GRASSROOTS JOURNALS

**Grassroots Journal of Natural Resources**, Vol.8 No.1 (April 2025)
ISSN: 2581-6853 | CODEN: GJNRA9 | Published by The Grassroots Institute
Website: https://grassrootsjournals.org/gjnr | Main Indexing: Scopus and WoS

**ISSN 2581-6853 | 8(1) April 2025**

**M – 00527 | Research Article**

# The Impact of the Ecosystem on Biodiversity Restoration in the Natural Ecosystems of Ukraine

**Anatolii Vakal*[1], Oleksandr Govorun[2], Dmytro Gulevets[3], Zhanna Korchynska[4], Yuliia Kushch[5]**

[1]Department of Biology and Teaching Methods of Biology, Sumy State Pedagogical University named after A. S. Makarenko, Sumy, Ukraine. Email: anatoliitarasenko923@gmail.com| ORCID: https://orcid.org/0000-0002-1386-7944

[2]Department of Biology and Teaching Methods of Biology, Sumy State Pedagogical University named after A. S. Makarenko, Sumy, Ukraine. Email: alex.govorun77@gmail.com ORCID: https://orcid.org/0000-0002-6626-1241

[3]Institute of Security, Interregional Academy of Personnel Management, Kyiv, Ukraine. Email: gulevets.d34@gmail.com | ORCID: https://orcid.org/0000-0002-1176-6912

[4]Department of Physical Geography and Efficient Environmental Management, Uzhhorod National University, Uzhhorod, Ukraine. Email: korchynska_zhanna0@gmail.com ORCID: https://orcid.org/ 0000-0003-2298-340X

[5]Department of Human Biology, Chemistry and Methods of Teaching Chemistry, Sumy State Pedagogical University named after A. S. Makarenko, Sumy, Ukraine. Email: julia.sumy@gmail.com | ORCID: https://orcid.org/0000-0003-0382-8877

**Corresponding author*

**How to cite this paper:** Vakal, A., Govorun, O., Gulevets, D., Korchynska, Z. and Kushch, Y. (2025). The Impact of the Ecosystem on Biodiversity Restoration in the Natural Ecosystems of Ukraine. *Grassroots Journal of Natural Resources*, 8(1): 945-963. Doi: https://doi.org/10.33002/nr2581.6853.080140

**Received**: 21 February 2025
**Reviewed**: 09 April 2025
**Provisionally Accepted:** 11 April 2025
**Revised**: 14 April 2025
**Finally Accepted:** 15 April 2025
**Published:** 30 April 2025




## Abstract

Biodiversity research is a key element in natural resource management and conservation, especially in large ecosystems such as biosphere reserves. In this context, the dynamics of changes in the plant species diversity on the territory of the Carpathian Biosphere Reserve were analyzed for 2010–2023. The research aimed to study the impact of ecological networks on biodiversity and to identify their role in maintaining ecosystem stability and preserving the species composition in the studied area. The state of biodiversity in the Carpathian Biosphere Reserve was evaluated by using the Simpson, Shannon, Brillouin, evenness (Ewens or Pilkington), and restoration indices, which were calculated using the R program for the following plant species: *Rhododendron myrtifolium*, *Leontopodium*, *Pulsatilla alba Reichen*, and *Erythronium dens-cani*. The study of plant biodiversity in the Carpathian Biosphere Reserve showed the stability of species evenness indices over the years, which indicates the stability of the ecosystem. Positive growth dynamics of recovery indices for all studied species were also noted. The indicator increased from 0.7025 to 0.7323 for *Rhododendron myrtifolium*, from 0.6024 to 0.6551 for *Leontopodium*, from 0.5025 to 0.5682 for *Pulsatilla alba Reichen*, while it remained at 0.7825 for *Erythronium dens-cani*. Biodiversity restoration strategies should be aimed at ensuring the sustainable restoration and preservation of plant diversity, which contributes to increasing the sustainability of ecosystems and preserving natural resources. The obtained data can serve as a basis for further academic research in the field of nature protection, ecology, and preservation of biodiversity.

