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ANALYSIS OF THE DISTRIBUTION OF *MUSCARDINUS AVELLANARIUS* (RODENTIA) IN UKRAINE USING THE MAXENT MODEL

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Muscardinus avellanarius, geographic distribution, environmental factors, Maxent model

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Abstract

In this study, the current state of hazel dormouse (*Muscardinus avellanarius*) populations in Ukraine was analysed in detail using the Maxent geographic modelling tool. It is known that fragmentation of natural ecosystems is one of the main threats to biodiversity conservation. Species with low population numbers, such as the hazel dormouse, are particularly vulnerable to this process. Reducing the area of forests leads to a reduction in the number of areas available for nesting, makes it more difficult to find food and can change the microclimate in forest fragments, which leads to changes in the vegetation cover on which the food base depends. The isolation of individual populations limits the opportunities for genetic exchange and adaptation to changing environmental conditions. To estimate the potential range, we developed a distribution model using data on records of the species and climatic characteristics of these areas. The results of the modelling allowed us to identify areas where there is a high probability of occurrence of this species and to identify key factors affecting its distribution. The model allowed us to identify areas where there is a high probability of occurrence of this species, even in the absence of direct observations. It is an important tool for planning measures to protect and restore natural habitats. The analysis of the obtained data showed that the distribution of the hazel dormouse is most influenced by climatic factors that reflect the temperature of the warmest months, humidity, and precipitation. It is these factors that we recommend to be used to develop more accurate distribution models of the species and predict the potential consequences of climate change for its range. The study highlights the importance of preserving forest ecosystems to maintain biodiversity in general and its index species, such as the hazel dormouse. The obtained results can be used to develop effective strategies for the conservation of the hazel dormouse and other species that depend on forest habitats, including the creation of new nature reserves, reforestation and preservation of old forests.

Cite as

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Аналіз поширення *Muscardinus avellanarius* (Rodentia) в Україні засобами моделі Maxent

Юлія Новосельцева

Резюме. У проведеному дослідженні було детально вивчено сучасний стан популяцій ліскульки рудої (*Muscardinus avellanarius*) на території України з використанням інструменту географічного моделювання Maxent. Відомо, що фрагментація природних екосистем є однією з головних загроз для збереження біорізноманіття. Особливо вразливими до цього процесу є види з низькою чисельністю популяції, такі як ліскулька руда. Зменшення площі лісових масивів призводить до скорочення кількості доступних для гніздування територій, ускладнює пошук їжі та може змінювати мікроклімат у фрагментах лісу, що призводить до змін рослинного покриву від якого залежить кормова база. Ізоляція окремих популяцій обмежує можливості для генетичного обміну та адаптації до змін умов середовища. Для оцінки потенційного ареалу ми розробили модель поширення, використовуючи дані про записи знахідок виду та кліматичні характеристики цих територій. Результати моделювання дозволили визначити ділянки, де існує висока ймовірність зустрічі цього виду, та ідентифікувати ключові фактори, що впливають на його поширення. Модель дозволила визначити ділянки, де існує висока ймовірність зустрічі цього виду, навіть за відсутності прямих спостережень. Це є важливим інструментом для планування заходів з охорони та відновлення природних місць існування. Аналіз отриманих даних показав, що на поширення ліскульки рудої найбільше впливають ті кліматичні фактори, які відображають температуру найтепліших місяців, вологості та опадів. Саме ці фактори варто використовувати для розробки більш точних моделей поширення виду та прогнозування потенційних наслідків кліматичних змін для його ареалу. Проведене дослідження підкреслює важливість збереження лісових екосистем для підтримки біорізноманіття загалом і його індикаторних видів, яким є ліскулька. Отримані результати можуть бути використані для розробки ефективних стратегій збереження ліскульки рудої та інших видів, які залежать від лісових біотопів, зокрема створення нових природно-заповідних територій, проведення заходів з лісовідновлення та збереження старих лісів.

Ключові слова: *Muscardinus avellanarius*, поширення, фактори середовища, модель Maxent.

Introduction

Habitat fragmentation caused by human activities is one of the main causes of negative impacts on biodiversity. This phenomenon consists of the transformation of larger habitat areas into smaller ones or fragments that are usually more isolated than in their original state [Rocha *et al.* 2021]. Critically assessing the environmental variables that affect the status of threatened species can help determine the relative impact of factors that are easier to change, such as habitat and its management, versus those that cannot be changed, such as climate.

The hazel dormouse, *Muscardinus avellanarius* (Linnaeus, 1758), is a European protected species listed in Annex IV of the European Commission Habitats Directive [EUR-lex, 1992].The species is listed as Least Concern on the IUCN Red List [Hutterer *et al.* 2021].

