



XX совещание по почвенной
зоологии и ЭКОЛОГИИ



IPAE
INSTITUTE OF PLANT
AND ANIMAL ECOLOGY

Стандартизация *in-situ* дыхания почвы по температуре и влажности: сравнение разных подходов к анализу многолетних данных

Иван А. Сморкалов
Евгений Л. Воробейчик



ЛАБОРАТОРИЯ ЭКОТОКСИКОЛОГИИ ПОПУЛЯЦИЙ И СООБЩЕСТВ

Laboratory of Population and
Community Ecotoxicology

Уральские горы

ЕВРОПА АЗИЯ

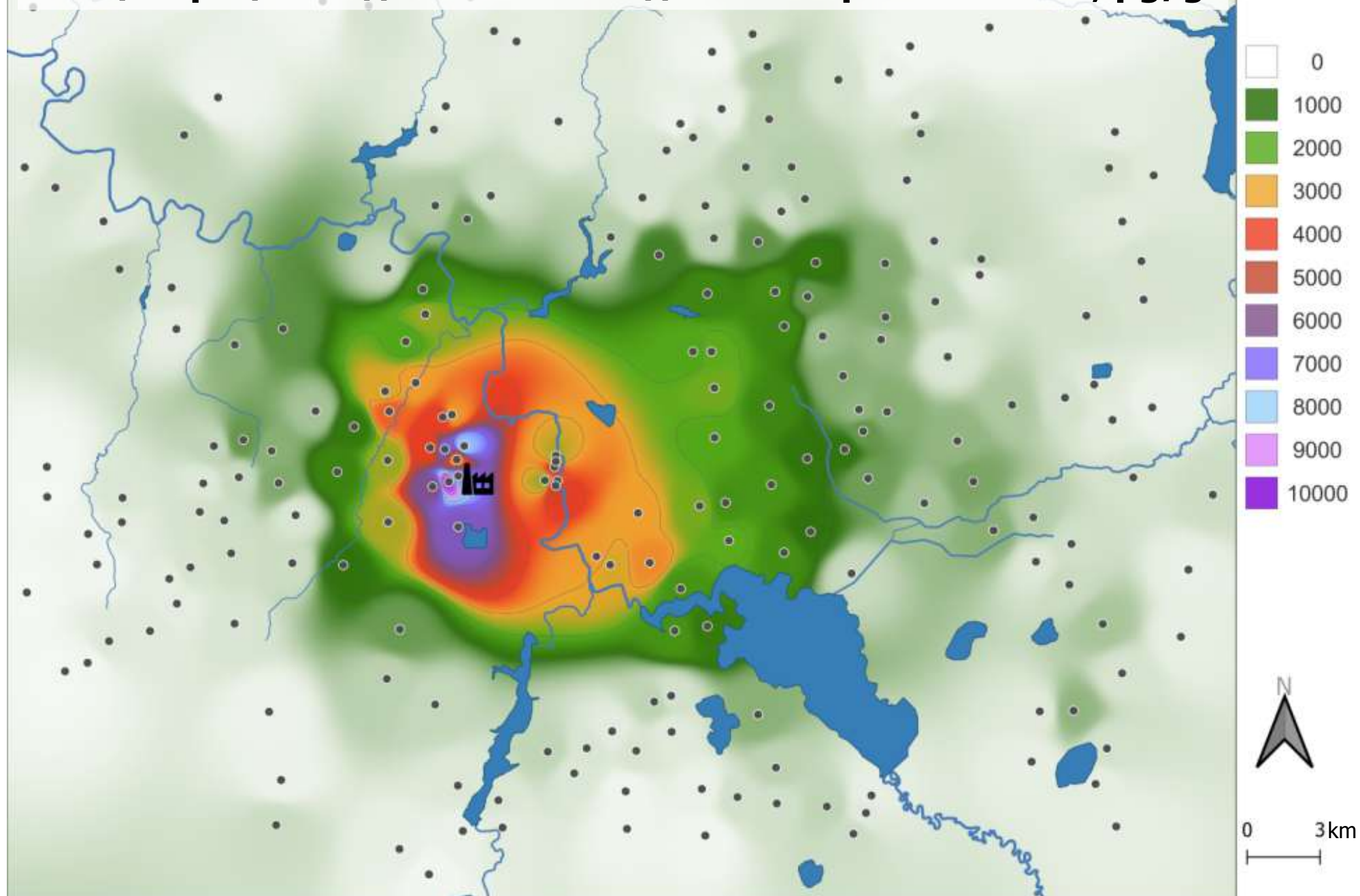
SO_2 + TM (Cu, Pb, Cd, Zn, Fe, Hg, and As)

Среднеуральский медеплавильный
завод (СУМЗ)

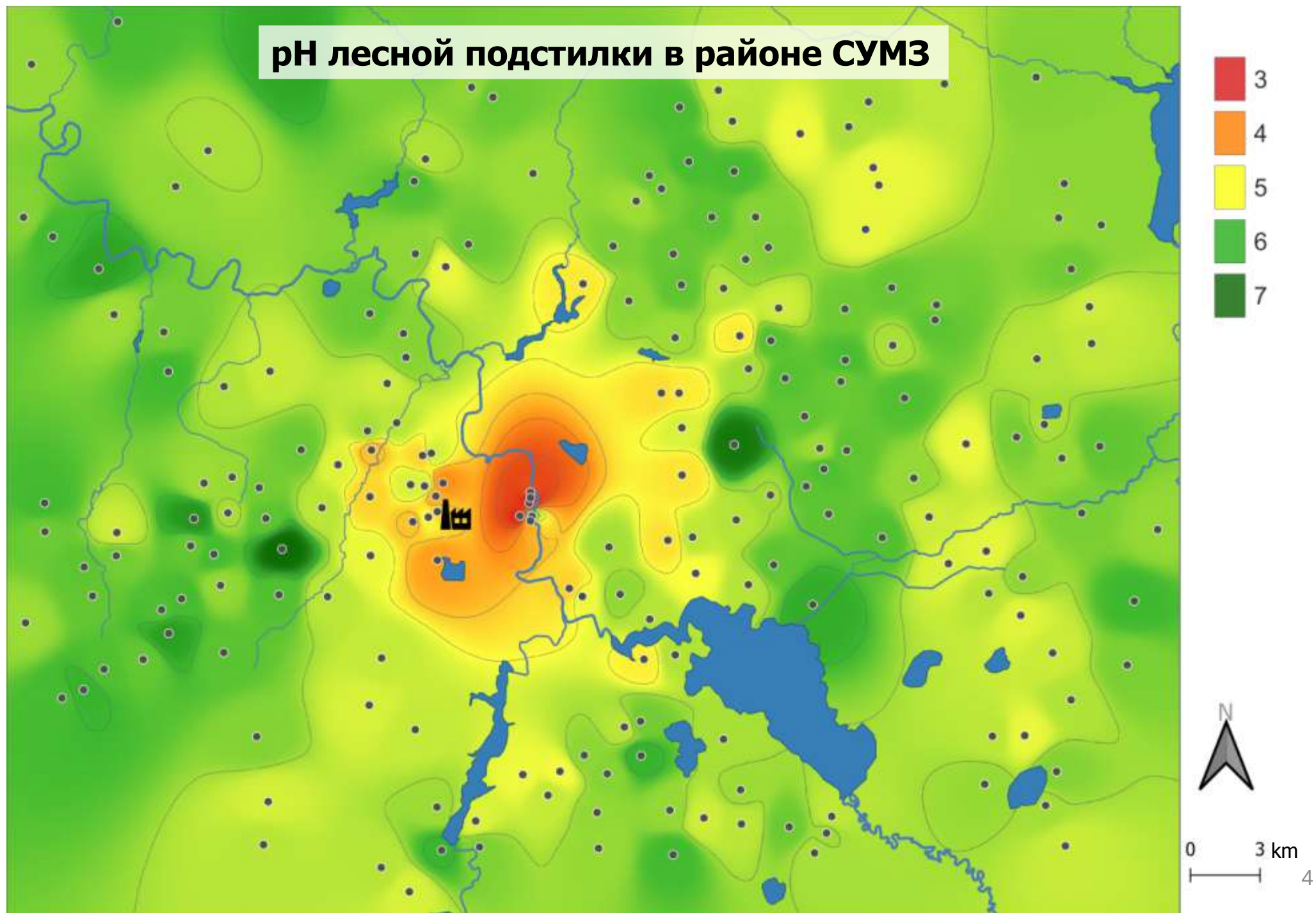
Карабашский медеплавильный
завод (КМЗ)

1000 km

Концентрация меди в лесной подстилке в районе СУМЗ, $\mu\text{g/g}$



рН лесной подстилки в районе СУМЗ



СУМЗ



>20 km

Фоновая



4-19 km

Буферная



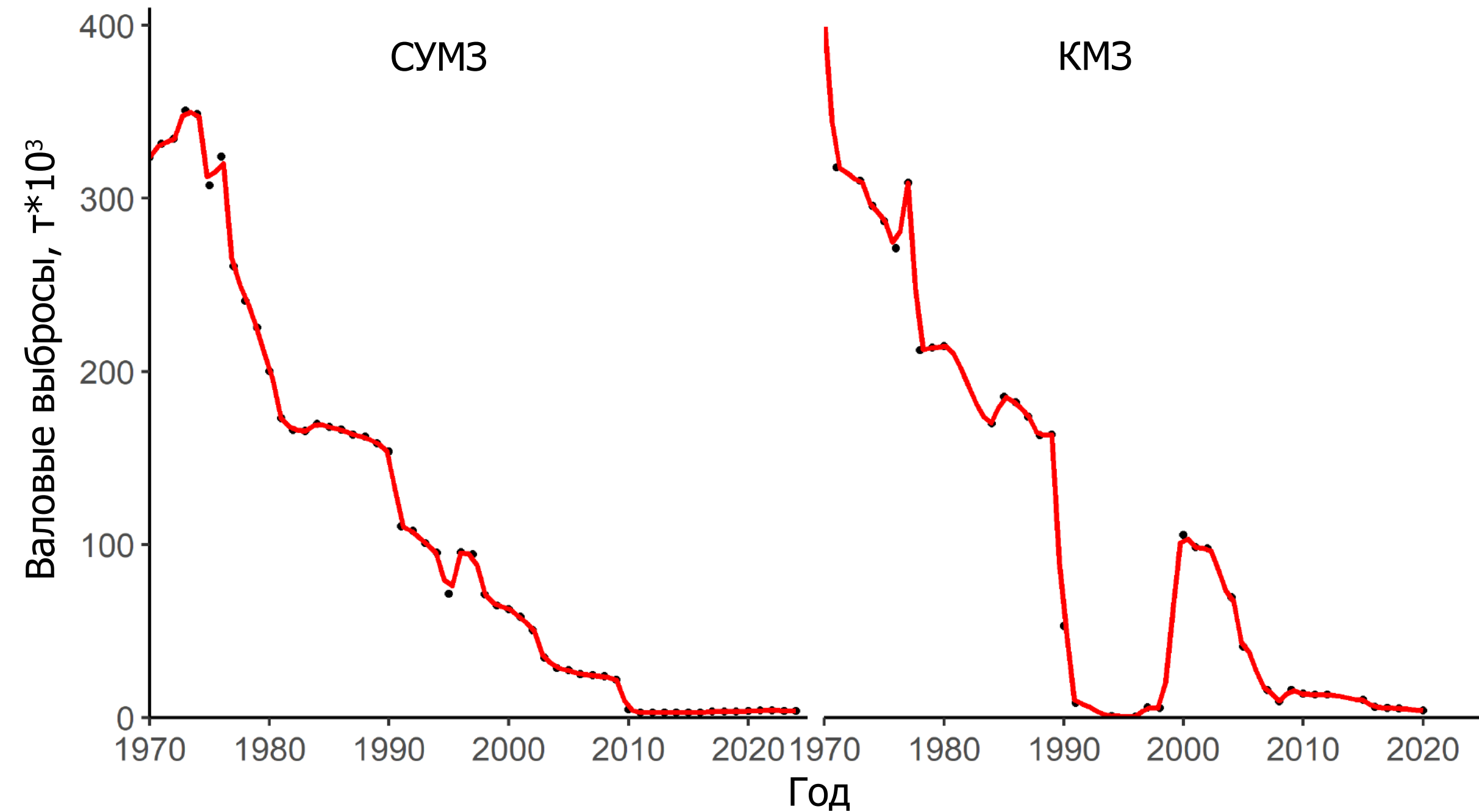
1-5 km

Импактная

КМЗ



Динамика эмиссии поллютантов



Assemblages of Ground-Dwelling Arachnids and Carabids in Metal-Polluted Forests: Are There Any Signs of Recovery after Reductions of the Middle Ural Copper Smelter Emission?