## Keywords

Species recovery; Ecological networks; Shannon index; Simpson index; Ecosystem resilience; Conservation strategies

## Introduction

Ecological networks are holistic systems of natural and semi-natural areas connected by ecological corridors. Their main goal is to preserve biodiversity, maintain ecological balance, and provide conditions for animal migration and plant distribution. Such networks are based on a combination of key protected areas (such as reserves or national parks), buffer zones around them, and restored areas that are gradually regaining their natural value. It is important that ecological networks not only encompass protected areas but also form connections between them, allowing for the preservation of ecological integrity in a broader landscape context. This ensures the sustainability of natural processes, contributes to the maintenance of the genetic diversity of species, and creates conditions for the adaptation of ecosystems to climate change and other external influences.

Ecological networks play a significant role in preserving and restoring the biodiversity of natural ecosystems. By creating interconnected corridors and systems, also known as eco-corridors, these networks contribute to the restoration of the ecological, functional, and genetic unity of ecosystems. In turn, this helps to preserve the genetic pool of flora and fauna, which ultimately benefits human well-being. In addition, ecosystems help to connect habitats by supporting species migration, protecting rare and endangered species, providing ecosystem services, offering restoration opportunities, and promoting community engagement and collaboration. The significance of ecological networks and implementing measures to strengthen and expand them emphasises the importance of intensifying efforts to conserve biodiversity and ensure the long-term health and sustainability of ecosystems (Li *et al*., 2022; Yang *et al*., 2021).

The legislation of Ukraine, in particular the Law of Ukraine "On the Ecological Network of Ukraine" and the Law of Ukraine "On the State Programme for the Formation of the National Ecological Network of Ukraine for 2000-2015", lays the foundation for the creation of the National Ecological Network. These laws, along with other legal acts aimed at preserving biological and landscape diversity and international conventions, create a legal framework for regulating relations related to the formation, preservation and rational, inexhaustible use of the ecological network. The purpose of such programmes is to increase the area of Ukrainian lands with natural landscapes to a level sufficient to preserve their diversity, close to the natural state, and to form a territorially unified system that ensures natural migration and settlement of plant and animal species. In turn, this contributes to the preservation of natural ecosystems, species and populations of plants and animals, and also ensures their functioning within the Pan-European ecological network (Špulerová *et al*., 2023; Strymets *et al*., 2018).

Regional and local programmes and schemes for the formation of eco-networks, as well as measures to protect biodiversity and landscape diversity, are established by decisions of regional and local councils. These decisions resolve the issue of the creation of territories and objects of the nature reserve fund, protection of rare and endangered plant and animal species, other organisational issues, as well as financing of planned events at the regional level. Therefore, ecological networks make a significant contribution to the preservation and restoration of the biodiversity of natural ecosystems of Ukraine. The current legal framework and mechanisms of public administration support the formation

and maintenance of these networks, ensuring the preservation of biological resources and promoting sustainable development (Barry *et al*., 2019; Terpay, 2021).

The relevance of ecological networks and their role in preserving and restoring the biodiversity of natural ecosystems is extremely high, especially in the context of modern environmental challenges. Preservation of natural diversity is a key task in the face of climate change, loss of natural environments, increasing anthropogenic pressure on ecosystems, and the threat of species extinction. This applies to Ukraine, which has a rich natural fund and where the creation and development of ecological networks is important for the preservation and restoration of the diversity of ecosystems, the protection of rare and endangered plants and animal species, as well as for ensuring sustainable development. The existing laws and public management systems help create and maintain these networks, which protect biological resources and encourage sustainable development.

Ecological networks play a key role in the conservation and restoration of biodiversity in natural ecosystems. They provide the opportunity for species to migrate in response to changing climatic and environmental conditions, which allows for the maintenance of viable populations (Artemenko *et al*., 2021; Van Der Plas, 2019; Qiao *et al*., 2023). Researchers, including Bhatia *et al*. (2023), Bullock *et al*. (2011), and Genung, Fox and Winfree (2020), note that ecological networks include protected areas that serve as refuges for rare and endangered species. Hermoso *et al*. (2021) and Fischer *et al*. (2021) emphasise that the interconnectedness of natural habitats contributes to the maintenance of genetic diversity by ensuring the exchange of individuals between populations. Addy and Wilkinson (2021), Girardin *et al*. (2021) argue that ecological networks support the provision of ecosystem services, such as water purification, pollination, and carbon sequestration, which contribute to the conservation of biodiversity and the restoration of degraded environments. Correia and Lopes (2023), Hogan *et al*. (2022) indicate that networks prevent population isolation, promote habitat restoration, and protect rare species. Herrero-Jáuregui and Concepción (2023), Litvak (2014), and Yan *et al*. (2023) emphasise the positive impact of ecological networks on environmental quality, which is important for human health and ecosystem resilience. At the same time, as Ma *et al*. (2021) point out, the effectiveness of ecological networks depends largely on the availability of effective governance mechanisms, a legislative framework, and adequate financing. Gonzalez *et al*. (2020) and Rasshyvalov *et al*. (2024) emphasise the importance of increasing the area of ecological networks, avoiding habitat fragmentation and improving management practices.

