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Przewalski's horse distribution analysis using geospatial data within the Chernobyl Exclusion Zone habitats

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Abstract. The recovery of the Przewalski's horse population in the Chernobyl Exclusion Zone, the protection of this unique species, and the creation of effective monitoring and habitat management plans using geoinformation technology are all crucial. Therefore, the purpose of this study was to develop a monitoring system for this species that

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considers various factors of the environment. The research methodology involved a multi-step process that included collecting data (through a literature review and field observations), figuring out which key factors to model, and confirming the findings. As a result, habitat suitability maps were created for Przewalski's horse distribution by synthesising data on terrain, climate, hydrology, vegetation cover, food competition, predator presence, and safety. The models were calibrated with factual observations from 2018 to 2024. The study found five harems of Przewalski's horses in the exclusion zone in 2023. The distribution of these species is substantially influenced by elevation above sea level, proximity to highways and water bodies, resource competition, and predator activity. The 10-kilometer radius around the Chernobyl Nuclear Power Plant was designated as the least favourable region due to wildfires and human activity, while the most ideal habitats were in the central section of the research territory. A cluster study found that the exclusion zone could give Przewalski's horses an extra 350 km^2 of habitat, which is vital for keeping the population alive during natural succession. The GIS models created in this study can simulate prospective future environments, considering environmental alterations and conservation efforts

Keywords: mammals; GIS; acclimatisation; preservation; suitability map

INTRODUCTION

Przewalski's horse (PH) is a unique example of successfully reintroducing an endangered megafaunal species into a post-industrial, radiation-affected landscape. This allows investigating ecological resilience under extreme environmental conditions. Therefore, precise monitoring of their distribution within the Chernobyl Exclusion Zone (CEZ) and identification of the best places for further settlement is critical. PH in the CEZ serve as a unique example of nature's resilience in extreme conditions, demonstrating high adaptability and resistance to radiation exposure while playing a key ecological role in maintaining ecosystem balance. P. Schlichting *et al.* (2020), N. Beresford *et al.* (2021) showed that despite radiation exposure, the populations of these animals stay stable, and disease rates do not exceed the expected levels. A total of 137 PHs was found in the Ukrainian part of the CEZ, according to a study by P. Gashchak and S. Paskevich (2019): 47 stallions, 66 adult and filly mares, and 24 foals (10 males, 4 females, and 10 of unknown gender).

The greatest problems for the PH population are poaching and genetic homogeneity, since there are few of the specimens. There are also risks from higher radiation levels, anthropogenic influence, and weather changes (Beresford *et al.,* 2023). In these conditions, Geographic Information Systems (GIS) serve as an essential tool for predicting the joint impact of all environmental and anthropogenic factors simultaneously, identifying the most suitable habitats, predicting future expansion areas, and developing suitability maps for conservation strategies worldwide. Many studies have used GIS and suitability mapping to identify the best locations for their introduction and distribution. For example, suitability analysis in Mongolia has identified Hustai National Park, Takhin Tal, and Khomin Tal national parks as most suitable for the reintroduction and PH conservation. They used various ecological, biological, and anthropogenic factors to assess the suitability of different regions for the survival of PH. I. Kajiwara *et al.* (2016) used the number of faeces found in 48 randomly chosen field plots to create a generalised linear model (GLM). This model helped them establish the factors affecting how horses use their habitat. The model used the amount of faeces found at each site as the dependent variable, and seven explanatory variables that could affect how PHs use their habitat. These were the distance to the river, the distance to the forest, the distance to the road, the slope, the difference in elevation with the environment, the number of plant communities, and the presence of dominant categories of forage plants.

Y. Zhang *et al.* (2024) described the different versions of suitability maps that were customised to natural and climatic conditions and emphasised the significance of environmental factors in the suitability analysis for the PHs. Therefore, it is critical to identify influencing factors when creating suitability maps. The PHs, native to the steppe regions of Mongolia, excel in semi-arid to temperate climates characterised by cold winters and dry summers. According to Q. Cao *et al.* (2023), the amount of precipitation, humidity, and temperature regime are vital determinants of suitable habitats. Like for other species, the availability of food resources plays a critical role in assessing the suitability of a territory for habitation. The presence of steppe vegetation, including grasses and shrubs, is crucial for the PHs' survival, as its primary diet consists of grasses.

Scientists T. Hare (2022) noted that the existence of settlements, agricultural land, and infrastructure (such as roads and fences) might adversely affect the region's appropriateness for horses. V. Lu *et al.* (2021) showed that regions with limited human interference are preferred. Regions with fragmented habitats resulting from anthropogenic activity, such as urbanisation or deforestation, may be less conducive. PH favour broad plains and steppe regions that allow for unrestricted movement. Level or inclined terrains are best for their locomotion and foraging. Inclined or forested regions may be less suitable.

The purpose of this study was to identify and combine the optimum parameters of PHs, analyse the territory of the CEZ, and determine the zones of the best settlement for PHs.

MATERIALS AND METHODS

Study area. The Chornobyl Radiation and Ecological Biosphere Reserve (CREBR) is located between latitudes N51.084 and N51.351 and longitudes E29.262 and E30.384 in the Kyiv Oblast of northern Ukraine (Fig. 1). The research area is situated at an elevation of 93 to 200 meters above sea level, with an average annual temperature of 8.2°C and an average precipitation of 619 mm. CEZ, encompassing approximately 2,600 km^2, contains the decommissioned nuclear power plant located in the eastern section of the zone, adjacent to the northwestern area of the cooling pond, known as CREBR (Fedoniuk *et al.,* 2024).