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Received June 25, 2024; revised September 26, 2024; accepted November 3, 2024

Abstract—Information regarding the natural recovery of ground-dwelling invertebrate communities following reductions in industrial emissions (industrial background) and ground-dwelling invertebrates (control). Two periods were compared: the period of emission cessation and the period of recovery. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

Keywords: Aranei, Opiliones, ecological traits of species, metal pollution, heavy metals, community structure, soil macroinvertebrates, earthworms, insects, mollusks

DOI: 10.1134/S1067413619020115

Initial Stages of Recovery of Soil Macroinvertebrates after Reduction of Emissions from a Copper Smelter

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Received August 16, 2018; revised August 20, 2018; accepted September 10, 2018

Abstract—Analysis of natural recovery of communities after reduction of emissions from a copper smelter. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

Keywords: dynamics, stability, resilience, natural recovery, recolonization, heavy metals, community structure, soil macroinvertebrates, earthworms, insects, mollusks

DOI: 10.1134/S1067413619020115

Soil macroinvertebrates in forest ecosystems largely determine the rate of biological turnover and plant provision with nutrients; contribute to the formation of soil structure, thereby influencing soil water regime and fertility; and modify the composition of soil microorganisms [1]. In view of such a significant role of this group, suggestions to include parameters characterizing its state in environmental monitoring [2] and environmental pollution control [3] are quite reasonable.

Various pollutants have a deleterious effect on soil macroinvertebrates [4]. Especially hazardous is soil pollution with heavy metals caused by nonferrous metal industries: some groups of these animals disappear or drastically decrease in abundance, which radically transforms the structure of communities [5–11]. Such transformations lead to retardation of organic matter decomposition and deceleration of biological turnover [12], destruction of soil aggregates [12, 13], elimination of mammals trophically connected with

macroinvertebrates [14]. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

Industrial pollution poses both direct and indirect effects on ecosystems, including changes in habitat structure and productivity, food webs, and performance of populations and individuals [Newman and Schreier, 1984; Hoffman et al., 1995; Clements and Newman, 2002]. The emissions of non-ferrous smelters are especially harmful to natural ecosystems due to a combination of sulfur dioxide and polycyclic aromatic hydrocarbons (PAHs) [Kozlov and Kozlov, 1989; Kozlov and Zvezdova, 2007]. Sulfur dioxide causes necrosis in plants, acidification of soil, and nutrient leaching [Kozlov, 1976]. Heavy metals persist in soil for centuries [Makal et al., 1995] and cause physiological disorders, impaired reproduction, and low survival in plants and animals [Schenhammer, 1987; Nagaiyoti et al., 2010; Jaisankar et al., 2014]. In recent decades, the improvement of technologies has led to reducing industrial emissions [Pacyna et al., 2007; Kozlov et al., 2009] and the recovery of disturbed ecosystems [Vorobeichik et al., 2014, 2019; Mikhailova, 2020]. However, our knowledge of the rate and factors facilitating the recovery of natural

1. Introduction

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systems after pollution. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

* This paper has been recommended for acceptance by Christian Sonne.

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https://doi.org/10.1016/j.envpol.2022.119089

Received 23 August 2021; Received in revised form 3 February 2022; Accepted 28 February 2022
Available online 2 March 2022
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Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol



Improved breeding parameters in the pied flycatcher with reduced pollutant emissions from a copper smelter*

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ARTICLE INFO

Keywords:
Pied flycatcher
Laying date
Clutch size
Fledging number
Recovery
Industrial pollution

ABSTRACT

In recent decades, industrial emissions have led to a significant reduction in the breeding parameters of the pied flycatcher. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

The Lichenologist (2024), 1–8
doi:10.1017/S0024282924000173

Standard Paper

Lichen recovery in a formerly polluted area: the importance of bark properties for soredia survival

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Abstract

An experiment was conducted on the development of *Hypogymnia physodes* (L.) Nyl. from soredia to branched lobes near the copper smelter in the Middle Ural 10 years after emission cessation. Soredia were cultivated in fir-spruce forests in heavily polluted and unpolluted areas. In both areas, soredia development was examined on fir bark collected from both the heavily polluted and unpolluted areas. The probability of lobe formation was lower in the polluted area even when soredia were cultivated on bark from the unpolluted area. Bark from the polluted area negatively impacted the success of soredia development, irrespective of the cultivation area. The lowest success of early development occurred when soredia were cultivated on polluted bark in the heavily polluted area, where the already low probability of lobe formation was accompanied by high mortality of the developed lobes. This study underscores the enduring impact of industrial pollution on *H. physodes* development, highlighting the need for ongoing environmental restoration and monitoring efforts in post-industrial areas to support biodiversity conservation.

Keywords: air pollution; early development; *Hypogymnia physodes*; Middle Urals; recolonization

(Accepted 9 May 2024)

Introduction

Lichens are known to be extremely sensitive to changes in the chemical composition of the environment. In response to air pollution, there occurs a decrease in species diversity, alterations in morphology and physiology, and an accumulation of pollutants in thalli. Furthermore, many lichen species are highly affected by alterations to habitats indirectly caused by pollution, such as fragmentation and microclimate changes. Therefore, they are widely used as sensitive indicators and monitors of environmental quality (Nimis et al., 2002).

In recent decades, technological advances have led to a global reduction in atmospheric emissions from industrial enterprises (Pacyna et al., 2007; Kozlov et al., 2009), presenting a unique opportunity to study ecosystem resilience. The recovery of lichen communities after declines in pollution has been observed both in urban areas (Rose & Hawksworth 1981; Bates et al., 1990; Seaward & Letrouit-Gallou 1991; Gilbert 1992) and in the surroundings of industrial enterprises (Beckett 1995; Howe & Lendemer 2011; Schram et al., 2015; Mikhailova 2020). In all cases, the recovery has been very slow, taking decades. Some possible explanations for slow recolonization rates have been proposed. In urban areas, a decrease in emissions of one pollutant often coincides with an increase in another, continuously impacting lichens (e.g. a decrease in SO₂ concentrations accompanied by a

increase in NO_x levels) (Bates et al., 1990; Loppi & Corsini 2003). Another possible explanation is the higher sensitivity of lichen reproductive stages to pollution compared to mature thalli: diaspore production and establishment may be suppressed in formerly polluted areas (Margot 1973; Gilbert 1992). Substratum contamination also poses a limiting factor for lichen re-establishment, with increased bark acidity impeding recolonization as observed on oaks in London, England (Bates et al., 1990). The importance of substratum contamination for diaspore development has been supported by laboratory experiments: the germination rate of *Hypogymnia physodes* (L.) Nyl. soredia was reduced when cultivated on metal-containing media (Marti 1985; Hauck et al., 2002).

Based on the above studies, we conducted an experiment aimed at revealing possible factors limiting lichen recolonization in the formerly polluted area near the Middle Ural Copper Smelter (MUCS), one of the largest copper smelters in Russia, during the first decade after emission ceased. As a model species, we chose the foliose lichen *Hypogymnia physodes* (L.), which dominates the epiphytic communities of the majority of tree species in the studied area. Previously, during the period of high emissions from MUCS (1995–1997), the response of this species to the pollution was studied in detail. *Hypogymnia physodes* abundance decreased along the pollution gradient, leading to the disappearance of the species at distances of 2–10 km from the smelter, depending on the wind rose (Mikhailova 2022). Under a strong pollution regime, a shift was observed in the population structure towards smaller and less sorediate thalli, reduced production of soredia, and decreases in soredial survival and

DEGRADATION, REMEDIATION, AND CONSERVATION OF SOILS

Long-Term Dynamics of Heavy Metals in the Upper Horizons of Soils in the Region of a Copper Smelter Impacts during the Period of Reduced Emission

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3, 2016

Heavy and acid-soluble heavy metals (Cu, Pb, Cd, Zn) in fir forests were studied in the area subjected to emissions from the Middle Ural Copper Smelter. It was found that the emissions of sulfur dioxide and dust with the emissions in 1980. Samples of litter and soil were collected in 1989, 1999, and 2012. The results indicate that the pH of the soil decreased from 4.5 to 4.0 after the beginning of the emission reduction. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported. The results of the study show that the hypothesis of the recovery of ground-dwelling invertebrate communities in the second period of recovery is supported.

soil recovery, metal mobility, ecosystem stability,

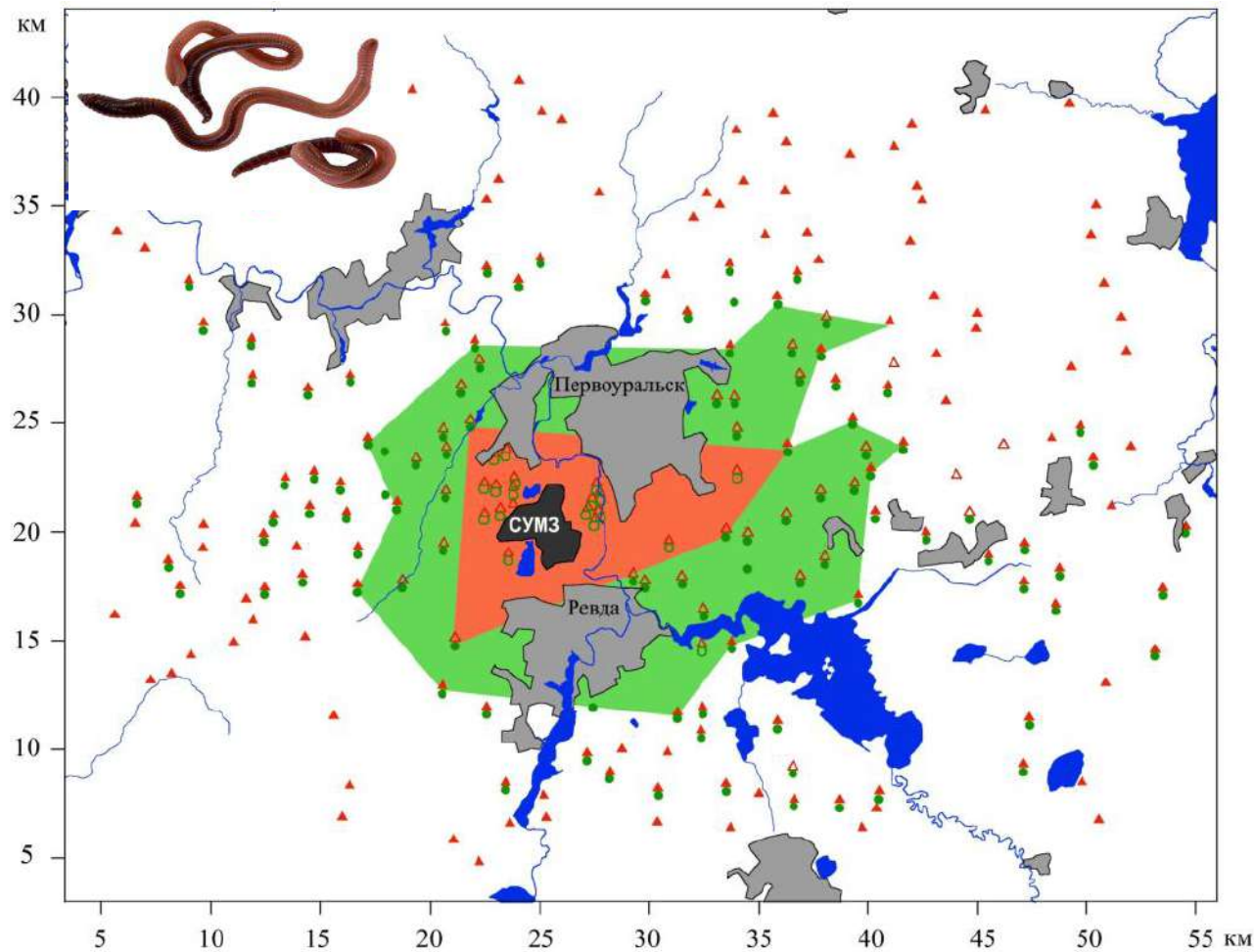
vious practical aspects (e.g., related to remediation strategies), studies in this field are important in terms of fundamental ecology, because they allow analyzing the stability mechanisms of ecosystems in the impact zone [9] (in our case, their resilience). Therefore, the analysis of biota dynamics during the period of emission reduction attracts interest [13, 21, 34, 52, 67].