Ecological networks are, therefore, an extremely important tool for the conservation of natural diversity. Their effectiveness depends on an integrated approach that includes scientific justification, competent management, adequate financing and consideration of climate change. Further research and implementation of best practices in the field of ecological network management are necessary to preserve biodiversity in the face of increasing anthropogenic pressure. Given the importance of ecological networks in preserving and restoring biodiversity, research and implementation of new methods of managing ecosystems and regulating the use of natural resources are becoming an integral part of sustainable development. Such measures can help to strengthen ecological networks, improve the efficiency of their functioning, and ensure the long-

term sustainability of natural ecosystems in the future. The research aims to study the role of ecological networks in preserving and restoring the biodiversity of natural ecosystems of Ukraine. The research includes the assessment of the impact of eco-networks on the preservation of plant biodiversity: the analysis of the diversity of species, their evenness of distribution and restoration, as well as the development of strategies for the ecological restoration of plant populations.

## Methods and Materials

The territory of the ecological network of the Carpathian Biosphere Reserve was chosen for the study, which was conducted during 2010-2023. This is one of the largest nature conservation areas in Ukraine, as it covers an area of 66,417.4 ha. The reserve is located in the Rakhiv, Tiachiv, Khust, and Vynohradiv districts of the Transcarpathian region (Figure 1).