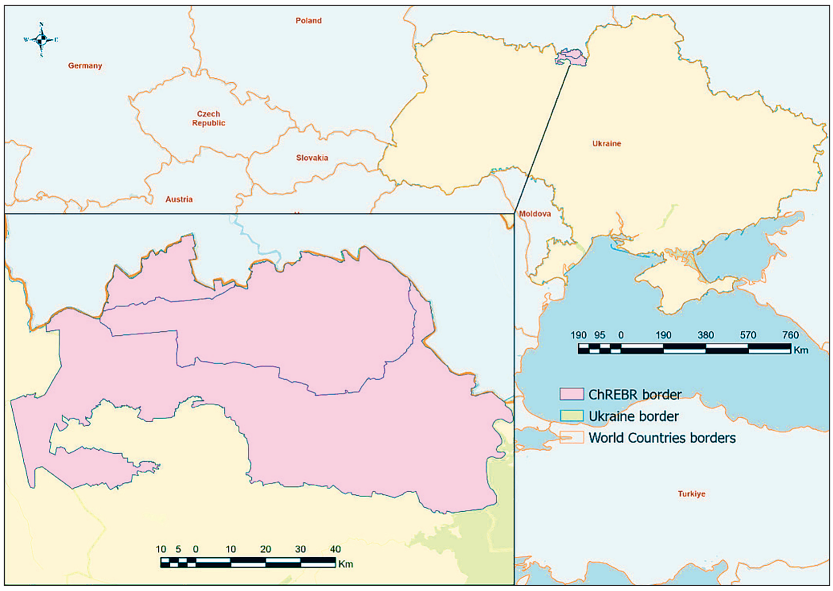

***Figure 1**. Location of the CREBR*

***Source:** T. Fedoniuk et al. (2024)*

The creation of landscape suitability maps for PH distribution and the identification of the best habitats was conducted in several stages: selection of input data (literature review and observational data), assessment of factor significance, modelling, validation, and result mapping. The study employed the Multi Scale Large (MS Large) methodology, a comprehensive suitability evaluation that considers extensive spatial contexts to identify suitable regions for infrastructure development or environmental conservation initiatives. These methods were employed in prior research, demonstrating excellent accuracy and reliability (Fedoniuk *et al.,* 2020). This method facilitates the analysis of extensive territories and leverages spatial dependencies, which is crucial for comprehensive planning in vast areas. Simultaneously, it was employed to integrate various data layers (maps) with weighting factors to identify the most suitable areas depending on specified criteria.

The construction of suitability maps encompassed several stages: gathering data on topography, climate, water source availability, vegetation cover, and information regarding the behaviour, dietary requirements, territoriality, and migration patterns of PHs, as well as documenting the presence of horses within the CEZ. To construct a suitability map, a composite of the key factors was established, encompassing the proximity to roads, water bodies, the presence of associated fauna (competitors for forage resources, the existence of predators), topographical elements, specifically elevation above sea level, and the classification of land cover (forest, pastures, buildings, roads), all of which were consolidated within a submodel.

Submodel analysis was conducted using ArcGIS Pro 3.3 software (with Spatial Analyst license) and the Suitability Modeler model (Implementation of suitability modelling workflow, n.d.). As for PHs, the best sites were selected based on a trade-off among three primary objectives: habitat, availability of food, and safety. For instance, the criteria for a safety objective included a preference for distance from highways and buildings, predator distribution, while staying in proximity to forests and protected areas. The three submodels were integrated to provide a final suitability map:

1. The submodel of habitat incorporated weighted and combined variables that comprehensively define habitats, including landscape, proximity to water sources, and geological characteristics of terrains.

2. Food availability submodel identified regions where PHs are most likely to locate sustenance,

considering the distribution of competing species for food supplies The security submodel identified the regions that were the safest for PHs. The most secure locations are distant from thoroughfares and residences.

3. The security submodel identified the regions that provide optimal safety for PHs. The most secure locations are distant from roads and residences and feature the presence of predators.

Analysis of suitability variables and weighting criteria was conducted using the "Multiplier" approach for the parameter "Weight by" in the "Settings" tab, whereby the transformed criteria values are multiplied by this number to generate a suitability map (Table 1). The aggregated converted criterion values were subsequently summed. A weight of 2 means that the criterion is twice as significant as a criterion with a weight of 1. A weight of 10 indicates that the condition is tenfold more significant. This strategy was employed as it is best for weighting criteria in relation to one another (Implementation of suitability modelling workflow, n.d.).

***Table 1**. The principal types of data (suitability maps) derived from weighting factors and evaluative hypotheses*

Factor	10-point scale evaluation	Evaluation statement	Factor transformation method
Roads	7	Roadside grassy coenoses act as a fodder base for horses, which also prefer to travel on roads	MS Large: the closer the better
Reservoirs	7	Horses frequent the floodplain and are often found within the first terrace	MS Large: the closer the better
Companion animals	6	Horses are unique in their eating behaviour, deer are close to them in behaviour.	MS Large: the closer the better
Animals are predators	3	Horses have a defence system against predators, so this factor is not critical	MS Large: the further the better
Height above sea level (m)	5	Horses prefer flat or moderately sloping areas.	Gaussian distribution
Herbaceous coenoses (as a component of the Land Cover (LCC)	6	Horses prefer open landscapes, such as fallows, forest edges, wastelands, forests without developed undergrowth.	9
Built-up areas (as a component of the LCC)	6	Avoid abandoned settlements but may be near abandoned farms.	3
Wooded areas (as a component of the LCC)	6	Horses are found mainly in light pine forests.	6
Agricultural land (as a component of the Land Cover (LCC)	6	Fallows and abandoned agricultural lands are especially attractive to them	10

***Source:** compiled by the authors of this study*

Identifying the best location for species conservation relies on the attributes of each site; for instance, it considers the gradient of the slope, proximity to roads or water sources, and the type of land use. The map was generated by modifying and prioritising the criteria. The suitability map assessed the significance of each environmental element using a 10-point scale. Submodels were subsequently weighted and aggregated to generate a final goodness-of-fit map. A model based on submodels or summary fitness maps for each submodel, the relative advantage of each location in relation to the goal of a specific submodel, was ranked. The final suitability map for each location determined how suitable it is based on whether it is a decent place to live, has enough food, and is safe. Environments that are the most acceptable, considering all the analysed parameters, were clustered separately. The simulation results were validated and calibrated by comparing the predicted data with real observations of Przewalski's horse populations. Models were calibrated to ascertain the accuracy of the maps. Observations in the exclusion zone were conducted in 2018-2024. The basis for the distribution map of PHs included over 2,000 records of their presence. The study superimposed the horse records data on the formed fitness maps, then visually assessed the coincidences. The study was conducted following the ARRIVE guidelines 2.0. (2010) for the use of animals in research.

RESULTS AND DISCUSSION

Przewalski's horse (Boddaert, 1785) is a wild equine species classified within the series *Equiformes* and the family *Equidae*. The International Union for Conservation of Nature (IUCN-2017) has classified PHs as extinct in the wild and classified it as threatened. PH, a wild equine species, is pertinent in this context due to its historical prevalence; nonetheless, significant habitat destruction has resulted in a global population decline (Orizaola, 2020). During 1998-1999, the CEZ received 13 stallions and 18 mares from the Askania-Nova reserve, housing them in a designated corral for acclimatisation. The PHs were introduced by personnel from the Chornobyl's SDP and experts from the CEZ. The rationale for establishing a free population zone for PHs within the area was articulated within the framework of the "Fauna" Program (2000), aimed at the conservation and restoration of this species, and aligned with the overarching objectives of the European Green Deal

regarding biodiversity preservation (Skydan *et al.,* 2022). The selection of the location was attributed to the availability of expansive open areas and lesser human impact, which fosters circumstances akin to the natural habitats of these horses in Central Asia.

In 2023, research on the Reserve's territory and the CEZ documented approximately 5 harem groups, with sizes varying from 3 to 15 members. The harem includes a stallion (leader), mares, yearling stallions, and the current year's foals. Dyads comprising one stallion and one mare inhabit the vicinity of the villages of Cherevach and Korogod. They act as the initial basis for the establishment of new harem groupings. Due to restricted access to the area and the inability to perform comprehensive study on the status of the PH population, as it was conducted in previous years, there is a lack of data regarding their overall numbers. Throughout the year, harem groups were documented in the vicinity of Kopachi village and the outskirts of Cherevach village in Chornobyl. First, the study weighed the relationship to the height of the surface above sea level (Fig. 2).

