European Proceedings of
Multidisciplinary Sciences
EpMS
www.europeanproceedings.com
e-ISSN: 2421-826X

DOI: 10.15405/epms.2024.09.88

MTMSD 2022
I International Conference «Modern Trends in Governance and Sustainable Development of Socio-economic Systems: from Regional Development to Global Economic Growth»

THE CAUCASUS ENDEMIC CARABUS EXARATUS IN THE MAXENT ENVIRONMENT

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Abstract

The research, titled "The Caucasus Endemic Carabus exaratus in the MaxEnt Environment," focuses on forecasting the geographic range of the ground beetle species Carabus exaratus, which is native to the Caucasus region. The primary objective of the study is to employ MaxEnt modeling, a robust ecological niche modeling technique, to predict the potential distribution of this endemic species based on various environmental variables. To execute the research, presence data for Carabus exaratus were meticulously collected from field surveys and museum records. Concurrently, relevant environmental variables encompassing climate, topography, and land cover were sourced from reputable databases and literature. The MaxEnt algorithm, a machine learning approach, was then utilized to construct a predictive model that estimates the probability of the species' occurrence across the defined study area. The accuracy and reliability of the MaxEnt model were subsequently evaluated through rigorous assessments, including the calculation of the area under the receiver operating characteristic curve (AUC-ROC) and other pertinent metrics. These measures serve to validate the precision of the model in capturing the intricate distribution patterns of Carabus exaratus. The results of the MaxEnt modeling effort yielded a comprehensive predictive map delineating potential habitats for Carabus exaratus throughout the Caucasus region. The accuracy assessments, particularly the AUC-ROC analysis, affirmed the dependability of the model in effectively representing the species' distribution dynamics. In conclusion, this research contributes valuable insights into understanding and forecasting the potential distribution of the Caucasus endemic Carabus exaratus.

Keywords: Energy efficient measures, Green Zoom, greenness indicators, integrated residential development, sustainable development, standards

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1. Introduction

One of the priority tasks of biogeography is the study of the regularities of the spatial distribution of the species. This task is of particular relevance in the context of increased anthropogenic pressure and global climate change, the consequences of which are the reduction and fragmentation of the habitat, which in turn damages biodiversity and can lead to the complete extinction of the species. Understanding how and to what extent climate change will affect its distribution is critical to developing appropriate climate change adaptation and mitigation strategies for the conservation of the species. Identification of the climatic niche of species is an important component of biogeographic and ecological research.

Bioclimatic variables affect the geographic distribution and range characteristics of poikilothermic organisms. Analysis of the influence of these variables on organisms makes it possible to model their potential ranges, as well as to predict their changes. The object of our study is the Caucasian endemic Carabus exaratus. In the conditions of the Chechen Republic, this species is common and distributed from the foothill steppes to the subnival zone (Aidamirova, 2011; Avtaeva et al., 2017).

The purpose of this work is to model the current and predicted ranges of Carabus exaratus under the conditions of global climate change in the MaxEnt environment.

MaxEnt is actively used to model the distribution of species based on location data using the principle of maximum entropy, taking into account the ecological constraints of the habitat. The ability to accurately predict the geographic distribution of a species over a territory is an important condition for its successful conservation (Avtaeva et al., 2019, 2020, 2021; Brygadyrenko et al., 2021; Khomitskiy et al., 2020; Sukhodolskaya et al., 2020).

The emergence of new methods, in particular, GIS technologies, has significantly expanded the capabilities of ecologists and makes it possible to model the dynamics of species ranges based on relationships with various environmental factors.

2. Materials and Methods

The research utilized a combination of literary sources and field collections to gather relevant materials and data. Field collections were conducted over several years within the territory of the Chechen Republic to obtain comprehensive information for the study. Specifically focusing on the ground beetle species Carabus exaratus, a total of 99 habitats were identified and included in the dataset for analysis. The incorporation of both literature-derived information and firsthand field data enhances the comprehensiveness and accuracy of the study, providing a robust foundation for subsequent analyses and modeling efforts.

The material for this work was data from literary sources and the authors' own field collections. Field collections were carried out in different years on the territory of the Chechen Republic. For C. exaratus, 99 habitats have been identified.