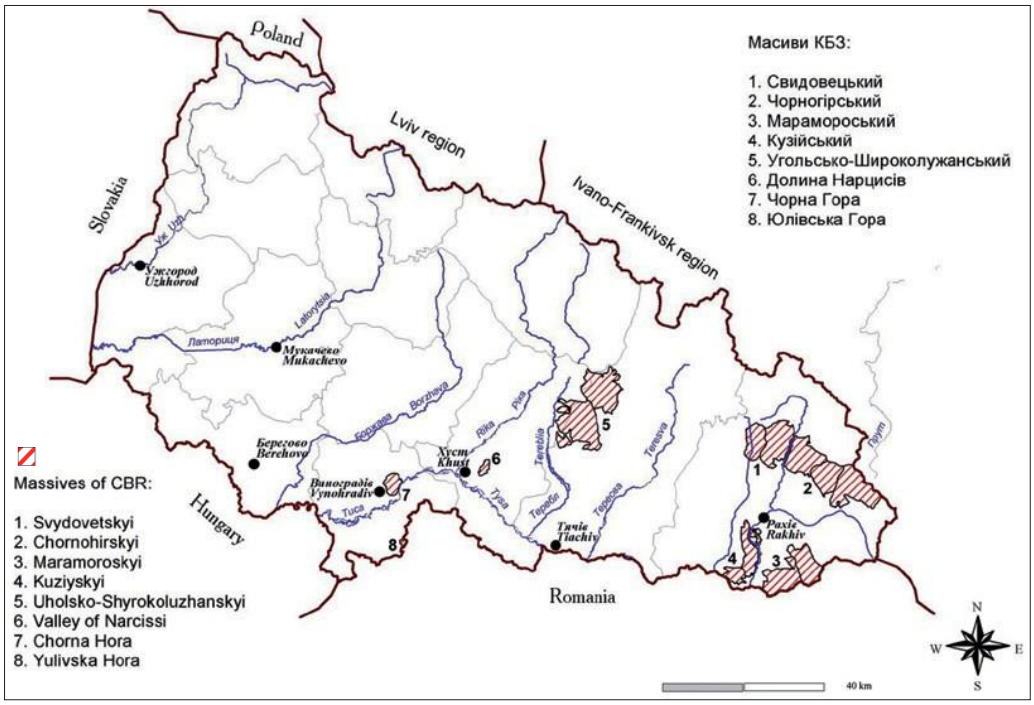


Figure 1: Map of the location of the Carpathian Biosphere Reserve

Secondary data was used for the study of the Ministry of Environmental Protection and Natural Resources of Ukraine (2024) and the State Statistics Service of Ukraine (2024). The data on vascular plants from the Red Book of Ukraine (2024) were also used. The diversity of flora on the territory of the Carpathian Biosphere Reserve was determined by using the method of sample plots. A total of 10 sample plots were selected with an area of 100 $m^2$ each. The following indicators were chosen for the research: species richness, species evenness, number of species, and genetic diversity. In particular, species richness and evenness were used to assess the diversity of plant communities, genetic diversity to identify unique or endangered species, and functional and

phylogenetic diversity to assess the role of different species in ecosystem processes and evolutionary history.

Field studies were used to explore the diversity of the flora, which included direct observation and identification of the following types of plants: the Eastern Carpathians Rhododendron (commonly known as red rue) (*Rhododendron myrtifolium*), edelweiss (*Leontopodium*), alpine pasqueflower (*Pulsatilla alba Reichen*) and dog's-tooth-violet (*Erythronium dens-cani*), listed in the Red Book of Ukraine (2024) in field conditions by route method. The data from the spatial monitoring and reporting system (SMART) were used for qualitative monitoring of the state of biodiversity in the Carpathian Biosphere Reserve. The system helps to collect, measure and evaluate biodiversity data effectively. The formulas were used to determine biodiversity indices, which were processed by a script written in the R programming language:

The Simpson index is a measure of species diversity that takes into account the number of species (S) and the relative abundance of each species (p). It is calculated as:

$$E = 1 / (\Sigma\ p\text{^}2), \quad (1)$$

Where p — the share of individuals in the community belonging to species i.

The Shannon Index — an indicator of species diversity that takes into account the number of species (S) and the relative abundance of each species (p):

$$S = -\Sigma\ p \times \log2\ (p), \quad (2)$$

where p — the proportion of individuals in a community belonging to a species i.

The Brillouin Index –a measure of species diversity that takes into account the number of species (S), the total number of individuals (N) and the number of individuals of each species:

$$H = \ln\ (N!) - \Sigma\ (S \times \ln\ (ni) / N), \quad (3)$$

Where N — the total number of species, ni — the number of individuals of each species.

Evenness index (Ewens Index or Pilkington Index) is a measure of the evenness of the distribution of species in the studied environment. Its value indicates how evenly distributed different species are in a given population or environment:

$$J = \frac{H}{lnS}, \quad (4)$$

where *J* — the Evenness Index, *H* — Shannon Index (information entropy), which takes into account both the number of species and their relative frequency, S — the number of species, ln(*S*) — the natural logarithm of the number of species.

The Restoration Index, which measures the degree of restoration of the ecosystem, is defined by the following formula:

$$I = \frac{A}{N} \times 100, \quad (5)$$

where A = number of recovered species, N = the total number of target species.

A script written in the R programming language was used to calculate the biodiversity indices of (Brillouin, Shannon, and Simpson) for 10 experimental plots of the data set:

```
library(vegan) 2
3# Calculate the indices for the first 10 rows of the data
```

```
4indices <- data.frame(
5  Brillouin = sapply(1:10, function(i) {
6    n <- apply(data[i,], 2, sum) # total number of individuals in plot i
7    s <- sum(n > 0) # number of species in plot i
8    N <- sum(n) # total number of individuals in all plots
9    H <- sum(n * log(n) / N) # Brillouin index
10    return(H)
11  }),
12  Shannon = sapply(1:10, function(i) {
13     n <- apply(data[i,], 2, function(x) ifelse(x > 0, x, NA)) # relative abundance of species in plot i
14    H <- diversity(n, index = "shannon") # Shannon index
15    return(H)
16  }),
17  Simpson = sapply(1:10, function(i) {
18     n <- apply(data[i,], 2, function(x) ifelse(x > 0, x, NA)) # relative abundance of species in plot i
19    D <- diversity(n, index = "simpson") # Simpson index
20    return(D)
21  })
22)
23
24# Print the results
25print(indices)
```

Following this complex methodology with formulas makes the research systematic and quantitative. The results of the study can provide valuable information about the impact of ecological networks on the preservation and restoration of biodiversity in natural ecosystems, and also provide a basis for conservation and management strategies. The research results were processed using statistical methods. The value was set at $p \leq 0.05$. For comparison with other biosphere reserves, an analysis of biodiversity data was carried out in the following reserves: Danube Biosphere Reserve (Romania), Slovenian Biosphere Reserve (Slovenia), and Pirin Biosphere Reserve (Bulgaria).