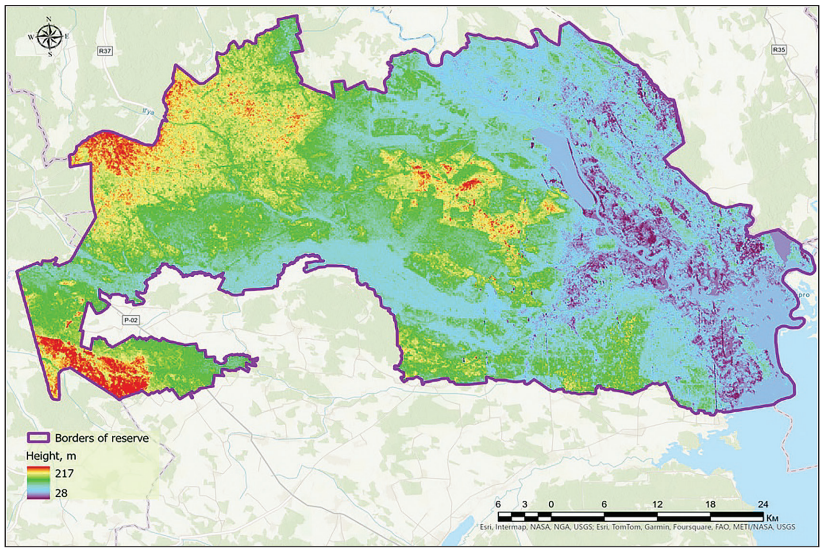

***Figure 2**. Elevation map of the territory of the CREBR*
***Source:** compiled by the authors of this study*

Proximity to roadways is a factor influencing the distribution of PHs. The distance from roads can profoundly influence the distribution and behaviour of PHs and other wildlife species. I. Kajiwara *et al.* (2016) considered seven factors that might affect the PH's choice of habitat: distance to a river, distance to a forest, distance to a road, slope, difference in elevation from the surrounding area, number of plant communities, and presence of dominant forage plant categories. W. Peng *et al.* (2020) noted that anthropogenic factors are the most significant. They were not significant in the present study, and therefore were not included in the territory suitability model. Instead, the study considered the proximity of the areas to roads. It is precisely the proximity to roads that greatly affects the ungulate migrations; this is also confirmed by the findings of T. Ito *et al.* (2017), who tracked the movements of ungulates on both sides of the Ulaanbaatar-Beijing railway and found that most animals never crossed the railway. The principal culprits are heightened noise and habitat disruption. A value of 7 represents the importance of proximity to roads. Roads are typically linked to elevated noise levels and human activity, which might deter wildlife and lead to their avoidance of certain regions (Fig. 3).

According to M. Turghan *et al.* (2022), Przewalski's horses, akin to numerous other animals, prefer locations that are tranquil and isolated from human interference, where their natural habitat is minimally disrupted. Roads can disrupt natural habitats, restricting the regions available for horses' movement and foraging. This results in the isolation of populations, which may diminish genetic diversity and compromise the species' longevity. The CEZ concurrently faces equivalent road traffic saturation. Observations indicate that horses in this area are more inclined to seek roadside phytocoenoses, whereas other animals use the roadways for movement (Fig. 4). Observations of horses in wild nature in the CEZ corroborate this, highlighting poaching and road traffic accidents as the principal risks for these species.

The modelling results suggest that the area directly adjacent to the building zone of the Chernobyl nuclear power station, known as the 10-km zone, is identified as the most unfavourable. In this region, PHs were documented solely in 2020. According to data from O. Skydan *et al.* (2021), during this year, about 66,222.5 ha of the reserve area was affected by fires, posing a threat to the animals (Fig. 5).

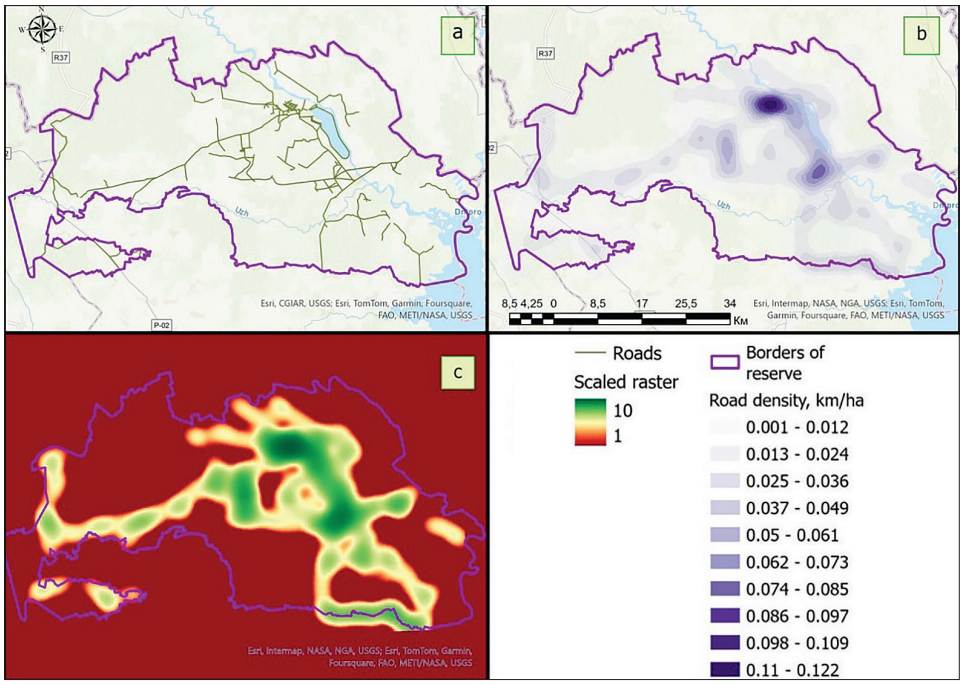

Figure 3. *Transformation of geoinformation about the road's placement in the CEZ using the Multi Scale Large function*
Source: *compiled by the authors of this study*

Figure 4. *Movement of PHs within the CEZ*
Source: *photograph by D. Vishnevskyi*

Figure 5. *Migration of PHs close to the industrial part of the CEZ during large-scale forest fires in April 2022*
Source: *photograph by D. Vishnevskyi*

Distance from bodies of water is also a significant factor influencing the distribution and behaviour of PH, as water is the main resource for the survival of any wild animal (Bernátková *et al.,* 2022). Specifically, the researchers noted that PHs, like most herbivores, require regular access to drinking water. PHs may have to concentrate near water sources in areas with limited water bodies (Chodkiewicz, 2020). Depending on climatic conditions, water may be less available at certain times of the year. They are particularly affected during periods of seasonal fires. In such cases, horses may migrate closer to water bodies, especially during dry seasons when natural water sources such as streams and lakes dry up.