In terms of the natural restoration of ecosystems, it is important to assess the rate of soil purification from pollutants, because this makes it possible to consider changes in the toxic load on vegetation and soil biota in time. Such estimates are especially necessary for the upper soil horizons, because, first, they concentrate the major part of roots and active soil biota, and, second, the maximum concentrations of metals in the polluted areas are usually observed in the upper 10–20 cm-thick layer of soil profile [40]. Consequently, the processes occurring in these horizons largely determine the rate and character of restoration of the tree ecosystem.

An extremely low removal rate of heavy metals from the soil was demonstrated in the early studies of

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Cite this article: Mikhailova I and Mikryukov V (2024) Lichen recovery in a formerly polluted area: the importance of bark properties for soredia survival. *Lichenologist* 1–8. <https://doi.org/10.1017/S0024282924000173>

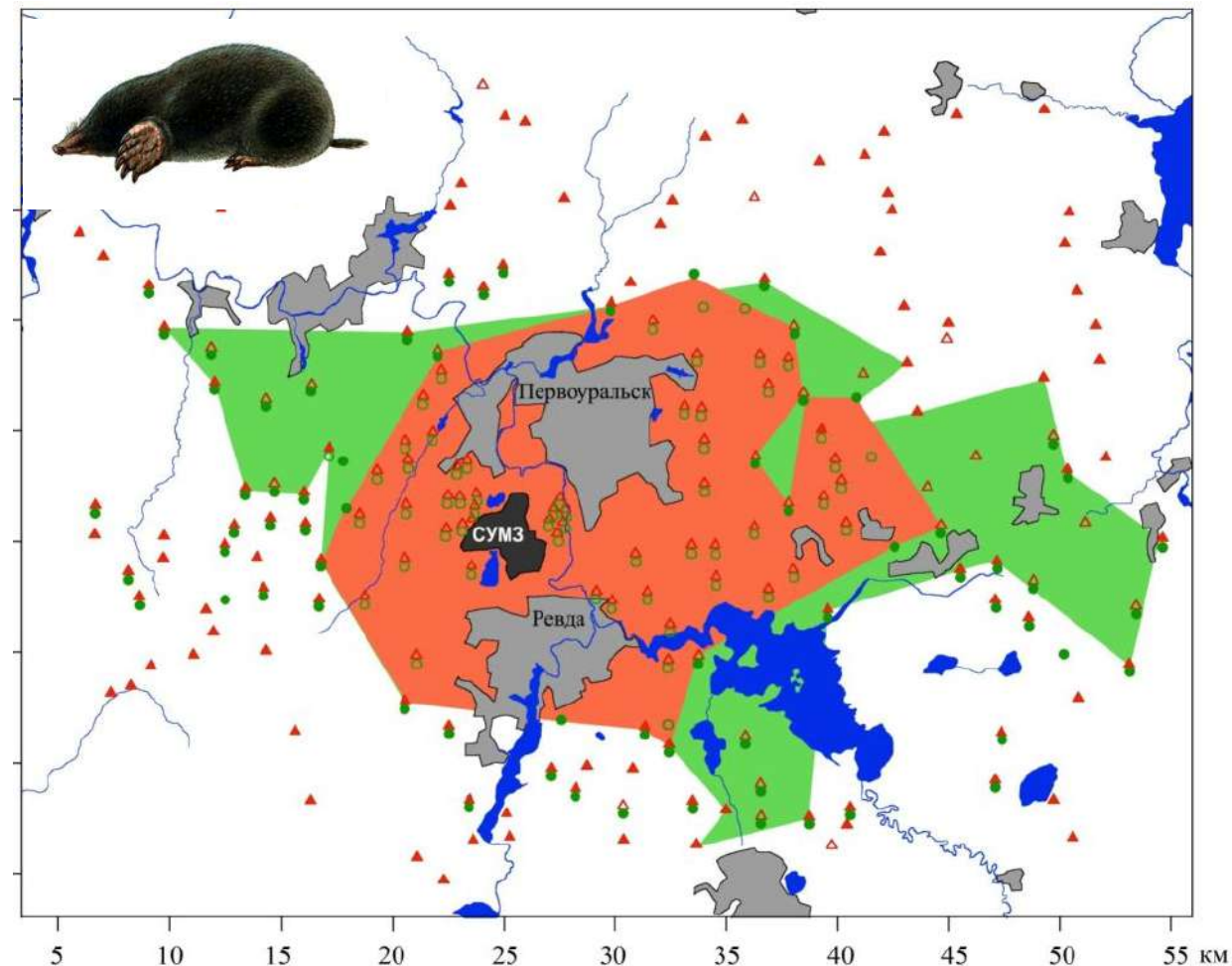
Уменьшение кротовой и люмбрицидной пустыни в районе СУМЗ



317 km² (1995-1998 гг.)

81 km² (2013-2015 гг.)

.....



576 km² (1995-1998 гг.)

354 km² (2013-2015 гг.)

.....

Воробейчик, Нестеркова, 2015

Нетипичные формы гумуса



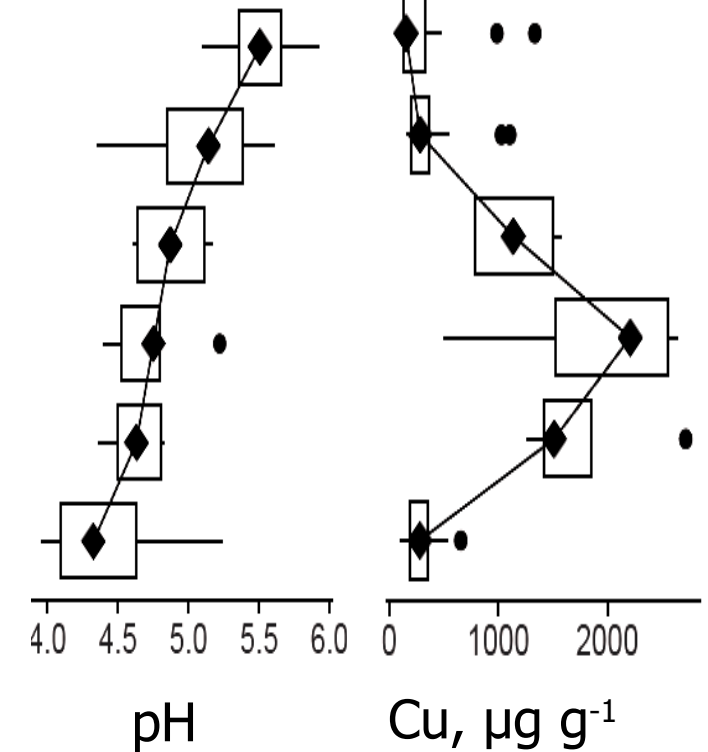
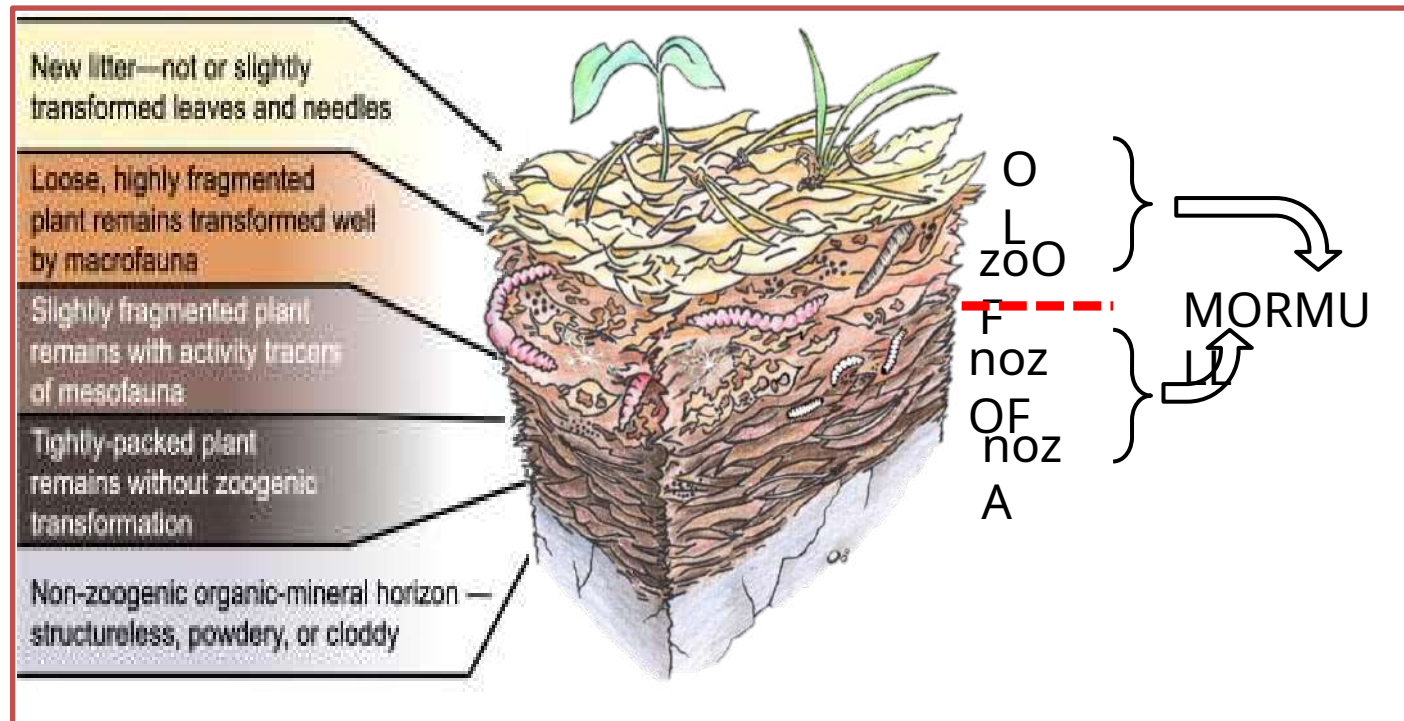
Science of The Total Environment

Volume 904, 15 December 2023, 166810



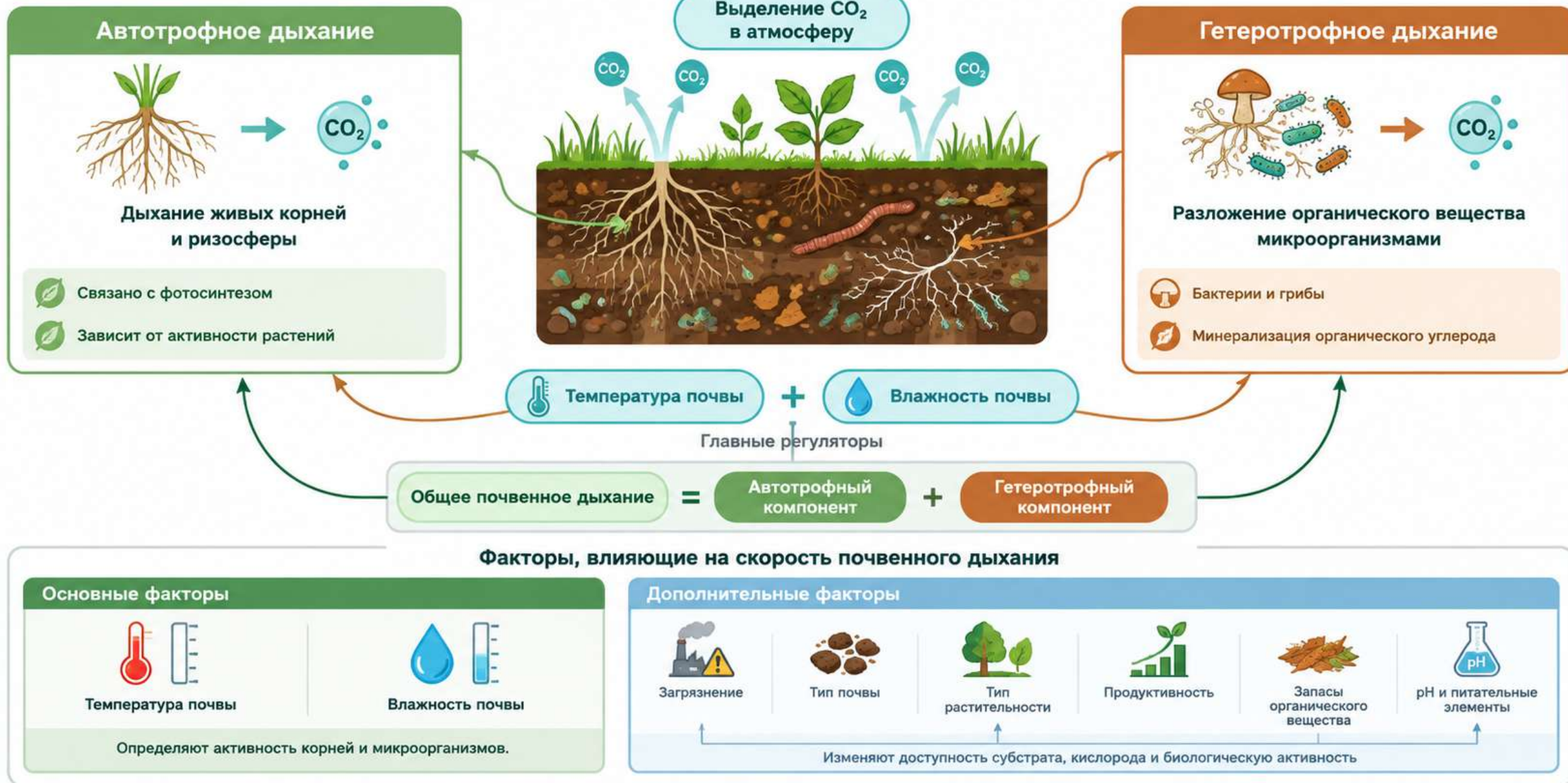
A bizarre layer cake: Why soil animals recolonizing polluted areas shape atypical humus forms