A study of the experience of EU countries in the field of biodiversity restoration was conducted to analyse foreign practice, in particular: National parks and reserves of the USA, national parks and reserves of Australia, and national parks and reserves of Canada.

## Results

The results of the study of biodiversity on the territory of the Carpathian Biosphere Reserve from 2010 to 2023 indicate important changes in the structure and dynamics of the vegetation cover. The analysis revealed the influence of ecological networks on the growth of plant biodiversity and showed their role in the preservation and recovery of species. The calculated biodiversity indices are all positive and range from about 2.6 to 3.4 for the Brillouin Index, about 1.6 to 1.9 for the Shannon Index, and about 0.5 to 0.7 for the Simpson Index. These values indicate that a moderate or high level of biodiversity

Doi: https://doi.org/10.33002/nr2581.6853.080140 Open Access

is observed at the ten identified sites (Table 1). Such results indicate the importance of preserving ecosystems and the natural environment of plants to maintain a high level of biodiversity and ensure balanced ecological sustainability.

Table 1: Plant Biodiversity Index in selected areas

| *Site* | *Brillouin Index* | *Shannon Index* | *Simpson Index* |
|---|---|---|---|
| 1 | 3.45 | 1.90 | 0.65 |
| 2 | 3.044 | 1.81 | 0.60 |
| 3 | 2.81 | 1.78 | 0.55 |
| 4 | 2.6 | 1.66 | 0.51 |
| 5 | 2.67 | 1.82 | 0.57 |
| 6 | 2.94 | 1.67 | 0.61 |
| 7 | 3.05 | 1.91 | 0.59 |
| 8 | 3.21 | 1.95 | 0.55 |
| 9 | 2.89 | 1.84 | 0.63 |
| 10 | 2.96 | 1.88 | 0.58 |

The spatial evenness index of the study species was calculated for each species separately, based on its distribution across plots in a given year, which allowed us to assess the stability of the spatial distribution of the species over time. Since not all species were present at each plot at the same time, we could not apply the classical approach at the group level. Based on the obtained evenness index data for each year and species, several conclusions can be drawn. In general, the evenness index for each studied plant species shows some stability over the years. It changes slightly from year to year, which may indicate the stability of the relative shares of each species in the vegetation cover of the study area. The evenness index shows that the distribution of species in the study plots is quite uniform. The index values for each species are relatively close to unity, which indicates a significant contribution of each species to the structure of the vegetation cover. When comparing evenness indices for different plant species in each plot to assess their contribution to the diversity and evenness of the vegetation cover, it can be argued that Leontopodium has higher evenness index values, which may indicate a more homogeneous distribution of this species compared to the others. However, this may also be due to the peculiarities of the ecology of each species (Table 2).

Table 2: Evenness Index of studied plant species in the Carpathian Biosphere Reserve

| *Year* | *Rhododendron myrtifolium* | *Leontopodium* | *Pulsatilla alba Reichen* | *Erythronium dens-cani* |
|---|---|---|---|---|
| 2010 | 0.7025 | 0.7825 | 0.5025 | 0.6024 |
| 2012 | 0.7257 | 0.7825 | 0.5413 | 0.6511 |
| 2014 | 0.7293 | 0.7905 | 0.5488 | 0.6464 |
| 2016 | 0.7274 | 0.7854 | 0.5621 | 0.6551 |
| 2018 | 0.7323 | 0.7854 | 0.5682 | 0.6544 |
| 2020 | 0.7286 | 0.7804 | 0.5694 | 0.6551 |
| 2022 | 0.7270 | 0.7769 | 0.5615 | 0.6502 |
| 2023 | 0.7229 | 0.7769 | 0.5635 | 0.6475 |

The obtained results of the Evenness Index indicate important aspects of the structure and dynamics of the vegetation cover in the studied territory of the reserve. First of all, the values of the index, which are close to one for most of the studied years and species, indicate a uniform distribution of plant species on the territory. This indicates that the different species coexist in relatively equal proportions, with no predominance of one species over the others. Furthermore, the stability of the values of the Evenness Index from year to year indicates the stability of the vegetation cover during the considered period. Changes in Evenness Index values from year to year can indicate the dynamics of vegetation cover and its response to external factors such as climate change or human activity. Such changes can affect the distribution of species and lead to changes in the evenness of the vegetation cover.

