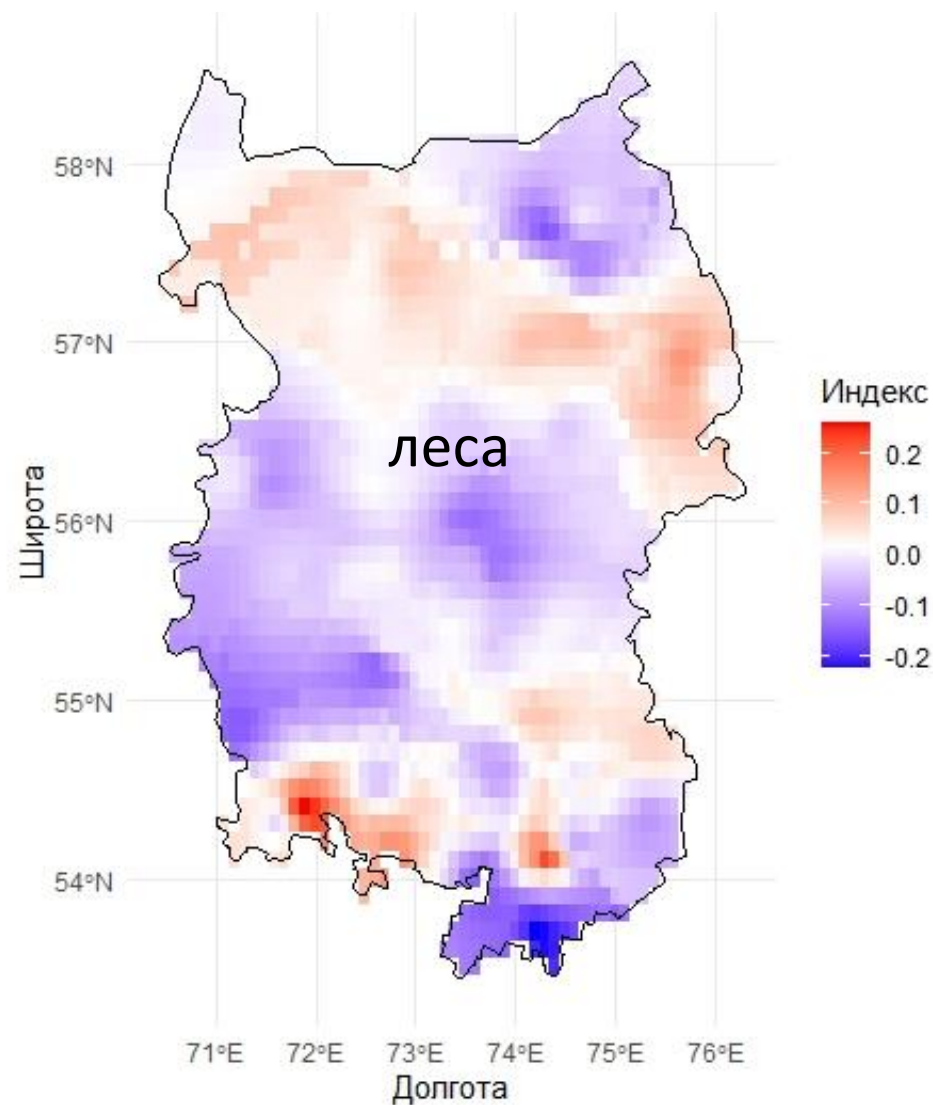


Зональные различия значений индикатора  $I_{\text{мас}}$  лесов между периодами 2009-2012 гг. и 2023-2025 гг. Варианты с разными буквами значительно различаются ( $p < 0,05$ , тест Mann-Whitney U Test). Вертикальные столбцы обозначают  $\pm$  стандартную ошибку, значок в центре столбца – среднее значение.