Water availability can affect equine reproduction. Females requiring supplementary resources, such as water, to sustain themselves and their progeny will typically stay in proximity to aquatic bodies (Bernátková *et al.,* 2024). Observations from 2018 to 2023 suggest that population concentrations near water bodies are particularly pronounced during mating and offspring rearing periods. Furthermore, closeness to aquatic environments is typically linked to heightened biodiversity and more resilient ecosystems, providing horses with greater access to food and shelter. Consequently, reservoirs provide water requirements while also enhancing the environment for existence. Observations of PHs in the CEZ indicated their regular presence in floodplains, especially on the first terrace. Consequently, proximity to water bodies is crucial and was evaluated in the current study by a score of 7 (Fig. 6).

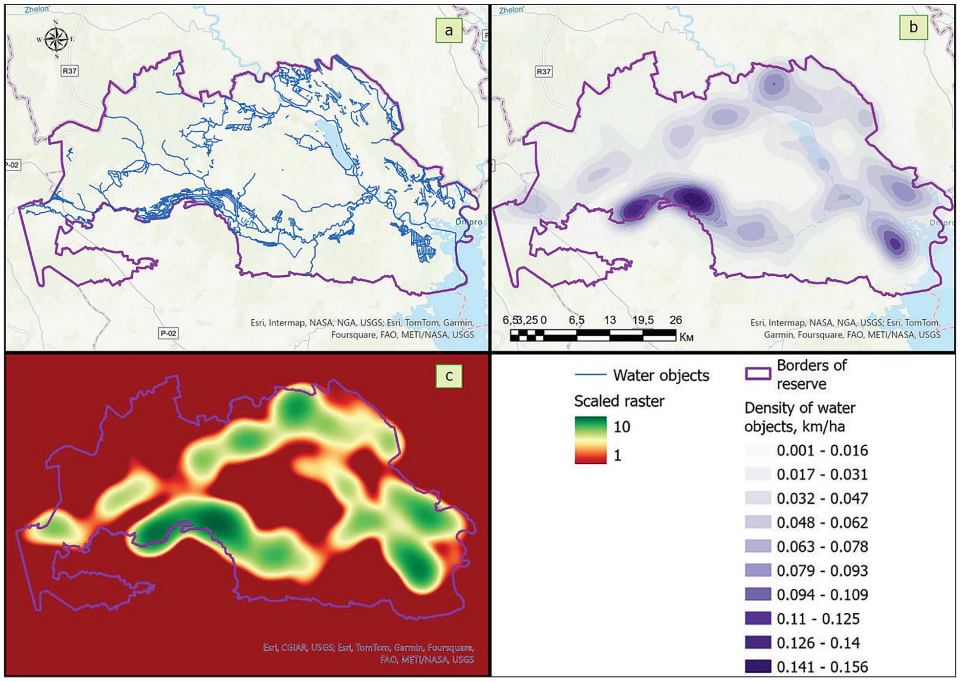

Figure 6*. Transformation of geo-information on water bodies captures in the CEZ using the Multi Scale Large function*
Source: *compiled by the authors of this study*

Therefore, the study included the proximity to water bodies as a variable in the suitability maps, along with the distance from roadways. The study employed the identical data processing procedure to convert vector data pertaining to reservoir locations within the CEZ into a raster format, after transforming it with the MS Large function. According to Q. Cao *et al.* (2025), the competition for resources between PHs and deer in the CEZ is an interesting subject since both species have comparable needs but live in slightly different ecological niches. A. Bernátková *et al.* (2024) noted that these animals' food preferences and their need for protection from predators both contributed to this behaviour.

Przewalski's horses and deer are both herbivorous, however they exhibit dietary variations. Horses mostly graze on grass, whereas deer, apart from grass, also actively ingest young shoots, branches, and foliage from trees and shrubs (Kerekes *et al.,* 2021). This suggests that when food is abundant, competition may diminish as each species concentrates on different regions of the available flora. In winter seasons, when vegetation is scarce, competition for pastures may intensify. During winter, snow restricts the accessibility of grass and other vegetation, prompting increased competition for food resources between PHs and deer. Deer may thrive in forested regions by consuming branches and tree bark. This confers a distinct advantage during the severe winter months, when the grass beneath the snow becomes unattainable for the horses. The rivalry among species in the CEZ parallels scenarios in Mongolia's national parks and other nations that have enacted environmental protection policies, wherein

diminished human activity facilitates the restoration of natural ecosystems. In US game reserves, where horses and deer coexist, variations in nutrition and habitat mitigate significant conflict (Stoner *et al.,* 2021). Competition between PHs and deer in the CEZ is present, although it is somewhat mitigated by their distinct dietary requirements and spatial preferences. Year-round records of PHs suggest that competition with other ungulates, particularly during winter, can substantially influence their distribution. Consequently, the incorporation of the distribution factor of spotted deer into the suitability maps is entirely warranted (Fig. 7).

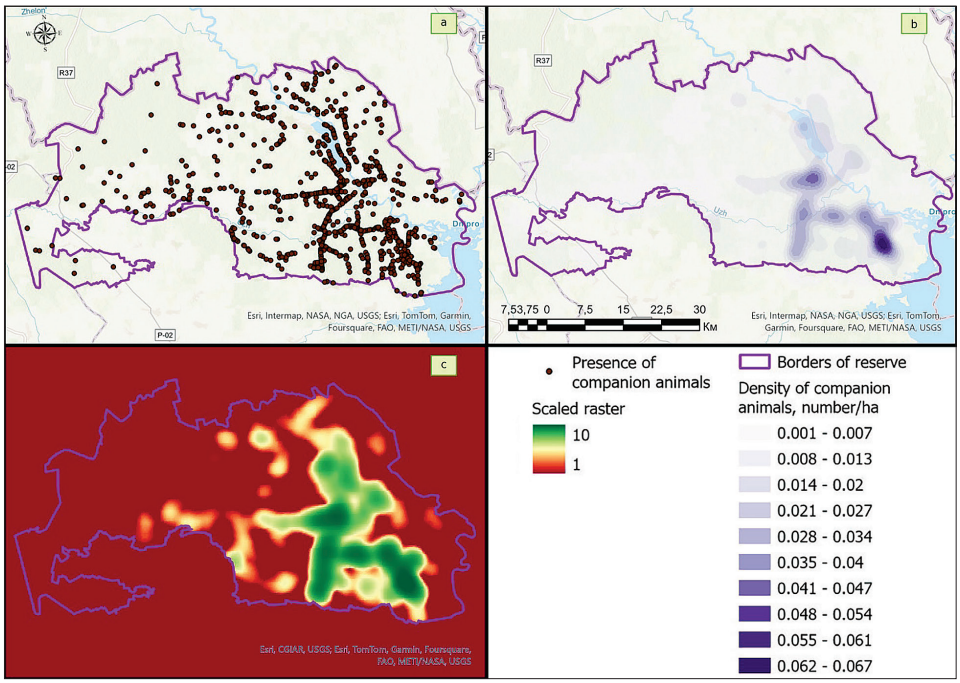

***Figure 7**. Transformation of geoinformation about the presence of companion animals in the CEZ using the Multi Scale Large function*