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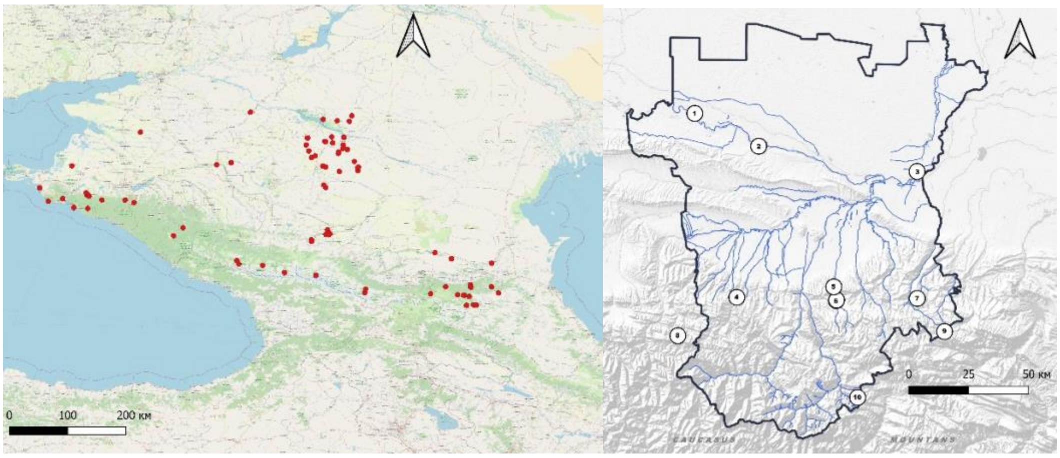

Figure 1. a - points of presence of Carabus exaratus in the Caucasus; b - points of presence of Carabus exaratus in the Chechen Republic

For bioclimatic modeling, 20 bioclimatic variables with a spatial resolution of 30 seconds of the global climate database WorldClim (www.worldclim.org) were used. Scripts in R Studio were used to improve the model. Some authors point to the impossibility of correctly assessing the contribution of each variable to the constructed species distribution model due to the high correlation between variables. R Studio allows you to reduce the correlation between climate characteristics by identifying and removing highly correlated variables. A matrix was obtained, the analysis of which made it possible to exclude all factors, the correlation between which did not exceed 0.75.

R also received an enmeval-results csv file that includes a table of evaluation statistics for each combination of settings. The simulation was performed according to the settings corresponding to the minimum value of AICc and ΔAIC = 0.

Potential habitat modeling was carried out in the Maxent 3.4.4 environment. Spatial cross validation was used to obtain independent data sets. Installed 10 replicates. To move on to predictions of encounter probabilities and to model the distribution of C. exaratus in space, we used the complementary log-to-log transformation “cloglog”. In all cases, a maximum of 500 iterations was used.

To verify the constructed models, we used the area (AUC) under the ROC curve (ROC - receiver operating characteristic - error curve, AUC - area under the curve - area under the error curve). Model accuracy parameters were estimated on randomly generated test samples. To be able to evaluate the resulting model, 25 (Random test percentage) was indicated, i.e. out of the entire array of points of presence, the program randomly selected 25% for subsequent testing of the resulting model. Thus, 75% of the data will be used to create the model as a training set, and 25% as a testing set. To assess the predictive capabilities of the model, the prediction binarization threshold was used: the conditions are considered suitable for the existence of the species if the prediction is above a certain threshold value, and unsuitable if it is lower. In modeling, a threshold of 10 percentiles was used to exclude from the analysis individuals living in atypical habitats. This means that 90% of the points of presence included in the analysis fall into the “potential area”, and the remaining 10% that do not fall into this area are regarded as living in atypical conditions and are not taken into account when constructing the climatic niche. AUC measures the ability of the model to distinguish between places where a species is present and places

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where it is absent, and ranges from 0 to 1. In our C. exaratus model, the mean AUC was 0.960 ± 0.008, i.e. the reliability of the resulting model is quite high.

In all simulations, the CCSM 4 (Community Climate System Model) climate model was used. The climate change scenario was taken into account: RCP8.5 (increase by 4.1 °C). To work with layers and calculate areas, we used the QGIS 3.18.0 program.

3. Results and Discussion

In this study, data from literary sources and field collections conducted by the authors were utilized to examine the distribution patterns of Carabus exaratus (C. exaratus) in the Chechen Republic. The field collections spanned various years and identified 99 habitats for C. exaratus across the region.

The analysis of the species' distribution unveiled several key environmental factors that significantly impact its presence. Among these, average annual temperature (Bio 1), precipitation during the warmest quarter (Bio 18), precipitation during the coldest quarter (Bio 19), seasonality of precipitation (Bio 15), isothermal conditions (Bio 3), and elevation above sea level (Bio 20) emerged as the most influential determinants.