The study established a growing trend of recovery indices for all studied species, which indicates the positive dynamics of the recovery of populations of these plant species in the studied territories. However, despite the general upward trend, the level of recovery may vary among species. For example, the indices restoration for *Rhododendron myrtifolium* increased from 43 to 62, for *Leontopodium* — from 46 to 76, for *Pulsatilla alba Reichen* — from 50 to 63, and for *Erythronium dens-cani* — from 49 to 56 for 2010-2023. *Leontopodium* and *Pulsatilla alba Reichen* show greater growth compared to other species, which may indicate a different state and population dynamics of these species in the studied areas. Changes in recovery indices from year to year are quite insignificant, which indicates the stable nature of the processes of recovery of populations of plant species in the studied territories during the considered period (Figure 2).

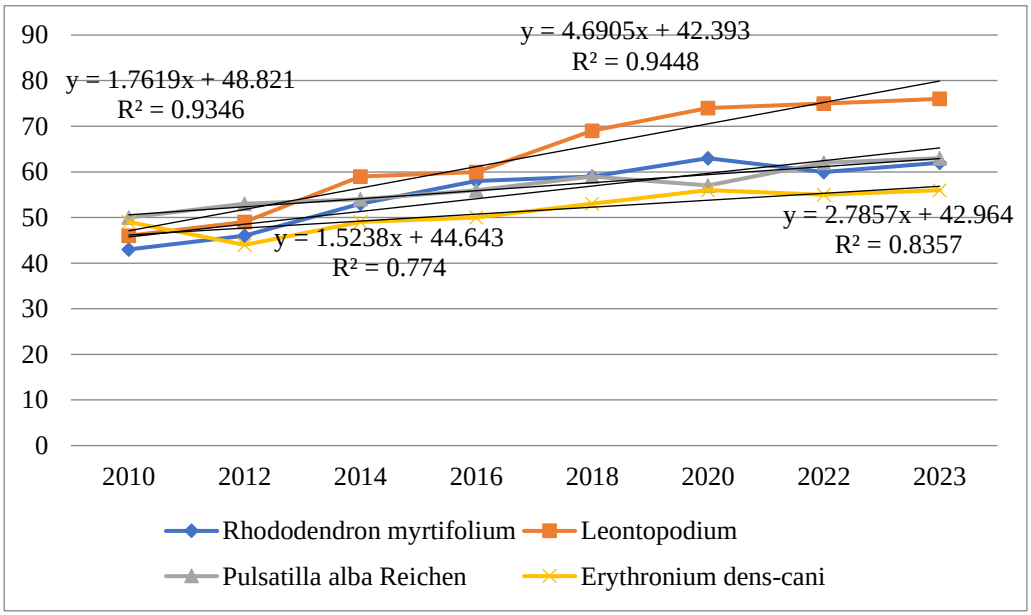


Figure 2: Recovery Index of studied plant species on average for all sites

The general growth trend of recovery indices for all species indicates the positive dynamics of the recovery of plant populations in the studied area, which indicates the effectiveness of ecosystem protection and management measures. Recovery indices may

differ for different species, which may indicate a different degree of vulnerability or a different level of influence of external factors on the populations of these species. The Carpathian Biosphere Reserve is characterised by a high level of biodiversity, which is confirmed by the Brillouin, Shannon, and Simpson indices. This level of biodiversity is similar to that observed in the Slovenian and Pirin Biosphere Reserves. However, compared to the Danube Biosphere Reserve, the Carpathian Biosphere Reserve has a lower level of biodiversity. This may be explained by the unique characteristics of the reserve, such as geographical location or environmental conditions, which contribute to its excellent biodiversity profile (Table 3). Possible explanations for the differences between the Carpathian Biosphere Reserve and other reserves may be related to geographic location, environmental conditions, and conservation efforts.