Evgenii L. Vorobeichik , Irina N. Korkina



Почвенное дыхание

Поток CO_2 из почвы в атмосферу



Методы

SR1LP (Qubit systems)
2010-2011

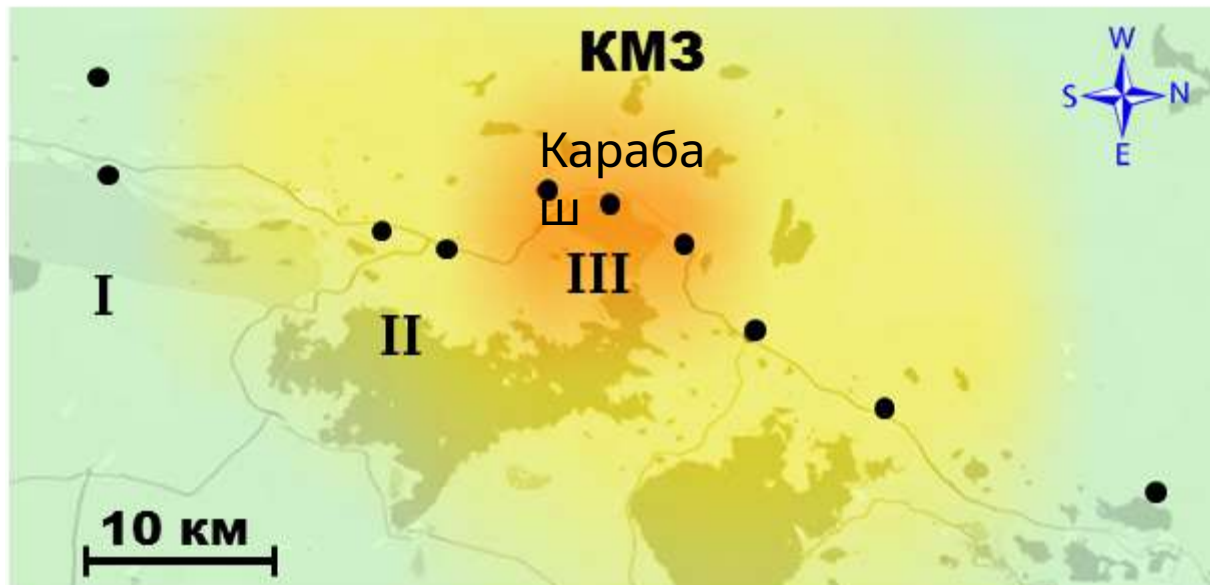
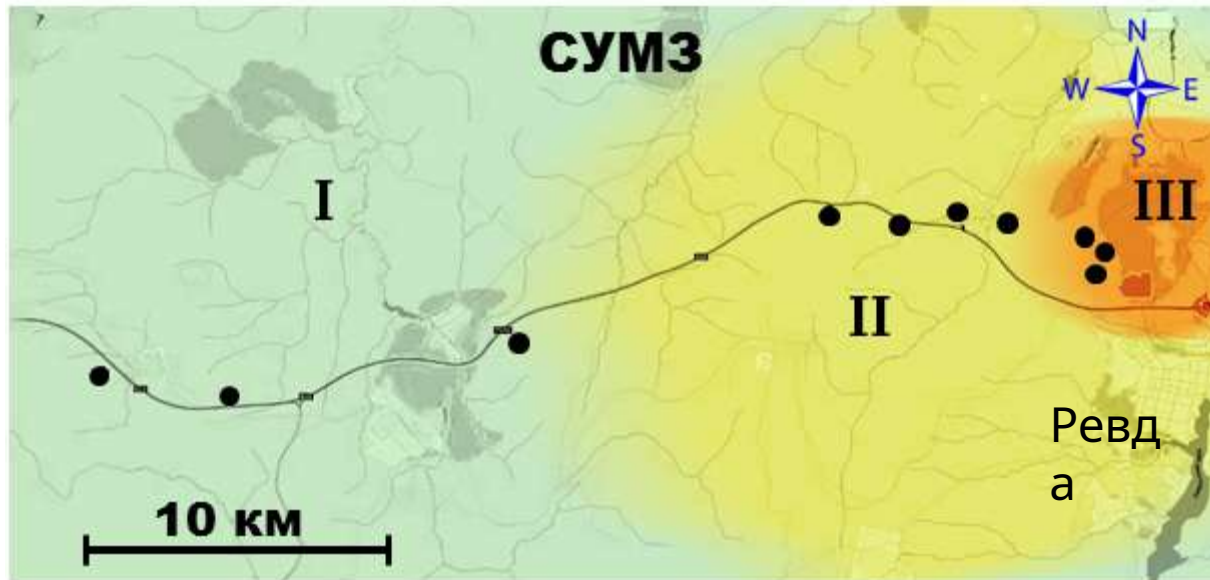


Li8100A (Li-Cor biosciences)
2012-2023



Li7810 (Li-Cor biosciences)
2024-...





2 завода

По 10 участков 1-33 km от завода

3 пробные площади (ПП) (25*25 m) на участок

5-15 случайных точек измерения на ПП

- 2010-13, 2018, 2023, 2024 гг. (летние или летние и осенние туры), 2020-2021 (измерения на отдельных участках) – всего, 36 туров

Более **6300** измерений дыхания почвы

Диапазоны условий во время измерений:
 $T_{\text{soil}} = -1 - +36^{\circ}\text{C}$, $T_{\text{air}} = 0 - +40^{\circ}\text{C}$, $M = 0.1-1$

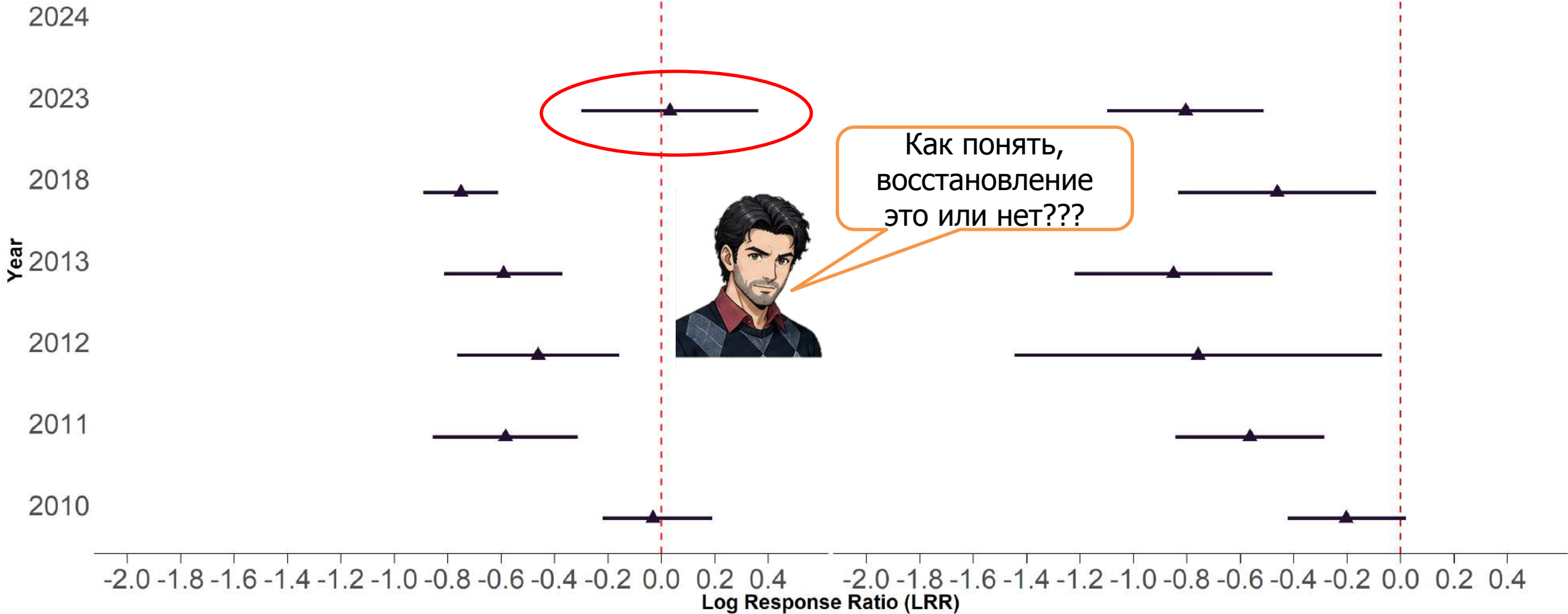
Отношение откликов дыхания почвы в летние туры