***Source:** compiled by the authors of this study*

In the CEZ, the lack of human presence and anthropogenic impact allows natural systems, including predation, to recover, influencing the behaviour and distribution of PHs in this environment. The primary predators of PH in the CEZ are wolves (*Canis lupus L.*), which are the most active predators in this area, although their population stays undetermined. The foundation for constructing a series of suitability maps was the documentation of wolf presence in the area from 2022 to 2024. Several other predators, under specific conditions, may also threaten PHs, such as the lynx (*Canis lupus L.*). Lynxes are not primary predators of horses, as they choose smaller prey; however, they may target foals or debilitated horses. These predators are infrequent in the region, although they still contribute to the food chain. In the lynx monitoring data from 2021–2022, 41 adults and 14 young specimens were recorded (Palmero *et al.,* 2023). Stray dogs (*Canis lupus familiaris*) represent a threat to ungulates in CEZ. Occasionally, wild dogs inhabit the CEZ, potentially endangering young or vulnerable PH, despite being less coordinated hunters than wolves.

Still, Przewalski's horses, being sizeable creatures, possess innate defence strategies against predators, including herding, which mitigates the probability of assault. Behavioural responses and inherent caution compel them to avoid areas with evident indications of dangerous creatures. This factor was assigned a score of 3 in the suitability map construction system. PHs are wild animals that must modify their behaviours, including locomotion and foraging, to evade predators like wolves found in the CEZ. This may lead them to select specific safer regions where the probability of encountering predators is diminished. Predators frequently pursue prey in specific locales, such as dense woodlands or around the peripheries of aquatic environments, where concealing their existence is facilitated. PHs may avoid these regions, preferring open steppes or flatter terrains, which affects their spatial distribution. Natural predators can influence the population size of a herd. Decreases in equine populations resulting from predation may restrict their capacity to extend their home ranges, as diminished populations often inhabit narrower territories. The existence of predators is crucial for sustaining ecological equilibrium. This natural method manages herbivore populations like PHs, ensuring balanced resource use and fair animal distribution across large areas (Fig. 8).

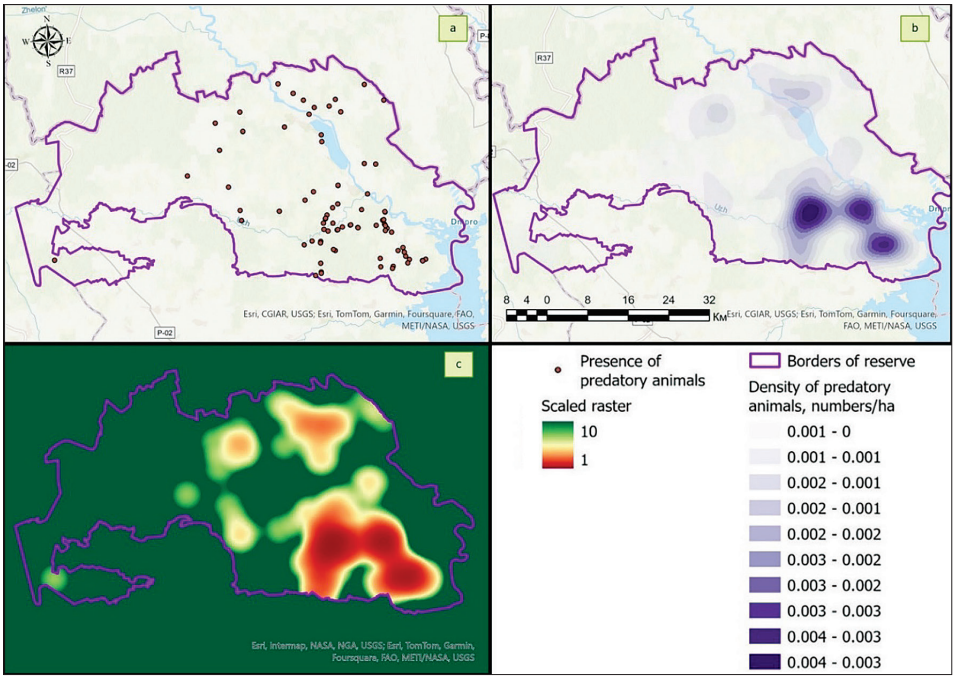

***Figure 8**. Transformation of geoinformation about the presence of predatory animals in the CEZ using the Multi Scale Large function*
***Source:** compiled by the authors of this study*

The map also details the establishment of PHs in the CEZ. This data is considered to mitigate the potential impact of other factors on the selection of PHs in reserve areas with specific requirements (Fig. 9).

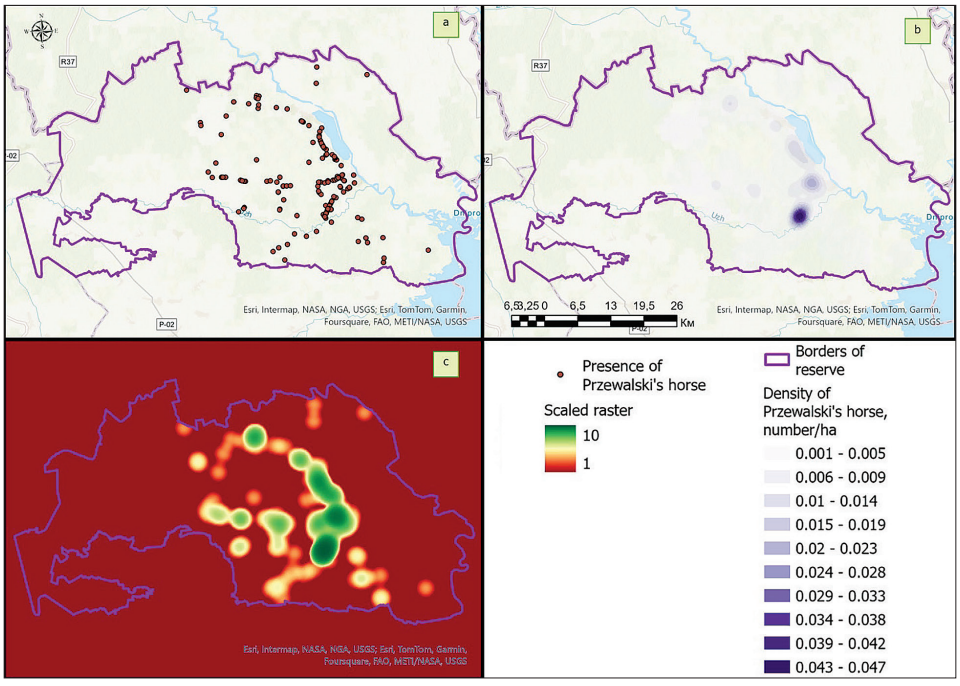

***Figure 9**. Transformation of geoinformation about the presence of PH in the CEZ using the Multi Scale Large function*
***Source:** compiled by the authors of this study*

The suitability map is based on the landscape cover map created by the authors of the present study in the previous stages of the work and published by T. Fedoniuk *et al.* (2024) (Fig. 10). Using the MS Large function, the bitmap image was transformed (Fig. 11). The suitability map was created using ecological

models, satellite photography, and remote sensing data, considering the previously listed factors. Individuals globally use these maps to pinpoint prospective areas for species reintroduction in the wild, such as in the national parks of Mongolia or the CEZ in Ukraine. Consequently, by integrating satellite imagery converted into landscape cover maps with ecological models that consider proximity to highways, the existence of water bodies, and the presence of rivals for food and predators, the study produced a suitability map (Fig. 12).