The average annual temperature was identified as a fundamental climatic variable shaping the ecological preferences of C. exaratus. Additionally, the amount of precipitation during both the warmest and coldest quarters played crucial roles, indicating the importance of seasonal precipitation patterns. The seasonality of precipitation, reflecting the distribution of rainfall throughout the year, was found to be a significant factor influencing the species' habitat requirements.

Isothermal conditions, characterized by constant temperature levels, were highlighted as an influential factor, emphasizing the species' preference for specific temperature ranges. Moreover, the elevation above sea level was identified as a significant factor, showcasing the relevance of altitude in determining the distribution patterns of C. exaratus.

The comprehensive understanding of these environmental factors provides valuable insights into the ecological requirements of C. exaratus and enhances our knowledge of the species' distribution in the Chechen Republic. The results contribute to the broader field of biodiversity research and ecological conservation, aiding in the formulation of informed strategies for the protection of this species and its habitats.

As a result of the analysis for C. exaratus, the most significant factors were: bio 1 – average annual temperature; bio 18 - precipitation of the warmest quarter; bio 19 - precipitation of the coldest quarter; bio 15 - seasonality of precipitation; bio 3 - isothermal; bio 20 - height above sea level (table 1).

Table 1. Estimation of bioclimatic parameters affecting C. exaratus distribution

Variable	Percent contribution	Permutation importance
bio18b	78.4	49.7
bio19b	6.6	7.1
bio15b	3.5	5.3
bio8b	2.7	2.2
bio7b	2.4	3.1
bio20b	2.4	10.7

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bio3b	2.1	5.8
bio11b	1.4	0.3
bio1b	0.5	15.8

The average AUC value was 0.96, which indicates the high efficiency of the obtained C.exaratus distribution model (Figure 1-2).

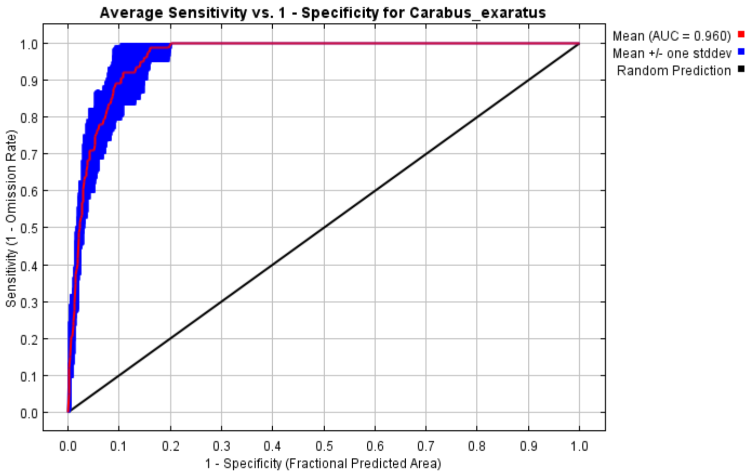

Figure 2. Analysis of the prognostic distribution model accuracy: operational curve trend AUC (1 – test data, 2 – training data, 3 – random prediction)

The simulation result showed that suitable habitat tends to decrease when the average annual temperature is below -10°C and above +10°C, and cannot exist above 15°C (Figure 3).

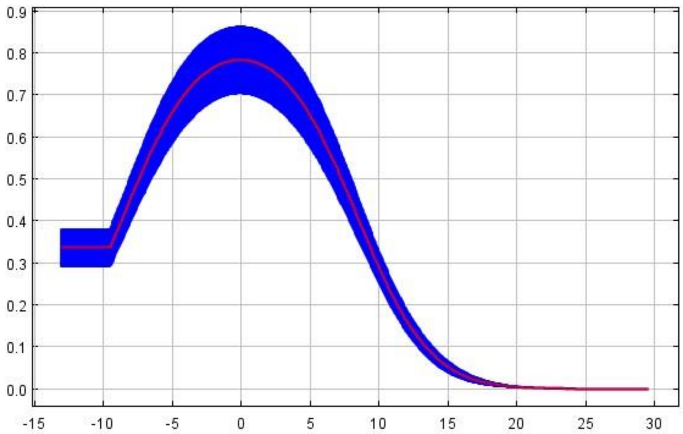

Figure 3. Model of Carabus exaratus preferences to environmental bioclimatic factors: bio 1 - average annual temperature indicators

At the same time, the ratio of average daily and average annual temperature amplitudes is from -7°C to +3°C (Figure 4).