$$RR = \ln(x_{imp}/x_{bkgr})$$

LRR±95% CI

СУМЗ

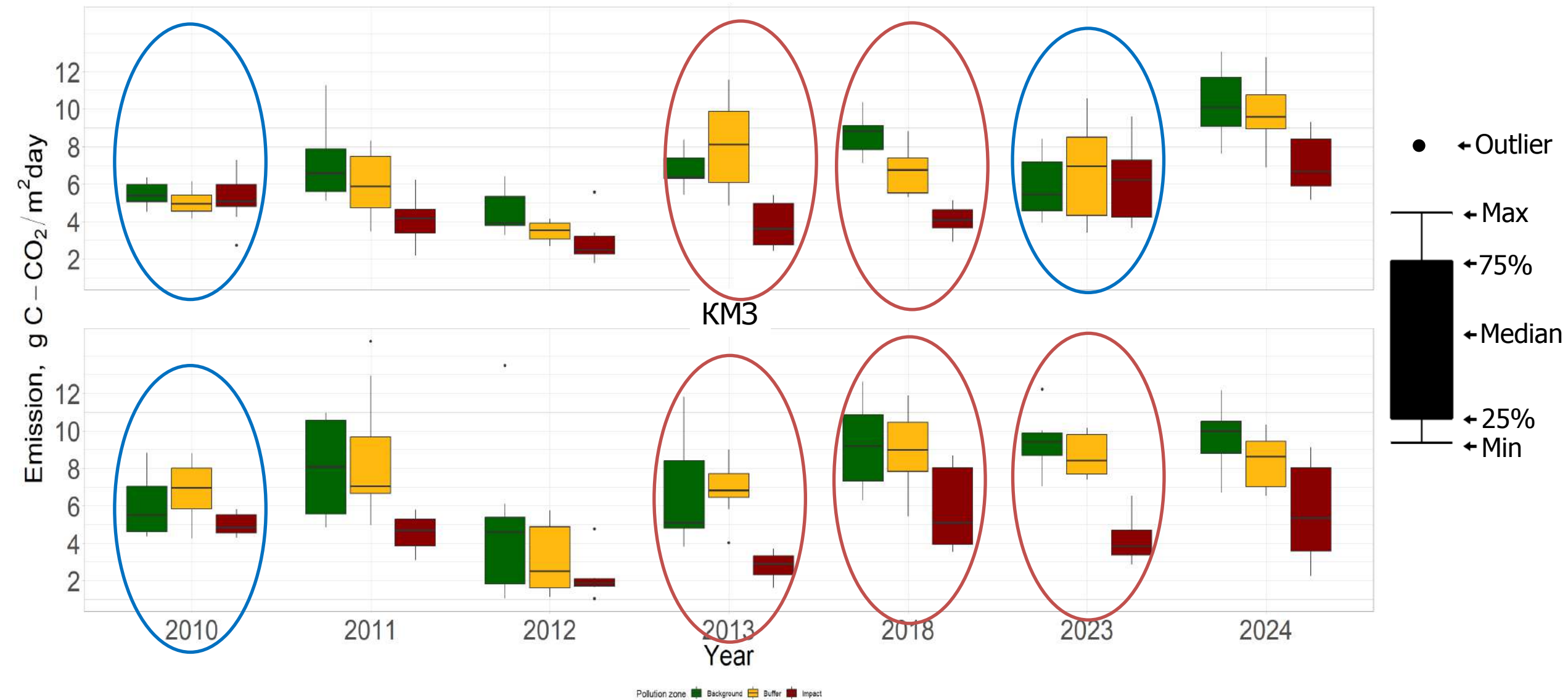
КМЗ

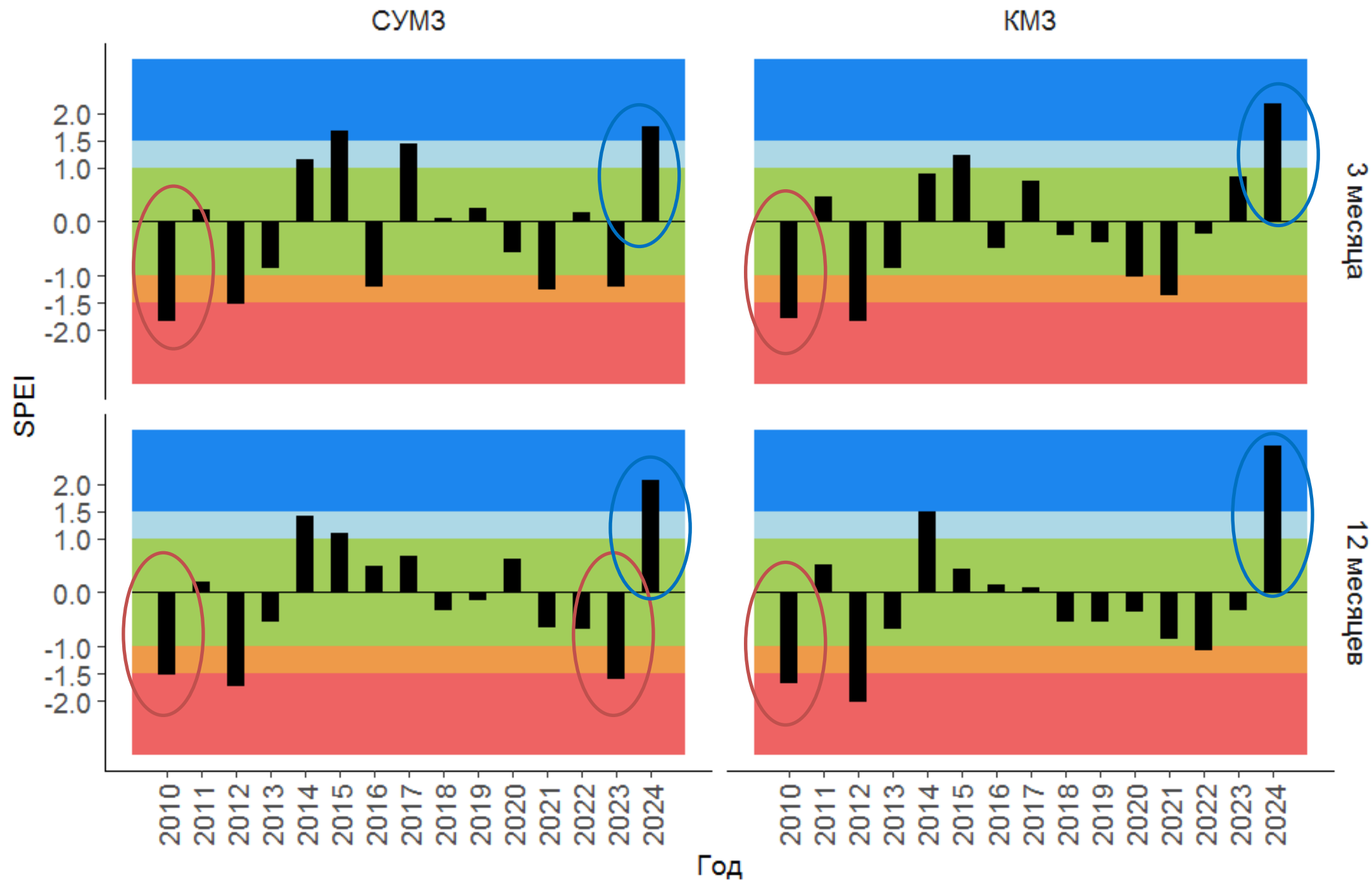


in-situ дыхание почвы в летние туры

СУМЗ

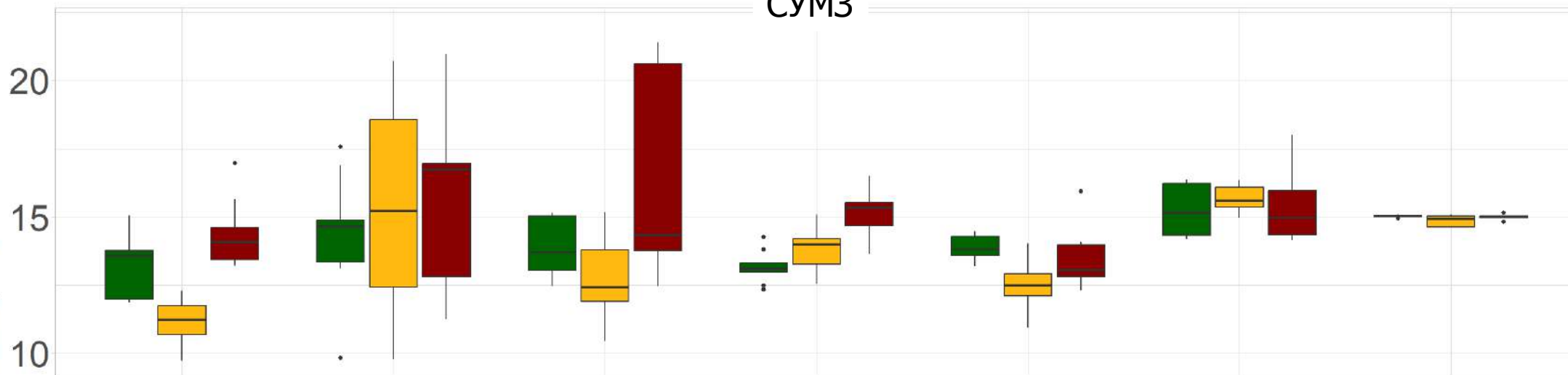
KM3



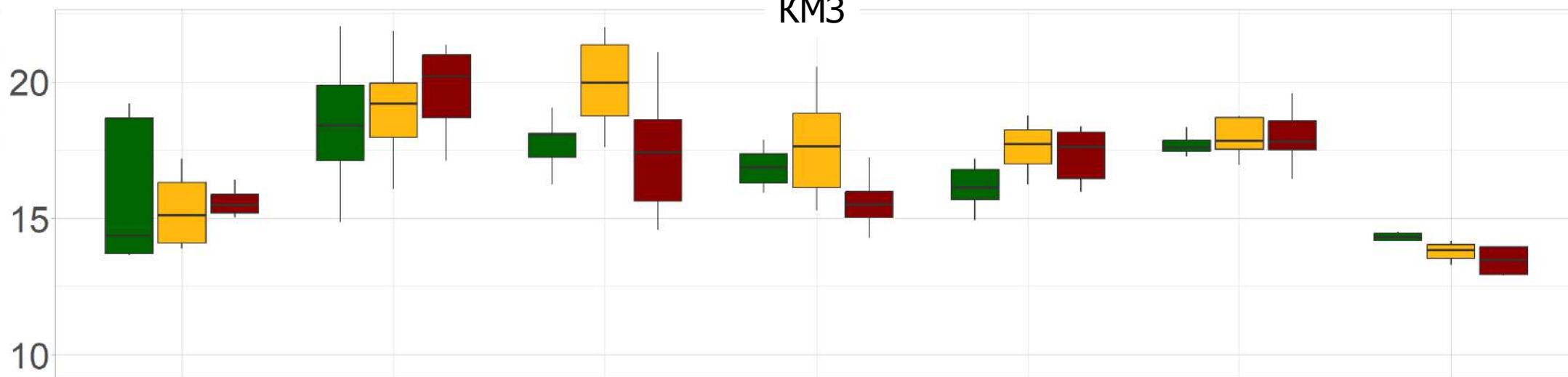


in-situ температура почвы в летние туры

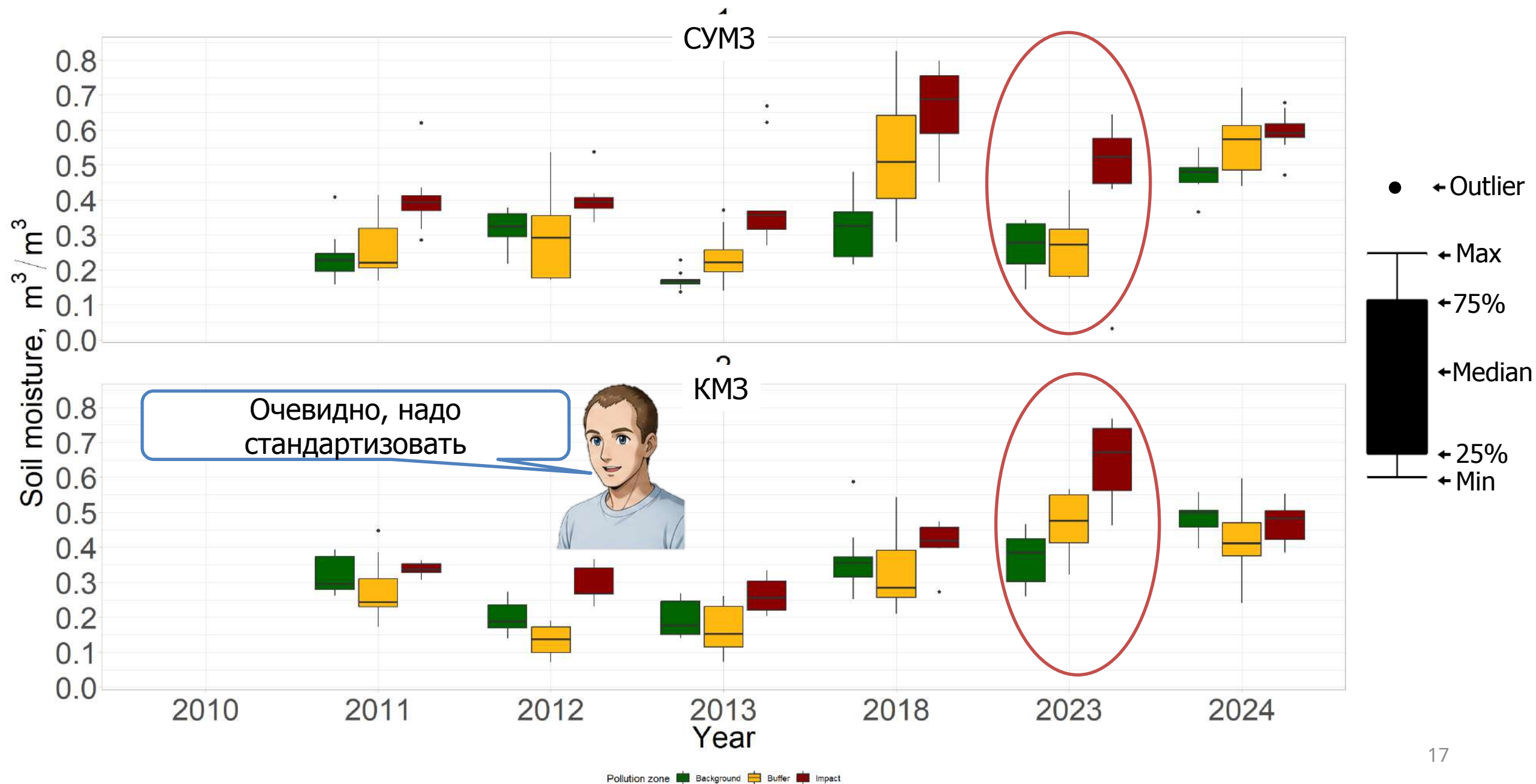
СУМЗ



КМЗ



in-situ влажность почвы летом



Temperature Sensitivity and Basal Respiration and Their Determinant Forests of North China

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Abstract

The basal respiration rate at 10°C (R_{10}) and the temperature sensitivity of soil predicting the instantaneous rate of soil respiration at a given temperature spatial variations in R_{10} and Q_{10} are not quite clear. R_{10} and Q_{10} were measured soil respiration and soil temperature for 11 mixed conifer-broadleaf stands at a catchment scale. The mean values of R_{10} were 1.83 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ and values of Q_{10} were 3.40 and 3.79, respectively, for mixed and broadleaved forest model parameters, but determinants of R_{10} and Q_{10} varied between the decreased greatly with the ratio of coniferous to broadleaved tree species temperature range and the variations in soil organic carbon (SOC), and soil texture with the spatial variances of herb-layer carbon stock and soil bulk density, and forest stands, R_{10} was markedly affected by basal area and the variations in SOC content; the value of Q_{10} largely depended on soil pH and the variations in SOC. Q_{10} can be accounted for jointly by five biophysical variables, of which SOC played an overwhelming role in determining the amplitude of variations in soil basal respiration. It was concluded that soil respiration of temperate forests was largely determined by temperature kept quite low.