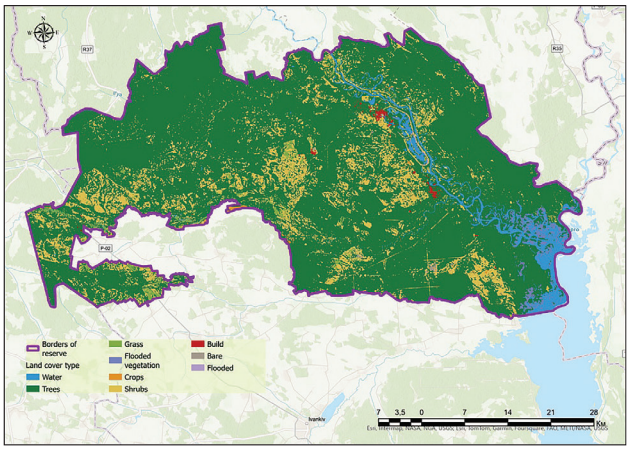

Figure 10. *The Chornobyl Radiation and Ecological Biosphere Reserve's (CREBR) landscape structure 2022*
Source: *T. Fedoniuk et al. (2024)*

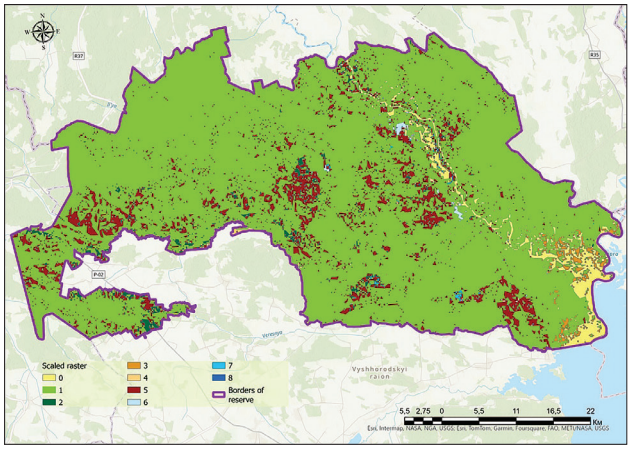

Figure 11. *Raster transformation of landscape structure map according to the MS Large function*
Source: *compiled by the authors of this study*

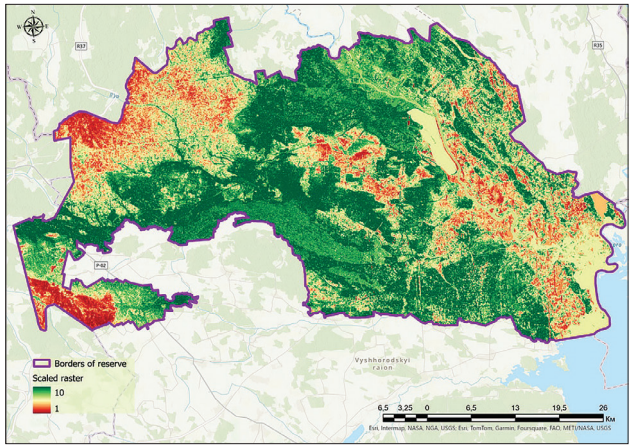

Figure 12. *Map depicting landscape cover, using models of environmental component influence*
Source: *compiled by the authors of this study*

The acquired fitness map contrasted with the factual outcomes of PHs recording. Figure 13 illustrates the correlation between actual records of horses and the expected ideal locations for the distribution of PHs.

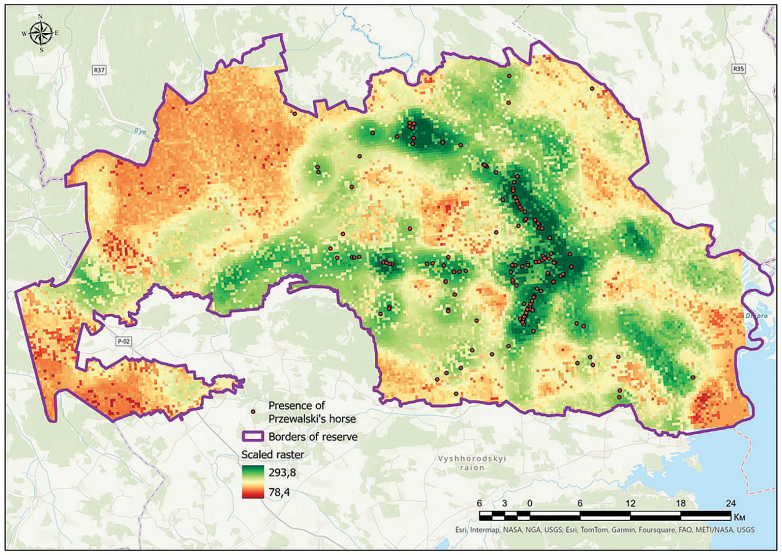

***Figure 13**. Suitability map with places of recording the facts of the presence of PHs*
***Source:** compiled by the authors of this study*

The clustering analysis of ecosystems was conducted within the CEZ, enabling the identification of the most suitable areas for the habitation and reproduction of PHs. The CEZ is a distinctive region with minimal anthropogenic impact, facilitating the resurgence of particular animal species, such as Przewalski's horse. Consequently, the best habitats were delineated in Figure 14: regions with suitable pastures, aquatic resources, limited human interference, and ample greenery for sustenance. The suitability map enabled the evaluation of environmental diversity, namely the various ecosystems that influence the survival and reproductive success of these species. Open meadows or regions with diminished forest cover may be more conducive for horses, as they offer access to feed; thus, the area presently has the capacity to extend the horse range by around 350 km^2.