This species was included in this category, in particular, due to insufficient data on its distribution and population status, as this is a difficult task for scientists, due to behavioural features such as nocturnal lifestyle, its habitats are difficult to study. The hazel dormouse is one of those species that suffers from habitat fragmentation due to low population density.

Currently, there is no accurate data on the distribution of the hazel dormouse in Ukraine, which is why the aim of this work is to develop a distribution model with further analysis of the climatic conditions that most affect its population.

Materials and Methods

Records of hazel dormouse occurrences in the territory of Ukraine were collected from five data sources:

1) museum data, primarily collection catalogues, including the collections of the Department of Zoology at the National Museum of Natural History, National Academy of Sciences of Ukraine [Shevchenko & Zolotukhina 2005], Benedikt Dybovsky Zoological Museum of Ivan Franko National University of Lviv [Zatushevskyy *et al.* 2010], and the Zoological Museum of Taras Shevchenko National University of Kyiv (card index);

2) online biodiversity databases (UkrBin [UkrBin], GBIF [GBIF]);

3) literature sources on the distribution of the family Gliridae [Bezrodny 1991; Zaytseva-Anciferova 2013], results of surveys [Lysachuk 2012; Geryak & Khalaim 2020; Havrylenko et al. 2023] and local studies of the mammal fauna [Zizda 2008; Skilskyi & Meleshchuk 2016; Tsvelykh 2020];

4) OSINT search for findings in social networks (Facebook, Instagram, and YouTube);

5) own field research and observations.

Expeditions to record species of the family Gliridae in artificial nests were conducted in 2023 in two locations: the Podilski Tovtry National Nature Park and the Polissia Nature Reserve. During the surveys in Podilski Tovtry NNP, on 6 July 2023, one hazel dormouse was found in 16 hollows, and on 26 September 2023, ten individuals were found in 19 artificial nests. In the Polissia Reserve, during surveys on 13–15.09.2023, one individual was found per 75 nest sites (Fig. 1*a*).

Based on the entire array of these data, a database of hazel dormouse finds in Ukraine was created. It was developed in Google Sheets software and contains information on geolocation points, the author of the find, and additional information. The database contains 248 records (locations) for 1900–2023, all of them are presented on the map (Fig. 1*b*).

The modelling of the distribution of the hazel dormouse in Ukraine was carried out according to standard methods of work in the Maxent software [Phillips *et al.* 2006, 2008] using GIS layers of 19 bioclimatic factors (Table 1), which are derived from average temperature and humidity for over 60 years, and contain the average climate conditions in 1940–2000.

The cell size (resolution) of the climate GIS layers and the resulting spatial models was chosen as 2.5 angular minutes for the maps of probable distribution within Ukraine. The reliability and predictive power of the model was calculated using standard methods and the AUC parameter. The AUC parameter of the model cannot be lower than 0.5, as this corresponds to a random forecast of distribution, in which case the Maxent model has no predictive power. According to the accepted standards for evaluating environmental and climate models, the predictive quality of a model is low if the AUC is in the range of 0.0...0.70; satisfactory if AUC = 0.70...0.80; good if AUC = 0.80...0.90, and excellent if AUC > 0.90 [Philips *et al.* 2008]. For our propagation model, the AUC value for the training data is 0.905, and for the test data it is 0.903, which means that the predictive quality of the model is excellent.

Table 1. Bioclimatic indicators used in the study

Таблиця 1. Біокліматичні показники, використані у дослідженні

Code	Description	Code	Description
BIO1	Annual mean temperature		
BIO2	Mean diurnal range (Mean of monthly (max temp – min temp))	BIO11	Mean temperature of coldest quarter
BIO3	Isothermality (BIO2/BIO7) (×100)	BIO12	Annual precipitation
BIO4	Temperature seasonality (standard deviation ×100)	BIO13	Precipitation of wettest month
BIO5	Max temperature of warmest month	BIO14	Precipitation of driest month
BIO6	Min temperature of coldest month	BIO15	Precipitation seasonality (coefficient of variation)
BIO7	Temperature annual range (BIO5-BIO6)	BIO16	Precipitation of wettest quarter
BIO8	Mean temperature of wettest quarter	BIO17	Precipitation of driest quarter
BIO9	Mean temperature of driest quarter	BIO18	Precipitation of warmest quarter
BIO10	Mean temperature of warmest quarter	BIO19	Precipitation of coldest quarter

Fig. 1. Hazel dormouse and its geographical range in Ukraine: (*a*) an individual found during the survey of artificial nests in the Polissia Nature Reserve; (*b*) record localities of the species in Ukraine in 1900–2023.

Рис. 1. Ліскулька руда та її ареал в Україні: (*a*) особина, виявлена під час обліку штучних гніздівель в Поліському природному заповіднику; (*b*) точки знахідок виду в Україні у 1900–2023 роках.