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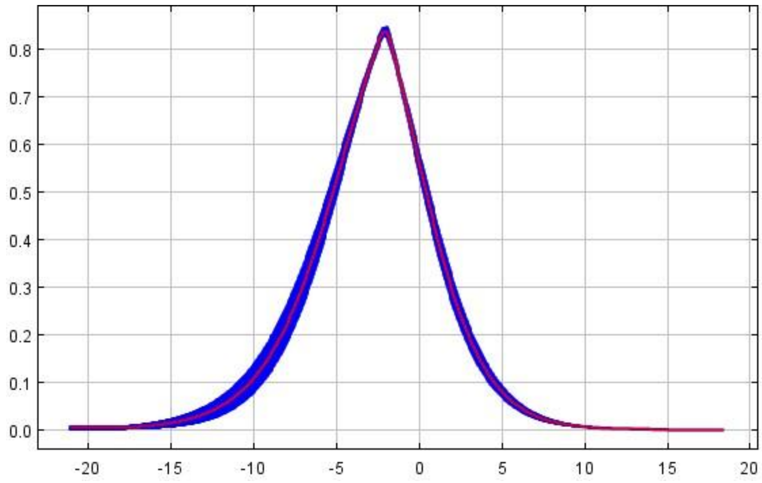

Figure 4. Model of Carabus exaratus preferences to environmental bioclimatic factors: bio 3

The simulation result showed that the most favorable height above sea level lies within the range of 0 to 500 m above sea level. m, with an increase in height, the comfort of living decreases, but does not become critical (Figure 5). In the conditions of the Chechen Republic, C. exaratus was recorded at different heights from 25 m to 2260 m above sea level. It was noted as a superdominant in the conditions of the floodplain forests of the Tersko-Kuma lowland.

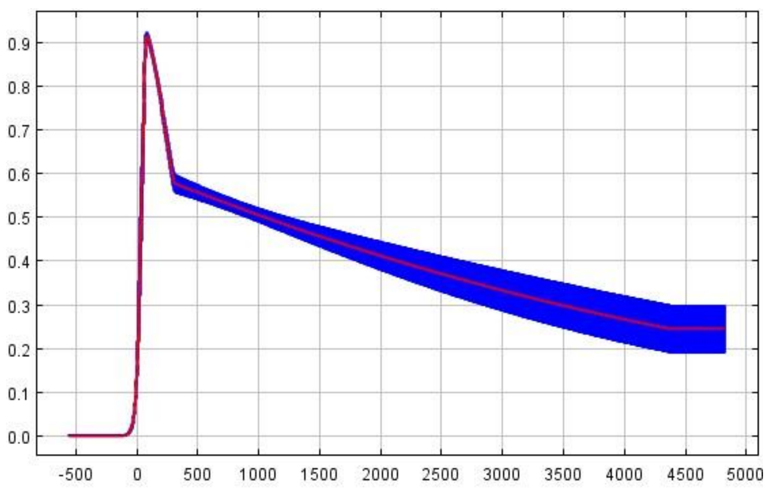

Figure 5. Model of Carabus exaratus preferences to environmental bioclimatic factors: bio 20 altitude

The distribution of Carabus exaratus is influenced by the precipitation of the warmest (bio 18) and coldest quarters (bio 19). In the warmest quarter of the season, the comfort of the environment decreases with precipitation below 100 mm and above 500 mm. The optimal amount of precipitation lies in the range of 150-350 mm (Figure 6).

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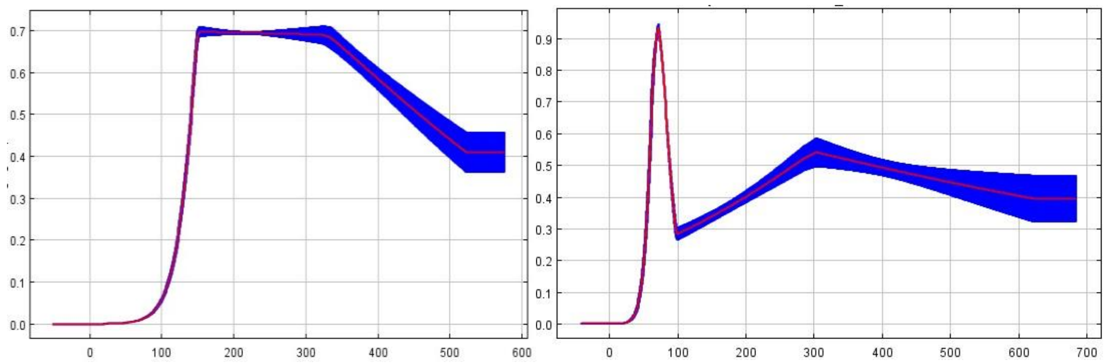