Citation: Zhou Z, Guo C, Meng H (2013) Temperature Sensitivity and Basal Rate of Soil Respiration in Forests of North China. PLoS ONE 8(12): e81793. doi:10.1371/journal.pone.0081793

Editor: Dafeng Hui, Tennessee State University, UNITED STATES OF AMERICA

Received: June 19, 2013; **Accepted:** October 16, 2013; **Published:** December 10, 2013

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Funding: This study was jointly funded by the National Foundation of Natural Science of China (Grant No. 31074008), the State Forestry Administration of China (Grant No. 201104008). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

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Article

Modeling of CO₂ Efflux from Forest and Grassland Soils Depending on Weather Conditions

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Abstract: Carbon dioxide (CO₂) efflux from soil (or soil respiration, SR) is one of the most important yet variable characteristics of soil. When evaluating large areas, CO₂ efflux modeling serves as a viable alternative to direct measurements. This research aims to identify site-specific differences and their effects on empirical CO₂ efflux modeling. The experimental data from 25 years of field observations were utilized to identify the optimal site- and weather-specific models, parameterized for normal, wet, and dry years, for the forest and grassland ecosystems located on similar Entic Podzols (Arenic) in the same bioclimatic coniferous-deciduous forest zone. The following parameters were considered in the examined models: mean monthly soil or air temperatures (Tsoil and Tair), amount of precipitation during the current (P) and the previous (PP) months, and the storage of soil organic carbon (SOC) in the top 20 cm of soil. The weighted non-linear regression method was employed to estimate the model parameters for the normal, wet, and dry years. To increase the magnitude of the model resolutions, we controlled the slope and intercept of the linear model comparison between the measured and modeled data through the change in R_0 —CO₂ efflux at Tsoil = 0 °C. The mean bias error (MBE), root-mean-square error (RMSE), and determination coefficient (R^2) were employed to assess the quality of the model's performance. The measured Tsoil, Tair, and P, as well as the litter (for forest) or sod (for grassland) horizon (modeled by the Soil SCLmate Statistical Simulator (SCLISS)), and soil temperatures (Tlit_m, Tsoil_m) and moistures (Mlit_m, Msoil_m), were used for SR simulation. For the CO₂ efflux in the forest ecosystem with the lower SOC availability for mineralization, the direct Tsoil and Tair measurements in combination with SOC storage provided better parameterization for the empirical TPPC model. For the CO₂ efflux in the grassland ecosystem with the high SOC availability for mineralization, the temperature became the governing factor, and the TPPrh model provided better performance over all the considered models. The model's performance was the best for the wet years, and the worst for the dry years for both ecosystems. For forest ecosystems, the model performance for average precipitation years was equivalent to that in wet years. For grassland ecosystems, however, the model performance was equivalent to that in dry years due to differing exposure and hydrothermal regimes. The wet-year R_0 obtained for both forest and grassland ecosystems differed from the normal- and dry-year values. The measured SR values relevant for the R_0 estimations distribute along the precipitation range



Academic Editors: Bal Ram Singh and Nick B. Comerford

Received: 29 November 2012

Revised: 31 January 2013

Accepted: 24 February 2013

Published: 6 March 2013

Citation: Kivalov, S.; Kurganova, I.; Bykhovets, S.; Khoroshaev, D.; Lopes de Gerenyu, V.; Wu, Y.; Myakshina, T.; Kuzyakov, Y.; Pripulina, I. Modeling of CO₂ Efflux from Forest and Grassland Soils Depending on Weather Conditions. *Soil Syst.* 2013, 9, 25. doi:10.1371/journal.pone.0081793

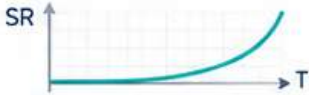
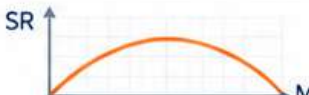
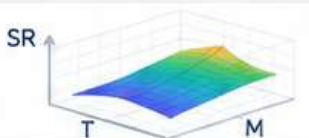
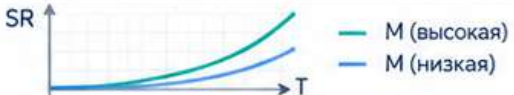
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Цель:

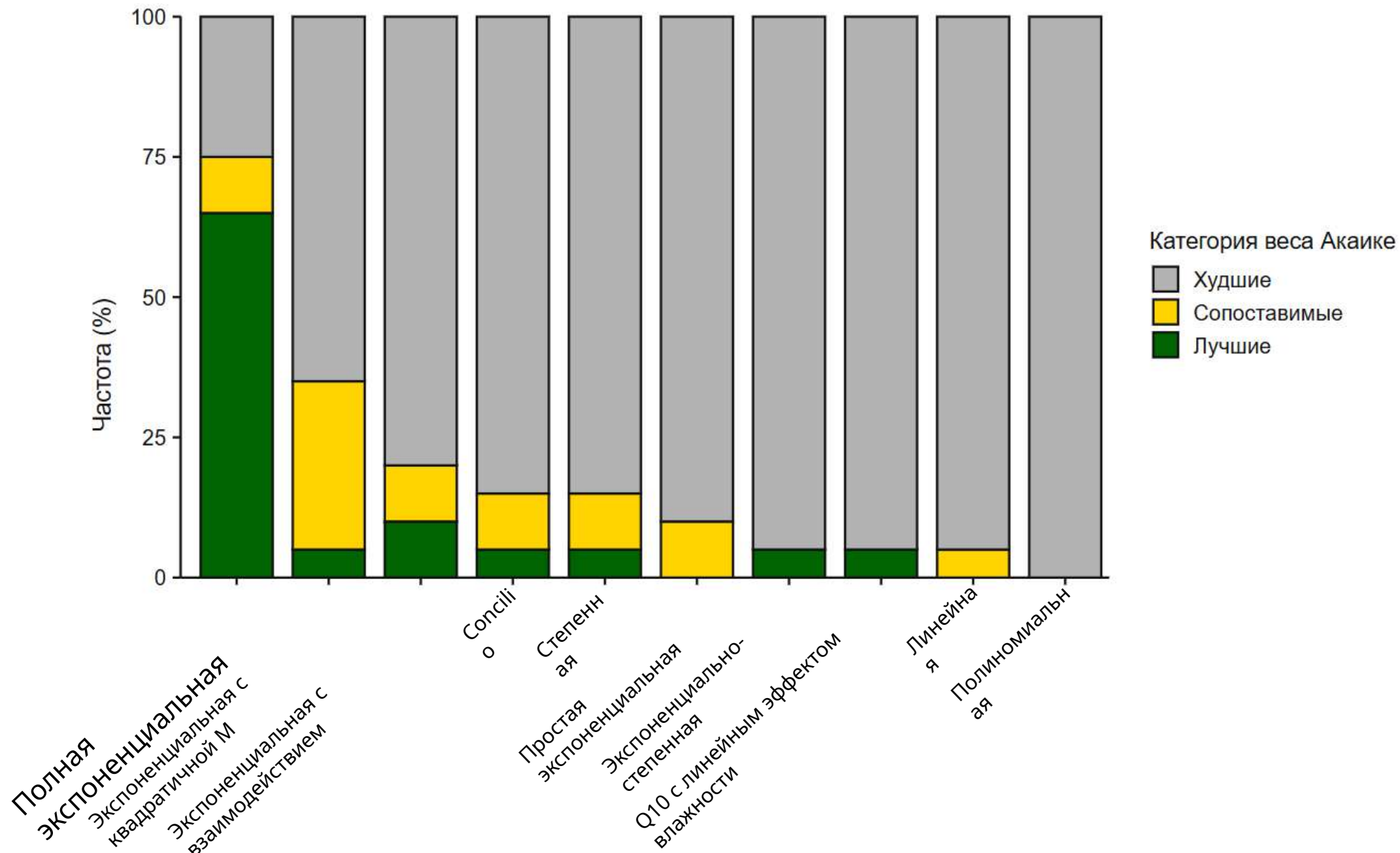
- Проанализировать межгодовую динамику дыхания почвы в условиях долговременного промышленного загрязнения с помощью стандартизации с применением классических регрессионных подходов и машинного обучения

Регрессионные модели зависимости почвенного дыхания от температуры и влажности

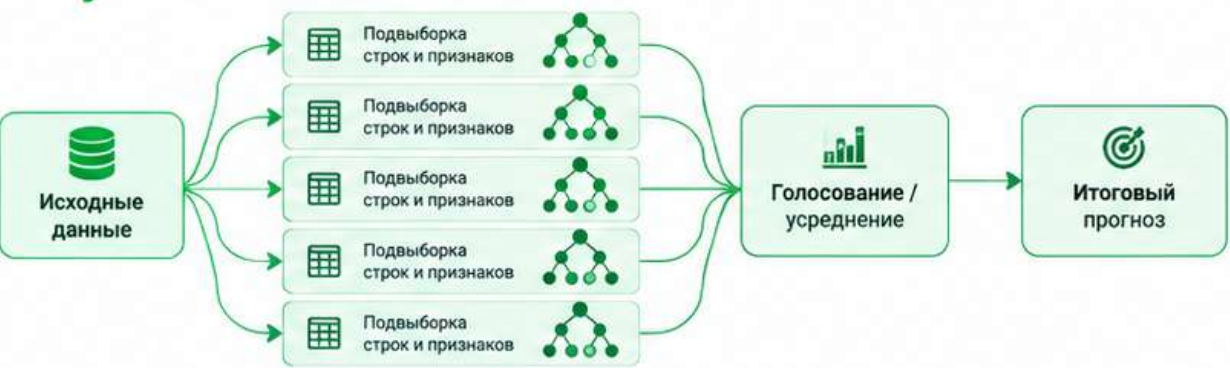
SR — скорость почвенного дыхания; T — температура почвы; M — влажность почвы.

Модель		Формула	
1.	Линейная	$SR = a + bT + cM$	
2.	Полиномиальная	$SR = a_0 + a_1T + a_2T^2 + a_3M + a_4M^2 + a_5TM$	
3.	Простая экспоненциальная	$SR = \exp(a_1 + a_2T + a_3M)$	
4.	Экспоненциальная с взаимодействием	$SR = \exp(a_1 + a_2T + a_3M + a_4TM)$	
5.	Экспоненциальная с квадратичным членом влажности	$SR = \exp(a_1 + a_2T + a_3M + a_4M^2)$	
6.	Полная экспоненциальная	$SR = \exp(a_1 + a_2T + a_3M + a_4TM + a_5T^2 + a_6M^2)$	
7.	Concilio	$SR = \exp(a_1T + a_2M + a_3TM)$	
8.	Степенная	$SR = aT^bM^c$	
9.	Экспоненциально-степенная	$SR = a \times \exp(bT)M^c$	
10.	Q10 с линейным эффектом влажности	$SR = a \times \exp(bT) + cM$	

Сравнение классических регрессионных моделей



Случайный лес



- Деревья обучаются независимо
- Случайные подвыборки объектов и признаков
- Классификация: голосование; регрессия: среднее

★ **Сильная сторона:** устойчивость к переобучению.