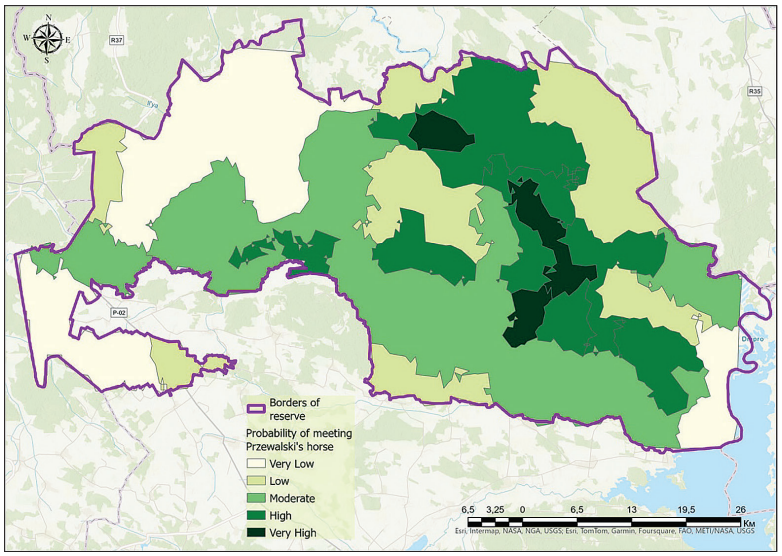

***Figure 14**. Acceptability clusters of PH dispersal zones within the CEZ*
***Source:** compiled by the authors*

Geo-informatics research of habitat conditions suggests that the ideal habitat regions are primarily located in the middle region of the reserve. PHs may potentially extend their habitat beyond their existing area. Consequently, the aggregation of habitats within the CEZ serves as a crucial instrument for

comprehending how PH acclimate to and use the available environment. By employing clustering data, researchers may monitor the ecosystems selected by PHs for their travel and habitat. This aids in comprehending their ecological preferences and modifying conservation policies accordingly. This facilitates their survival and population resurgence in the distinctive environment established post-accident. The CEZ exemplifies an environment undergoing natural succession devoid of human intervention. Clustering facilitates the examination of how these processes influence PHs, allowing to discern which vegetation types and habitats are most conducive at various stages of area restoration. The identification of clusters helps to optimise protective measures aimed at preserving the population of Przewalski's horses. For instance, knowledge of the locations of these animals allows creating special conservation zones or plan corridors for their free movement between clusters.

CONCLUSIONS

The present study developed a suitability map for the PH population in CEZ using GIS. The primary factors influencing population distribution include elevation above sea level, proximity to roads and water bodies, resource competition, and predator activity. The generated habitat suitability maps suggest that the most favourable conditions for the horses are found in the central part of the study area, whereas the 10-kilometer zone around the Chernobyl Nuclear Power Plant is the least suitable due to frequent wildfires and anthropogenic impact. Cluster analysis showed that the CEZ could give PH an extra 350 km^2 of suitable habitat, which is crucial for the population's long-term survival in natural succession. The models developed in this study can be employed to predict future habitat changes and inform conservation strategies.

A significant conclusion is that Przewalski's horses exhibit a high degree of adaptation to the extreme conditions of the CEZ, including increased radiation levels. This finding presents opportunities for further research into their ecological resilience and the application of the obtained data in international reintroduction programmes for wild species. Thus, the findings of the present study not only provided insights into the current state of the PH population in the CEZ but also proposed effective conservation strategies. The use of geoinformation technologies for planning future conservation measures is essential for ensuring the long-term survival of the species. The methodologies and data from this study can be effectively used to assess habitat suitability for other herbivorous species, such as European bison (*Bison bonasus*), etc. By using analogous environmental factors like elevation, distance to water sources, land cover, predator presence, and human influence, geoinformatics models can be used to identify possible habitats for bison populations. Moreover, the clustering and suitability analysis approach employed in this study provided valuable insights into how large herbivores use landscapes. Applying these models to herbivorous animal populations can facilitate the identification of migration corridors, high-quality grazing zones, and potential risks such as habitat fragmentation or competition with other ungulates. Additionally, predictive modelling can help forecast the effects of climate change on bison habitats, enabling proactive conservation planning.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

REFERENCES

[1] Beresford, N.A., Barnett, C.L., Gashchak, S., Kashparov, V., Kirieiev, S.I., Levchuk, S., Morozova, V., Smith, J.T., & Wood, M.D. (2021). Wildfires in the Chornobyl exclusion zone – risks and consequences. *Integrated Environmental Assessment and Management*, 17(6), 1141-1150. doi: 10.1002/ieam.4424.

[2] Beresford, N.A., Gashchak, S., Wood, M.D., & Barnett, C.L. (2023). Mammals in the Chornobyl Exclusion Zone's Red Forest: A motion-activated camera trap study. *Earth System Science Data*, 15, 911-920. doi: 10.5194/essd-15-911-2023.

[3] Bernátková, A., Oyunsaikhan, G., Komárková, M., Bobek, M., & Ceacero, F. (2024). Origin and experience influence the leading behaviour of reintroduced Przewalski's horses. *Animal Behaviour*, 215, 89-96. doi: 10.1016/j.anbehav.2024.07.008.

[4] Bernátková, A., Oyunsaikhan, G., Šimek, J., Komárková, M., Bobek, M., & Ceacero, F. (2022). Influence of weather on the behaviour of reintroduced Przewalski's horses in the Great Gobi B Strictly Protected Area (Mongolia): Implications for conservation. *BMC Zoology*, 7, article number 32. doi: 10.1186/s40850-022-00130-z.

[5] Cao, Q.L., Pukazhenthi, B.S., Bapodra, P., Lowe, S., & Bhatnagar, Y.V. (2023). Equid adaptations to cold environments. In *The equids: A suite of splendid species* (pp. 209-246). Cham: Springer International Publishing. doi: 10.1007/978-3-031-27144-1_8.

[6] Cao, Q.L., Zhang, Y., Songer, M., Leimgruber, P., Hu, D., Li, J., Wang, Ch., & Rubenstein, D. I. (2025). Coexistence between Przewalski's horse and Asiatic wild ass in the desert: The importance of people. *Journal of Applied Ecology*, 00, 1-13. doi: 10.1111/1365-2664.70013.