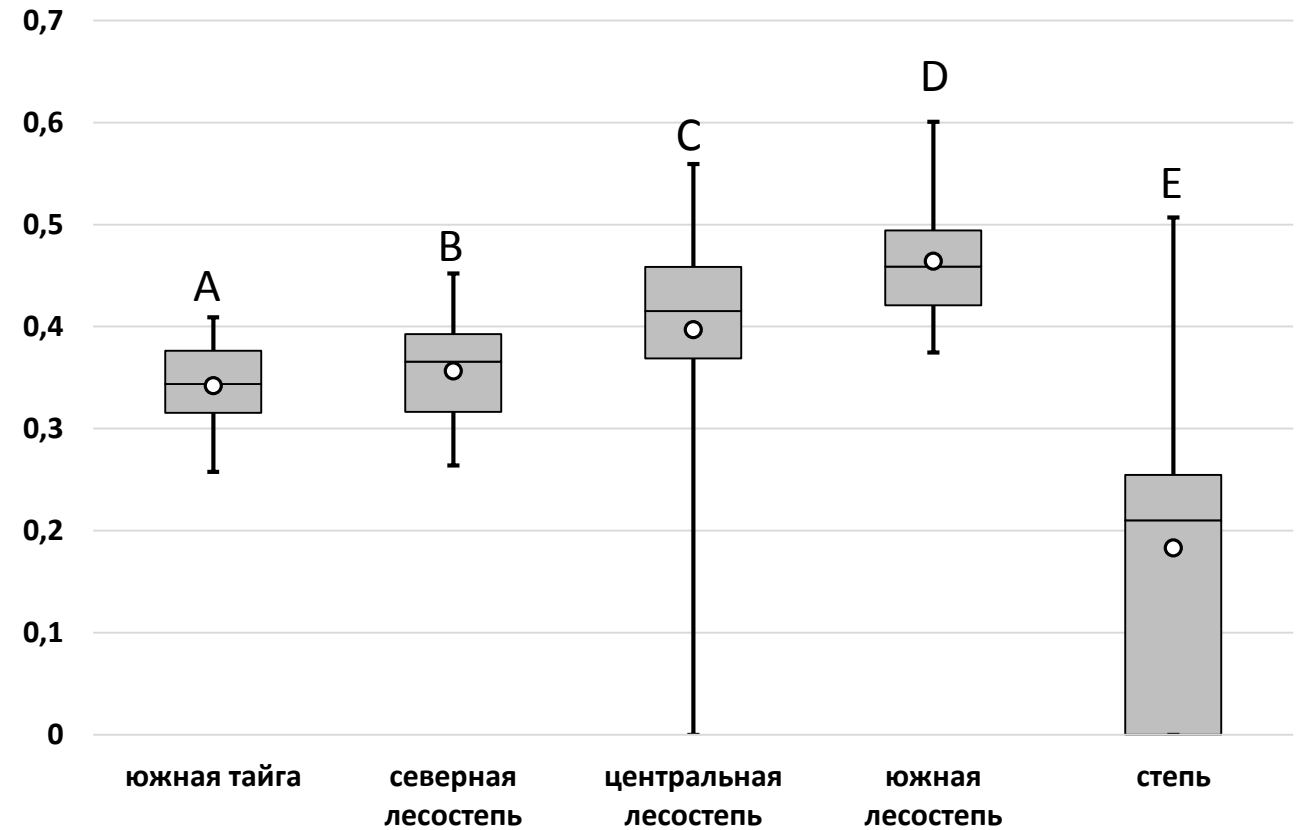
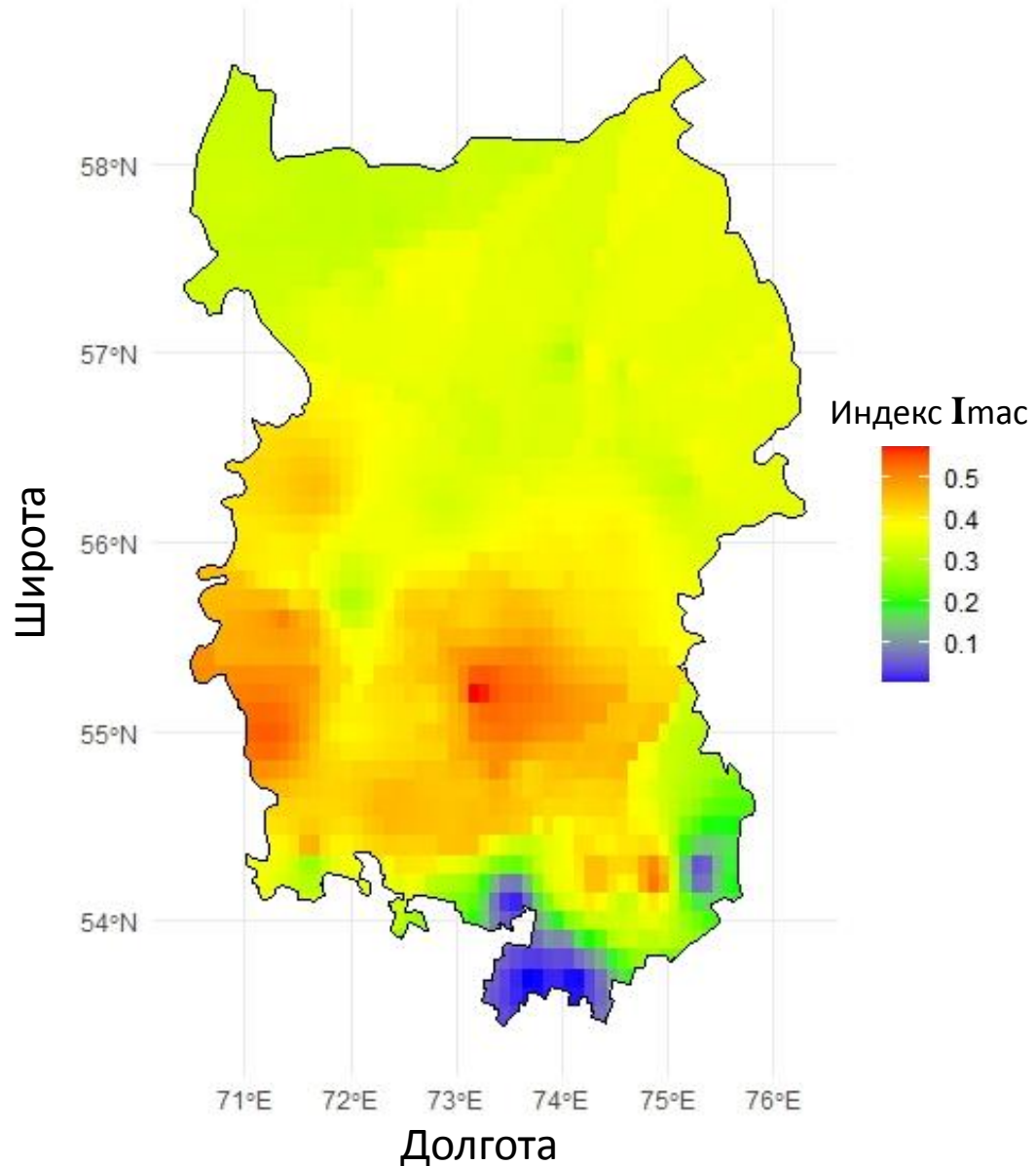
Разница значений индикатора **I<sub>мас</sub> (луга)** между 2023-25 и 2009-12 гг. на территории Омской области



Разница значений индикатора **I<sub>мас</sub> (леса)** между 2023-25 и 2009-12 гг. на территории Омской области



# Пространственное распределение индикатора $I_{\text{мас}}$ лесов в Омской области за 15 лет



Зональное распределение значений индикатора  $I_{\text{мас}}$  (среднее, медиана, 1Q-3Q и выбросы) лесов Омской области по усредненным данным с 2009-2025 гг. Большими буквами показаны различия между зонами ( $\alpha=0,05$  PERMANOVA).



# Распространение *Eisenia nordenskioldi pallida* (Malevic, 1956) и *Aporrectodea caliginosa* (Savigny, 1826) в Омской области



На юге Западной Сибири широко распространился экзотический вид *A. caliginosa*, встречающийся теперь практически во всех природных ландшафтах.

# ПОЧВЕННАЯ МАКРОФАУНА КАК ИНДИКАТОР ЭКОСИСТЕМНЫХ УСЛУГ В ШИРОТНОМ ГРАДИЕНТЕ ОМСКОЙ ОБЛАСТИ

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