Figure 6. Model of Carabus exaratus preferences to environmental bioclimatic factors: bio 18 - precipitation of the warmest quarter; bio 19 - precipitation of the coldest quarter

In the process of modeling, we obtained maps of predictive ranges of Carabus exaratus under changing climate conditions in accordance with the RCP 8.5 climate scenario. It has been established that it is the ground layer of biogeocenoses that is the most sensitive to climate change. The litter layer does not protect the soil surface from atmospheric precipitation, heating, evaporation, surface runoff, etc. The ongoing climate change may lead to a shift in the boundaries of species ranges. Climatic variables affect the life cycle and seasonal dynamics of a species. Carabus exaratus is a species with a recyclic autumn type of reproduction (figure 7).

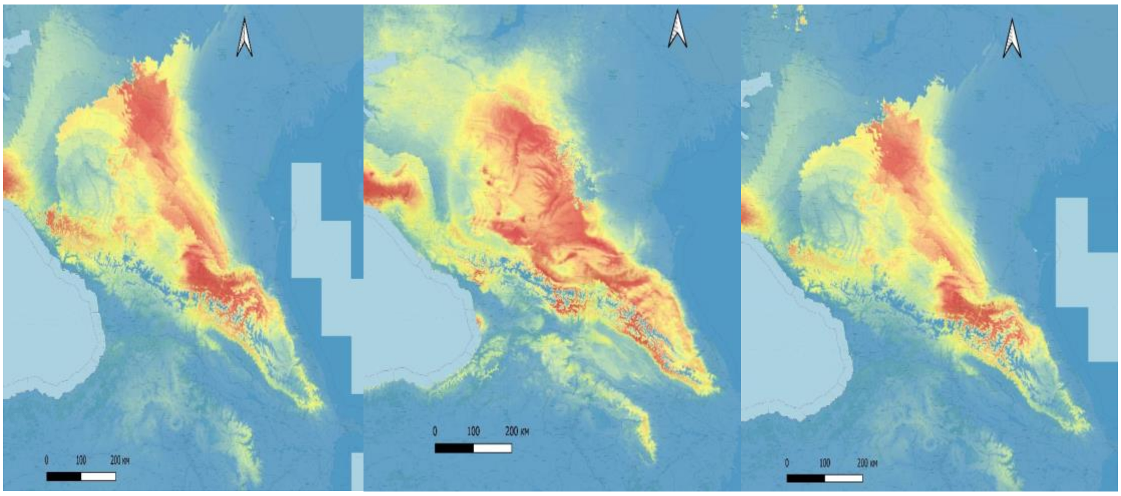

Figure 7. Bioclimatic area in Carabus exaratus: a-modern area; b- area of 2050 according to the RCP 8.5 scenario; c – area of 2070 according to RCP 8.5 scenario

Using the field calculator in QGIS, based on the obtained point layers, we calculated the area of the modern range and the area of the predicted ranges according to the RCP 8.5 scenario for 2050 and 2070 (Table 2).

Table 2. Bioclimatic area size (sq. km) in C.exaratus according to RCP 8.5 scenario

RCP 8.5	0.4-0.6	0.6-0.7	0.7-0.8	0.8-1.0
2020	53613,4	47157,4	50015,4	41261,9
2050	41746,2	42386,8	35903,3	12938,1
2070	42212,9	29374,5	23105,2	12845,5

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4. Conclusion

In conclusion, the analysis of the data reveals a notable reduction in the predicted ranges of Carabus exaratus compared to its current distribution. Specifically, there is a significant decrease in the extent of the most favorable areas characterized by a comfort index of 0.8-1.0 and 0.7-0.8.

The predictive maps generated through the MaxEnt algorithm, utilizing identified ecological and climatic niches, align well with the observed distribution of the species within the confines of the Caucasus region. This concordance underscores the reliability of the model in predicting the species' presence based on environmental factors.

The findings suggest that the ongoing phenomenon of global warming is causing a shift and substantial contraction in the bioclimatic range of Carabus exaratus. The reduction in the favorable areas highlights the ecological impact of climate change on the distribution patterns of this species. These insights are crucial for understanding the implications of environmental shifts on biodiversity and can inform conservation efforts aimed at mitigating the effects of climate change on vulnerable species like Carabus exaratus in the Caucasus region.

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