[7] Chodkiewicz, A. (2020). Advantages and disadvantages of Polish primitive horse grazing on valuable nature areas – a review. *Global Ecology and Conservation*, 21, article number e00879. doi: 10.1016/j.gecco.2019.e00879.
[8] Fauna Program. (2000). Approved by the Minister of Emergency Situations of Ukraine V.V. Durdynetsm.
[9] Fedoniuk, T.P., Galushchenko, O.M., Melnichuk, T.V., Zhukov, O.V., Vishnevskiy, D.O., Zymaroieva, A.A., & Hurelia, V.V. (2020). Prospects and main aspects of the GIS-technologies application for monitoring of biodiversity (on the example of the Chornobyl Radiation-Ecological Biosphere Reserve). *Space Science and Technology*, 26(6), 075-093. doi: 10.15407/knit2020.06.075.
[10] Fedoniuk, T.P., Pyvovar, P.V., Skydan, V., Melnychuk, T.V., & Topolnytskyi, P.P. (2024). Spatial structure of natural landscapes within the Chornobyl Exclusion Zone. *Journal of Water and Land Development*, 60, 79-90. doi: 10.24425/jwld.2024.149110.
[11] Gashchak, S.P., & Paskevich, S.A. (2019). Przewalskis horse (Equus ferus przewalskii) in the Chornobyl Exclusion Zone after 20 years of introduction. *Theriologia Ukrainica*, 18, 80-100. doi: 10.15407/pts2019.18.080.
[12] Hare, T. (2022). *Animal habitats: Discovering how animals live in the wild*. Singapore: Marshall Cavendish International Asia Pte Ltd.
[13] Implementation of the suitability modeling workflow. (n.d.). Retrieved from https://pro.arcgis.com/en/pro-app/latest/help/analysis/spatial-analyst/suitability-modeler/implement-the-suitability-modeling-workflow-using-the-suitability-modeler.htm.
[14] Ito, T.Y., Lhagvasuren, B., Tsunekawa, A., & Shinoda, M. (2017). Habitat fragmentation by railways as a barrier to great migrations of ungulates in Mongolia. In *Railway ecology* (pp. 229-246). doi: 10.1007/978-3-319-57496-7_14.
[15] Kajiwara, I., Yoshihara, Y., & Sato, S. (2016). A preliminarily assessment of landscape factors affecting habitat use by Przewalski horses and habitat evaluation in Hustai National Park, Mongolia. *Mammalian Biology*, 81(3), 340-344. doi: 10.1016/j.mambio.2016.02.009.
[16] Kerekes, V., Sandor, I., Nagy, D., Ozogany, K., Göczi, L., Ibler, B., Széles, L., & Barta, Z. (2021). Trends in demography, genetics, and social structure of Przewalski's horses in Hortobagy National Park, Hungary over the last 22 years. *Global Ecology and Conservation*, 25, article number e01407. doi: 10.1016/j.gecco.2020.e01407.
[17] Lu, V., Xu, F., & Turghan, M.A. (2021). Przewalski's Horses (*Equus ferus przewalskii*) responses to unmanned aerial vehicles flights under semireserve conditions: Conservation implication. *International Journal of Zoology*, 2021, article number 6687505. doi: 10.1155/2021/6687505.
[18] Orizaola, G. (2020). From nuclear desert to evolutionary lab: The response of living organisms to Chernobyl's ionising radiation. *Mètode Science Studies Journal*, 10, 193-199. doi: 10.7203/metode.10.15682.
[19] Palmero, S., *et al.* (2023). Shining a light on elusive lynx: Density estimation of three Eurasian lynx populations in Ukraine and Belarus. *Ecology and Evolution*, 13(11), article number e10688. doi: 10.1002/ece3.10688.
[20] Peng, W., López-Carr, D., Wu, C., Wang, X., & Longcore, T. (2020). What factors influence the willingness of protected area communities to relocate? China's ecological relocation policy for Dashanbao Protected Area. *Science of the Total Environment*, 727, article number 138364. doi: 10.1016/j.scitotenv.2020.138364.
[21] Schlichting, P.E., Dombrovski, V., & Beasley, J.C. (2020). Use of abandoned structures by Przewalski's wild horses and other wildlife in the Chernobyl Exclusion Zone. *Mammal Research*, 65(1), 161-165. doi: 10.1007/s13364-019-00451-4.
[22] Skydan, O.V., Dankevych, V.Y., Fedoniuk, T.P. Dankevych, Y.M., & Yaremova, M.I. (2022(. European green deal: Experience of food safety for Ukraine. *International Journal of Advanced and Applied Sciences*, 9(2), 63-71. doi: 10.21833/ijaas.2022.02.007.
[23] Skydan, O.V., Fedoniuk, T.P., Pyvovar, P.V., Dankevych, V.Ye., & Dankevych, Y.M. (2021). Landscape fire safety management: The experience of Ukraine and the EU. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences,* 6(450), 125-132. doi: 10.32014/2021.2518-170X.128.
[24] Stoner, D.C., Anderson, M.T., Schroeder, C.A., Bleke, C.A., & Thacker, E.T. (2021). Distribution of competition potential between native ungulates and free-roaming equids on western rangelands. *The Journal of Wildlife Management*, 85(6), 1062-1073. doi: 10.1002/jwmg.21993.
[25] The ARRIVE guidelines 2.0. (2010). Retrieved from https://arriveguidelines.org/arrive-guidelines.
[26] Turghan, M.A., Jiang, Z., & Niu, Z. (2022). An update on status and conservation of the Przewalski's horse (*Equus ferus przewalskii*): Captive breeding and reintroduction projects. *Animals*, 12(22), article number 3158. doi: 10.3390/ani12223158.
[27] Zhang, Y., Liu, J., Zhang, K., Wang, A., Sailikebieke, D., Zhang, Z., Ao, T., Yan, L., Zhang, D., Li, K., & Huang, H. (2024). Biological response to Przewalski's horse reintroduction in native desert grasslands: A case study on the spatial analysis of ticks. *BMC Ecology and Evolution*, 24(1), article number 61. doi: 10.1186/s12862-024-02252-z.

Аналіз розподілу популяції коня Пржевальського із використанням геопросторових даних у середовищах Чорнобильської зони відчуження

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Анотація. Відновлення популяції коня Пржевальського в Чорнобильській зоні відчуження, захист цього унікального виду та створення ефективних систем моніторингу і управління середовищем існування за допомогою геоінформаційних технологій є надзвичайно важливими завданнями. Метою дослідження було розробити систему моніторингу для цього виду з урахуванням різноманітних екологічних чинників. Методологія дослідження передбачала багатоступеневий процес, який включав збір даних (під час аналізу літературних джерел і польових спостережень), визначення ключових факторів для моделювання та верифікацію результатів. У результаті було створено карти придатності середовищ існування для розподілу коня Пржевальського шляхом синтезу даних щодо рельєфу, кліматичних умов, гідрології, рослинного покриву, конкуренції за ресурси, наявності хижаків та рівня безпеки. Моделі були відкалібровані за фактичними спостереженнями, отриманими у період з 2018 по 2024 роки. У 2023 році на території зони відчуження було виявлено п'ять гаремів коней Пржевальського. Розподіл цих тварин суттєво залежав від висоти над рівнем моря, близькості до автомагістралей та водних об'єктів, конкуренції за ресурси та активності хижаків. Радіус у 10 кілометрів навколо Чорнобильської атомної електростанції визначено як найменш сприятливу територію через часті лісові пожежі та антропогенний вплив, тоді як найбільш придатні середовища знаходяться в центральній частині досліджуваної зони. Кластерний аналіз показав, що зона відчуження може забезпечити коням Пржевальського додаткові 350 км² придатних середовищ існування, що є важливим для збереження популяції в умовах природної сукцесії. Створені за допомогою ГІС моделі дають змогу прогнозувати потенційні майбутні середовища існування з урахуванням екологічних змін і заходів із охорони природи

Ключові слова: ссавці; ГІС; акліматизація; збереження; карта придатності