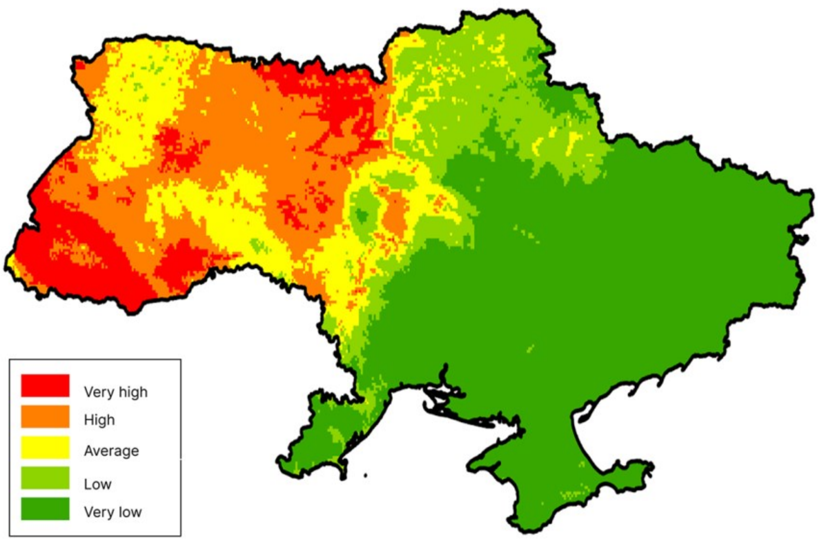

Fig. 2. A model of hazel dormouse distribution based on the processing of original data. A variant of the model based on log-transformed data was used.

Рис. 2. Модель поширення ліскульки рудої на підставі опрацювання масиву оригінальних даних. Використано варіант моделі, що базується на логістичному форматі даних.

Distribution model

When building the model, its graphical representation (Fig. 2) uses colours to indicate the predicted probability that conditions are suitable: red indicates a very high probability of suitable conditions for a species, orange indicates a high probability, yellow indicates a medium probability, and pale and intense green indicate a low and very low probability of detecting a species.

For the hazel dormouse, we see that the appropriate conditions, according to the model, are highest in four administrative regions (oblasts) of Ukraine: Zakarpattia, Ivano-Frankivsk, Chernivtsi, and Zhytomyr. There is also a high probability of occurrence in the south-western part of Lviv Oblast, the western part of Volyn Oblast, the northern part of Kyiv Oblast, and most of Rivne, Ternopil, Khmelnytsky, and Vinnytsia oblasts. Small pockets are observed in the west of Chernihiv and Kirovohrad oblasts, as well as in the centre of Cherkasy and in the north of Odesa oblasts. The model predicts mediocre conditions in Chernihiv, Sumy, and Poltava oblasts. In other regions of Ukraine, the probability of suitable conditions for the hazel dormouse is low.

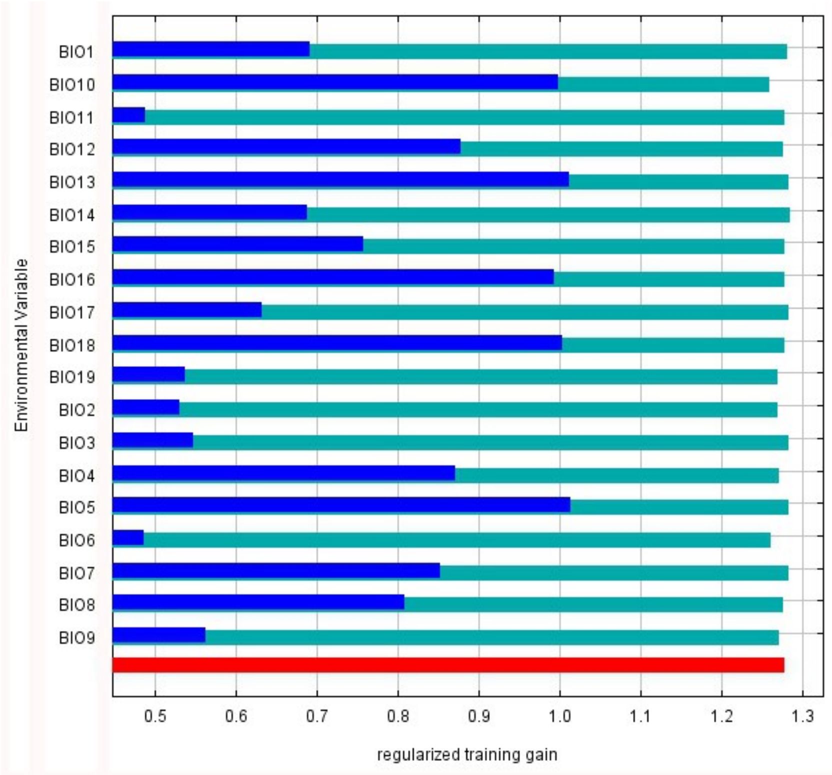

Fig. 3. A jackknife of training gain based on training data.