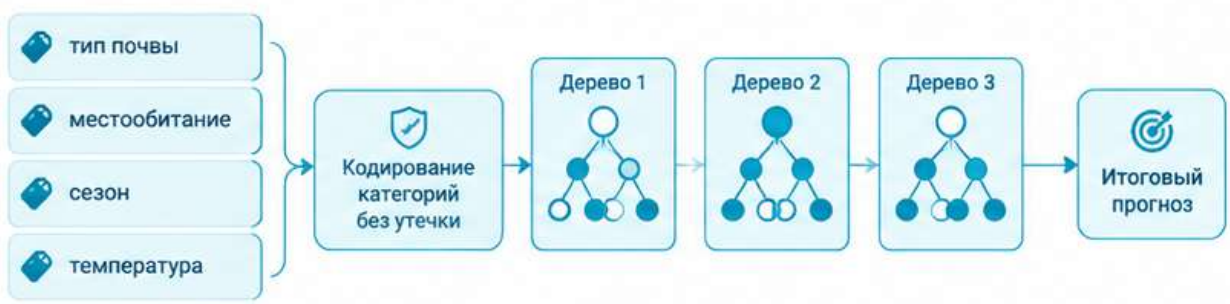
XGBoost



- Деревья добавляются последовательно
- Новое дерево уменьшает ошибки предыдущих
- Регуляризация ограничивает сложность модели

★ **Сильная сторона:** высокая точность на табличных данных.

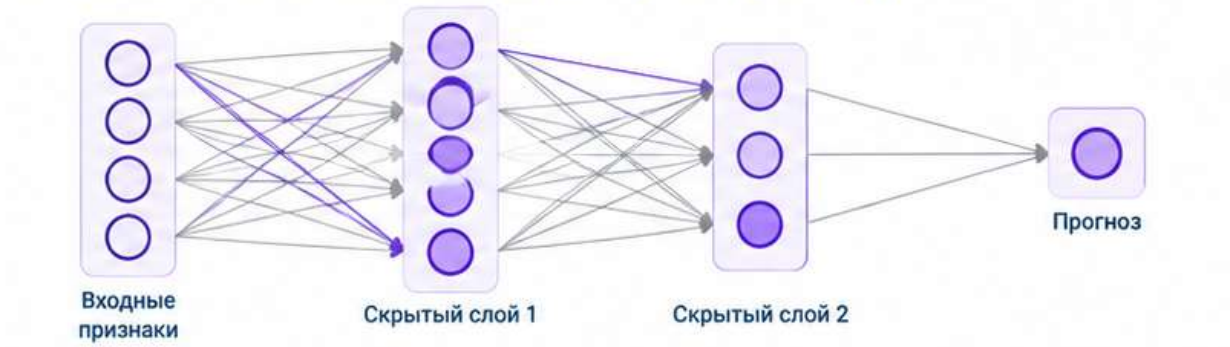
CatBoost



- Поддерживает категориальные признаки
- Использует симметричные деревья
- Упорядоченное обучение снижает утечку цели

★ **Сильная сторона:** удобная работа с категориями.

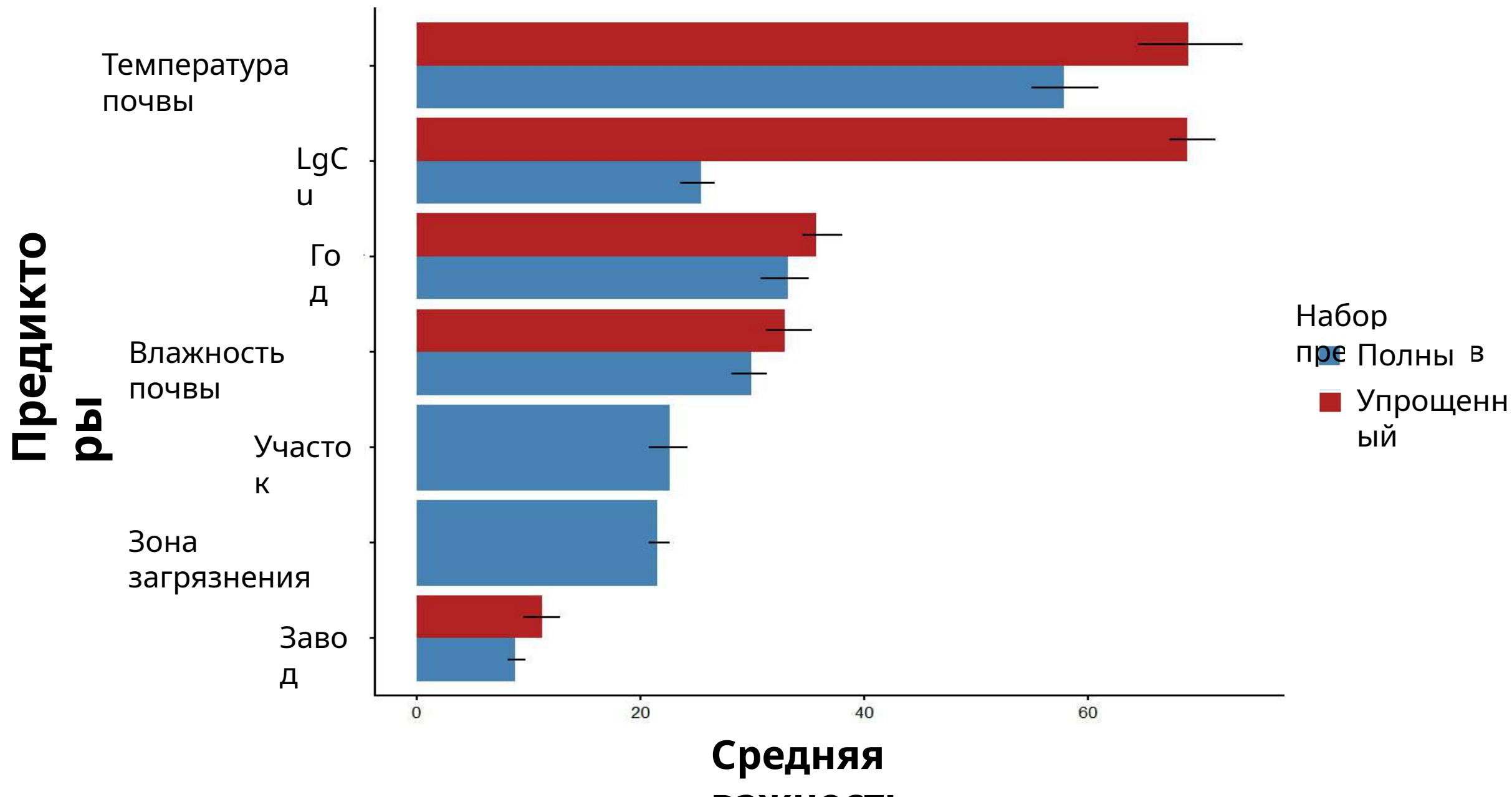
Многослойный перцептрон (ANN)



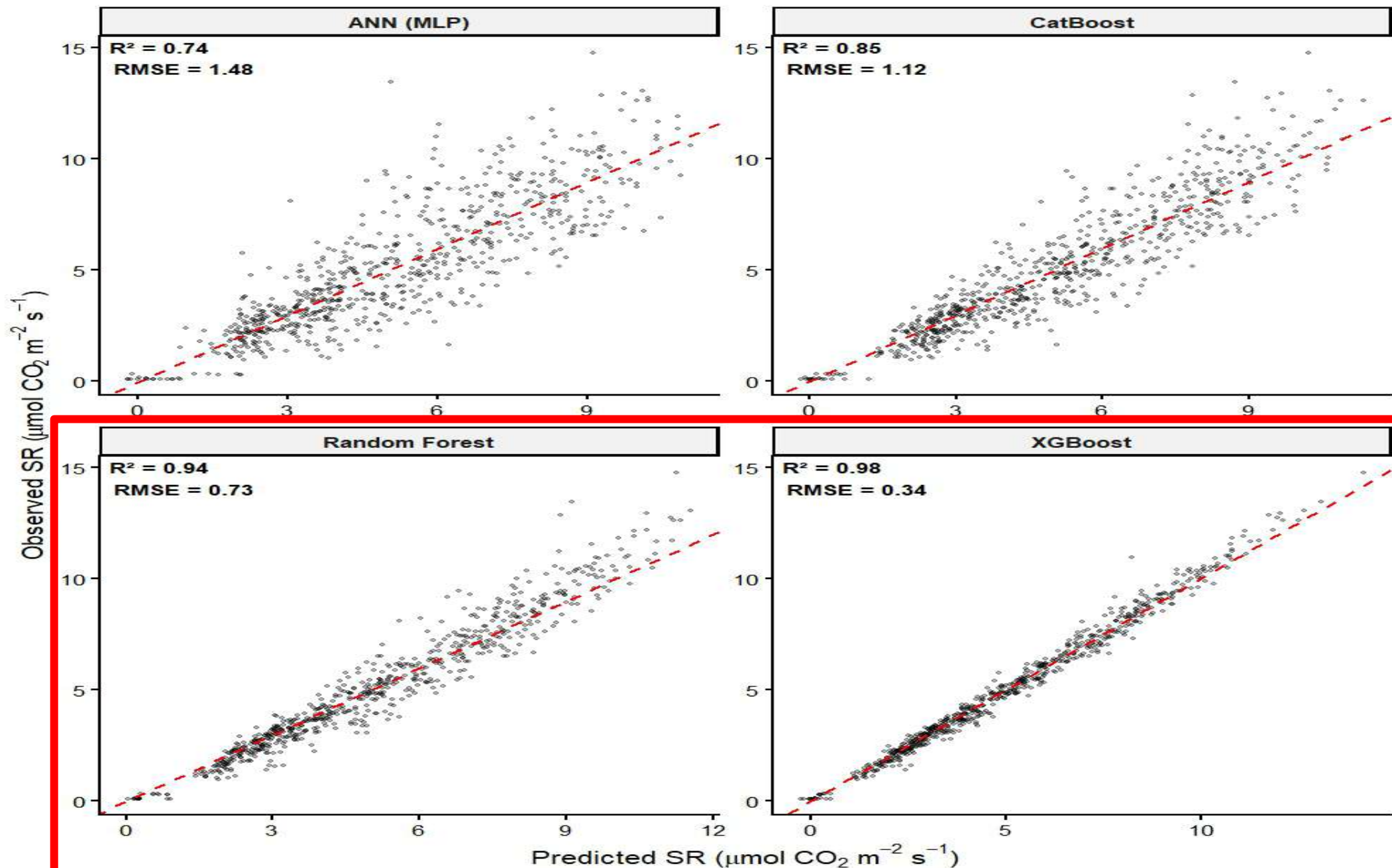
- Нейроны преобразуют входные признаки
- Связи имеют обучаемые веса
- Ошибки корректируются обратным распространением

★ **Сильная сторона:** выявление сложных нелинейных связей.

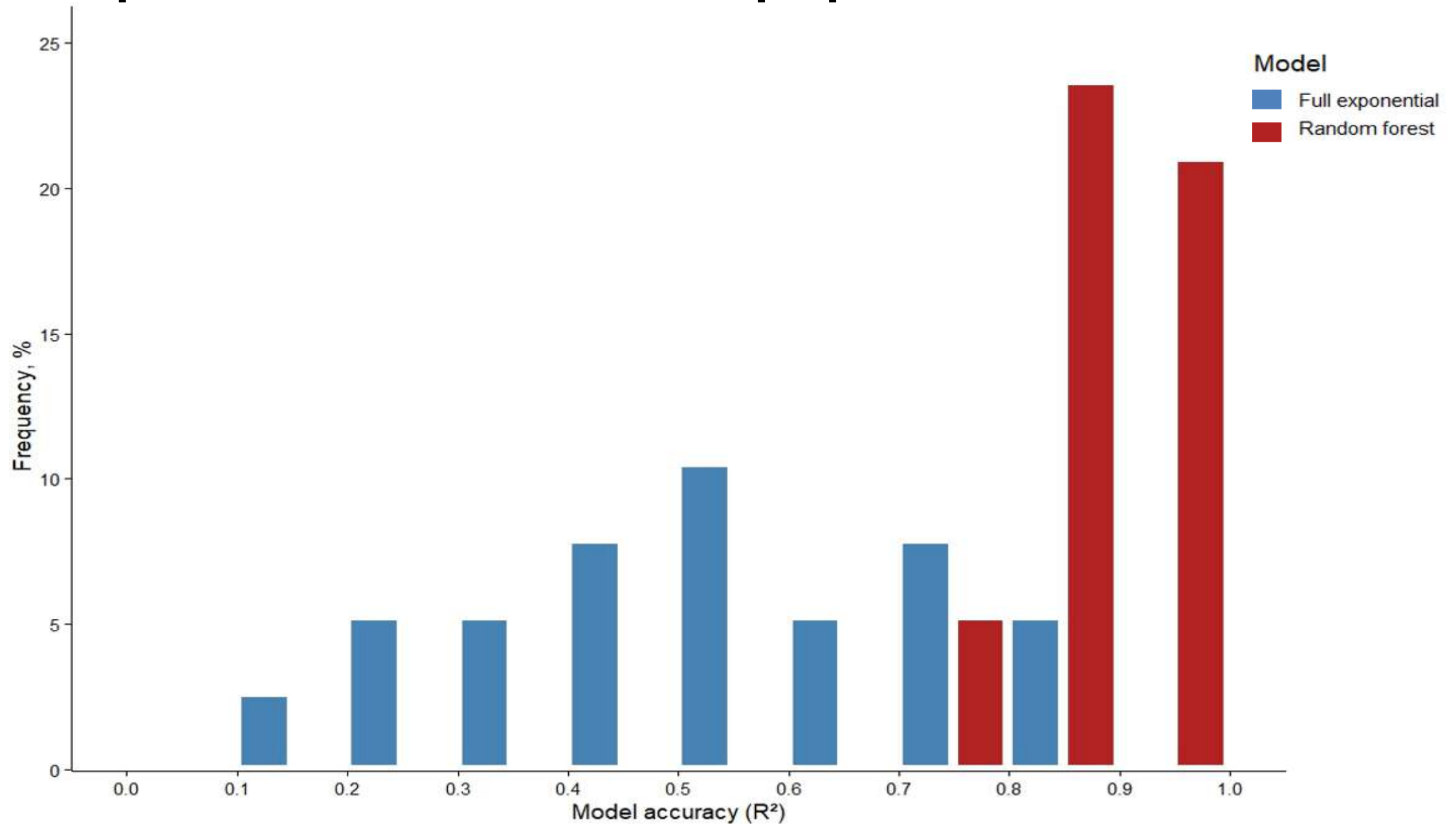
Выбор предикторов с помощью *Boruta*



Сравнение ML регрессионных моделей



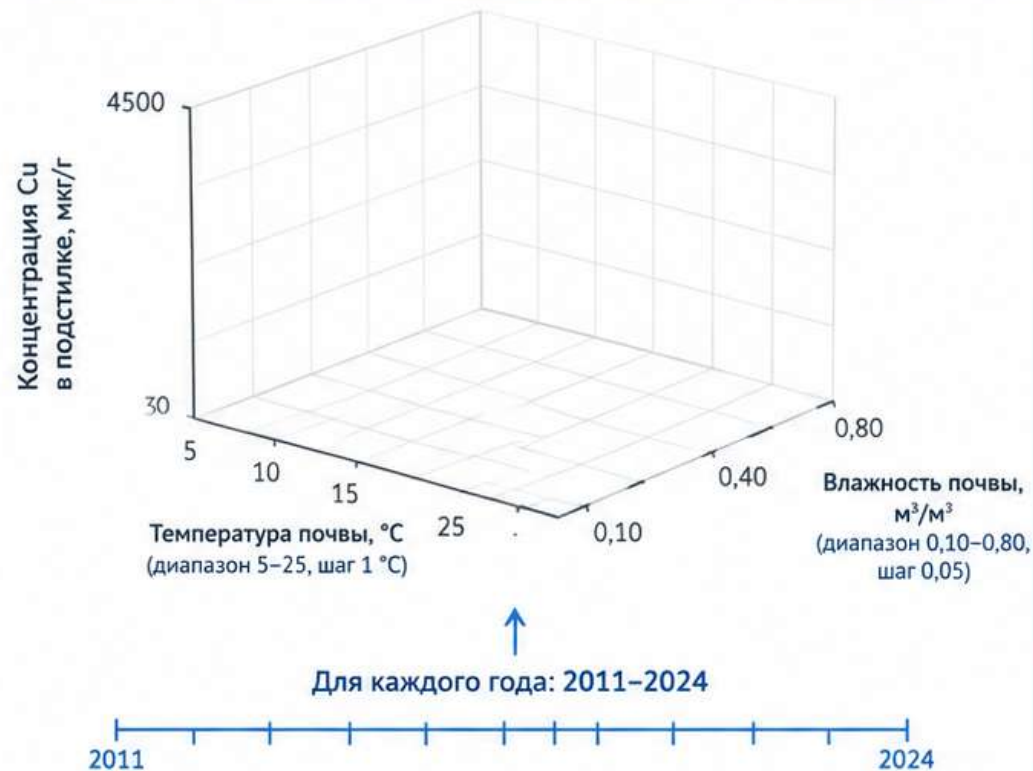
Сравнение классических и ML регрессионных моделей



Сетка предикторов для модельных предсказаний

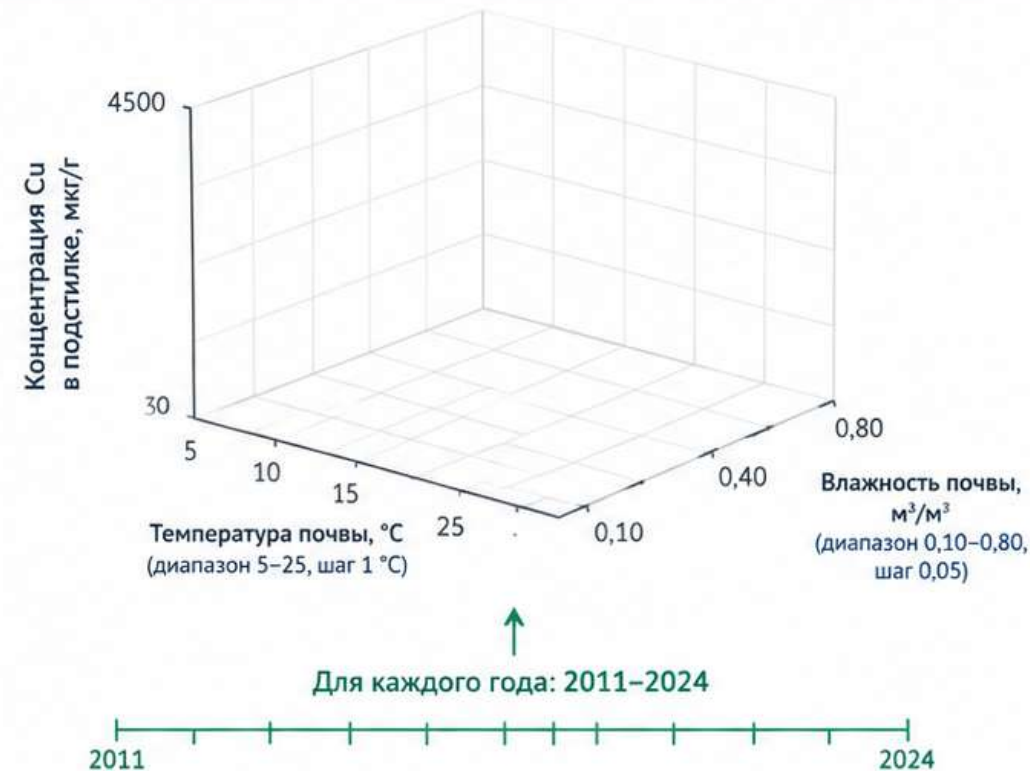
СУМЗ и КМЗ: набор условий для каждого года, 2011–2024.

СУМЗ



Расчёт прогнозов моделей

КМЗ



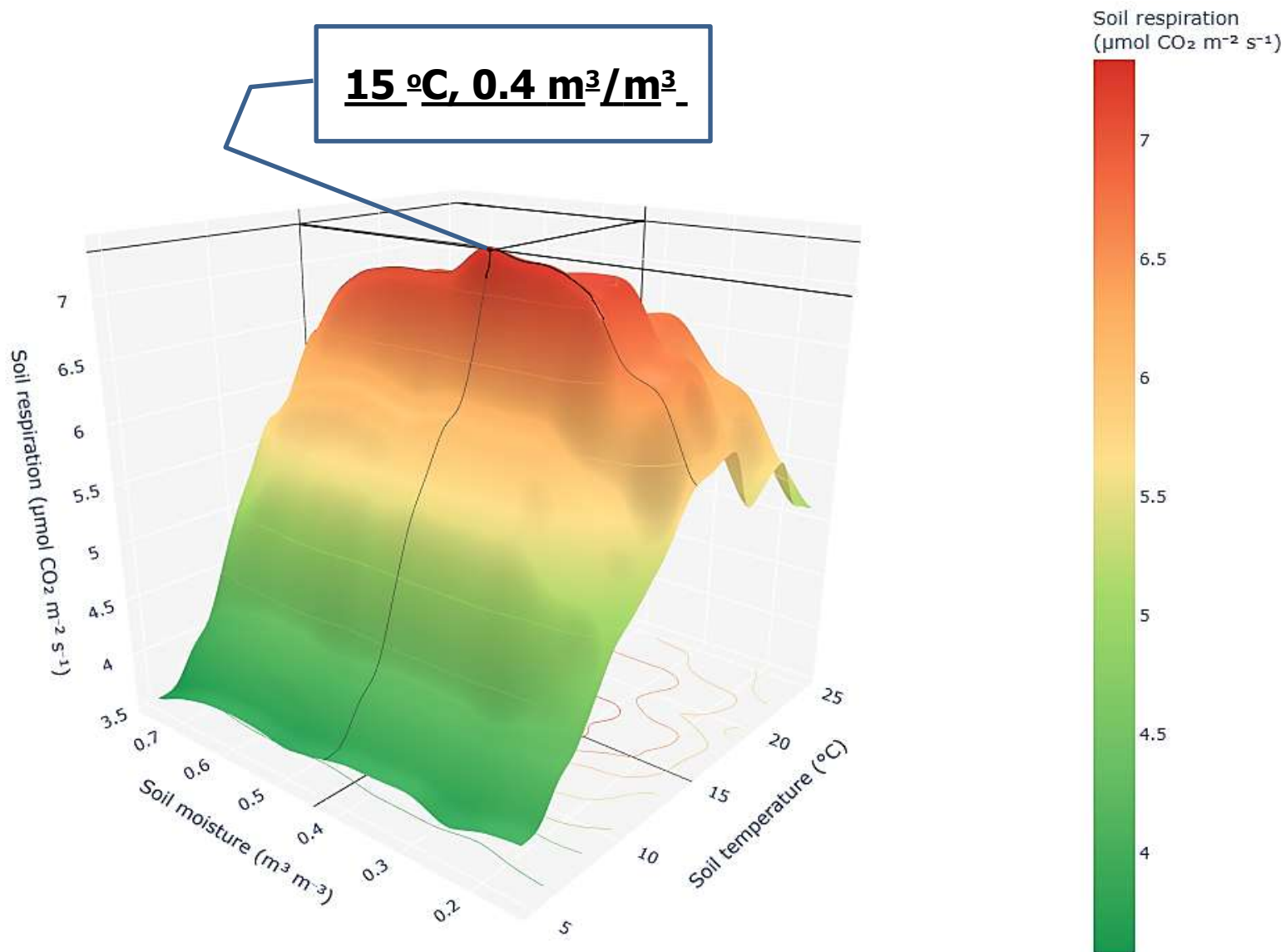
Параметры сетки

Годы:
2011–2024

Температура:
5–25 °C; шаг 1 °C

Влажность:
0,10–0,80 м³/м³; шаг 0,05

Si в подстилке:
30–4500 мкг/г



Средние (медианные) in-situ значения
Температуры и влажности почвы

T: 14°C , (14.3°C)

M: $0.38 \text{ m}^3/\text{m}^3$, ($0.35 \text{ m}^3/\text{m}^3$)

Стандартизация

$$SR_{std} = SR_{obs} \frac{f(T_{ref}, M_{ref})}{f(T_{obs}, M_{obs})}$$

raw vs. normalized (15 °C, 0.4 m³/m³) data

LRR±95% CI

СУМЗ

KM3

Year

2024
2023
2018
2013
2012
2011
2010

-2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 -2.0 -1.8 -1.6 -1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4

Log Response Ratio (LRR)

Data type ▲ Raw ● Классическая регрессия ■ ML регрессия



- Стандартизация полевых данных позволяет избежать ошибочной интерпретации отсутствия/наличия разницы дыхания почвы между фоновыми и загрязненными территориями
- Машинное обучение дает более ясные результаты



- **Благодарности**

- Д.А. Бедину за введение меня в случайный лес и обучению пути в машинное обучение

- И.Е. Бергману и А.А. Габерштейну за помощь в проведении полевых работ

- Работа выполнена при поддержке РФФ (**проект № 25-24-00318**)

Бедин
Д.А.



Бергман
И.Е.



Габерштейн
А.А.



Спасибо за внимание!



СУМЗ в 2007 и 2018 (фото Е.А. Бельского)



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