Рис. 3. Складено-ножева перевибірка моделі на основі тренувальних даних.

Standard methods were used to analyse the propagation model, one of which is the jackknife of training gain. For the model, we conducted three tests to assess the importance of the variables: a test based on training data, testing data, and an AUC-gain test. We analyse the first test based on training data (Fig. 3).

The columns of the graph indicate how important each variable is for the model: dark blue sectors are when only one variable is used, blue sectors are when this variable is excluded and all others are used. Analysing the dark blue columns of the graph based on the training data, we see that the lowest increase in predictive power for the model is for BIO11 (mean temperature of coldest quarter) and BIO19 (precipitation of the coldest quarter), BIO2 (mean diurnal range (mean of monthly (max temp – min temp)), BIO3 (isothermality (BIO2/BIO7) (×100)), BIO6 (min temperature of the coldest month), and BIO9 (mean temperature of driest quarter).

The largest increase is observed in the following indicators: BIO10 (mean temperature of warmest quarter), BIO13 (precipitation of wettest month), BIO16 (precipitation of wettest quarter), BIO18 (precipitation of warmest quarter), and BIO5 (max temperature of warmest month).

Discussion

Over the years, different authors have also noted the distribution of the hazel dormouse in Ukraine. Mygulin [1938] showed that the species is distributed mainly in the forest and forest-steppe zones of Ukraine, in particular, in Kyiv, Chernihiv, and Poltava oblasts. Sokur [1960] noted a significant expansion of the species' range in Right-bank Ukraine (west of the Dnipro River), including the Carpathians and to the south, to Odesa Oblast. Tatarynov [1956] confirmed its widespread distribution in the Carpathians and Lviv Oblast. Bezrodny [1991] studied the distribution of the species in Zakarpattia, Lviv, and Zhytomyr oblasts in detail, clarifying previously known data.

In general, we can observe an expanding tendency in the range of the hazel dormouse in Ukraine during the 20th and 21st centuries. However, it is worth noting that this is more likely due to the development of research technologies and methods, because due to the specifics of the species' ecology, findings in the wild are usually accidental, and modern research is based on records in artificial nesting sites. It can also be linked to habitat fragmentation, as the smaller the forest area, the easier to find a hazel dormouse nest by chance.

The analysis of factors that affect the species' distribution shows that the smallest increase in the model's predictive power is provided by indicators related to temperatures of the coldest months. This may be due to the fact that the hazel dormouse is a species that hibernates during the cold season [Gubert *et al.* 2023], and that is why these indicators are less significant for building the model.

There was also a small increase in the average daily temperature ranges, average temperatures of the driest month, and isothermicity. This is probably due to the behavioural characteristics of the species and its typical habitat, as these rodents are active at night, and their habitat is the forest understorey [Juškaitis & Büchner 2013], which maintains stable conditions even on the driest and hottest days of summer.

The best increase in predictive power of the model is provided by indicators reflecting the temperature of the warmest months, humidity, and precipitation. This is probably due to the specifics of the habitats of the hazel dormouse, as the growth of plants that provide shelter and food resources for these animals depends on all these indicators. Also, in favour of this hypothesis, we can note that the plants preferred by this species are primarily hazel, buckthorn, raspberry, and honeysuckle [Juškaitis & Baltrūnaitė 2013], are moisture-loving.

Conclusions

The development of distribution models for vulnerable species is an important measure, as it allows us to estimate the probability of occurrence of a species in a particular area of its range, identify regions with the best habitat conditions, and develop methods of territory management to preserve local habitats. The study provides a comprehensive analysis of the distribution model of the hazel dormouse in Ukraine.

The analysis suggests that the following five indicators have a high predictive ability: BIO10 (mean temperature of warmest quarter), BIO13 (precipitation of wettest month), BIO16 (precipitation of wettest quarter), BIO18 (precipitation of warmest quarter), and BIO5 (max temperature of warmest month). All of them are most important for building models of distribution of this species, and the author recommends using them for further studies of the distribution of the hazel dormouse.

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Declarations

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Conflict of interests. The author has no conflicts of interest to declare that are relevant to the content of this article.

Handling of materials. All manipulations with living animals were carried out using non-lethal techniques and in compliance with the current legislation of Ukraine; collection specimens were handled according to the regulations of the respective housing institutions.

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