Table 3: Comparison of biodiversity indices in biosphere reserves

| *Biosphere Reserve* | *Brillouin Index* | *Shannon Index* | *Simpson Index* |
|---|---|---|---|
| Danube Biosphere Reserve (Romania) | 3.12 ± 0.25 | 2.01 ± 0.13 | 0.62 ± 0.06 |
| Slovenian Biosphere Reserve (Slovenia) | 2.85 ± 0.20 | 1.83 ± 0.10 | 0.55 ± 0.04 |
| Pirin Biosphere Reserve (Bulgaria). | 2.92 ± 0.22 | 1.92 ± 0.12 | 0.59 ± 0.05 |

*Source:* World Commission on Protected Areas (2024)

Table 4 demonstrates international experience in restoring biodiversity. Countries with developed systems of national parks and reserves, such as the United States, Australia, and Canada, are making various efforts to restore biodiversity. They focus on protecting endangered species, protecting unique ecosystems, mitigating the effects of climate change and managing invasive species. In Ukraine, the Carpathian Biosphere Reserve is one of the most important objects of the nature reserve fund, which needs special protection, preservation, and restoration. International experience in restoring biodiversity can be useful for Ukraine in developing its strategy for restoring biodiversity in the Carpathians, in particular, in developing a network of national parks and reserves, protecting the unique ecosystems of the Carpathians, mitigating the effects of climate change in the region, and managing invasive species.

Table 4: International experience in restoring biodiversity

| *Country* | *National parks and nature reserves* | *Biodiversity restoration efforts* |
|---|---|---|
| USA | 63 National Parks, 560 National Wildlife Reserves | Implementation of programmes for the preservation of rare species, restoration of ecosystems, fight against invasive species, creation of corridors for wild animals |
| Australia | 685 National Parks, 274 Nature Reserves | Restoration of forests and grassland ecosystems, protection of wetlands, reintroduction of endangered species, and fire management |

| *Country* | *National parks and nature reserves* | *Biodiversity restoration efforts* |
|---|---|---|
| Canada | 48 National Parks, 154 National Wildlife Reserves | Preservation and restoration of Arctic and boreal ecosystems, protection of marine ecosystems, integration of indigenous peoples into nature conservation projects |

*Source:* World Commission on Protected Areas (2024)

So, the analysis of biodiversity indices in different biosphere reserves shows that the Carpathian Biosphere Reserve has a relatively high level of biodiversity, comparable to other European biosphere reserves. International experience in restoring biodiversity highlights the importance of protecting unique ecosystems, conserving endangered species, and managing invasive species.

## Discussion

The ecological networks play a key role in the conservation of biodiversity, contributing to the protection of various species, including rare and vulnerable ones. Ecological networks provide connectivity between different parts of natural areas, allowing species to migrate, exchange genetic material, and maintain healthy populations. This increases the resilience of ecosystems to external influences, such as climate change and anthropogenic pressure. The study established that ecological networks contribute to the preservation of not only biodiversity but also ecological sustainability, which is critically important for the long-term preservation of natural resources and the provision of ecosystem services.

The overall positive dynamics of restoration indices, obtained as a result of research on the territory of the Carpathian Biosphere Reserve during 2010–2023, indicate a positive direction of restoration of the plant population, which indicates the effectiveness of environmental protection and ecosystem measures. In addition to supporting species migration, ecological networks can also help to maintain genetic diversity within species. Ecological networks can facilitate gene flow and reduce the risk of inbreeding by connecting isolated populations. This is important for maintaining the long-term viability of populations and preventing the loss of genetic diversity. Ecological networks can also contribute to the restoration of degraded ecosystems. Ecological networks can help to restore ecological processes and functions by connecting fragmented environments, leading to biodiversity restoration. This is especially important in the context of changes in human land use, which often lead to fragmentation and degradation of the natural environment (Atkinson *et al*., 2022; Sudmeier-Rieux *et al*., 2021; Wang *et al*., 2021).

According to the results of research by Solé and Levin (2022), there is a positive trend in increasing the number of rare plant species in the territories where ecological networks operate. One of the key factors influencing changes in biodiversity is land use change. The authors established that the regular reduction of the area of natural ecosystems as a result of land exploitation worsens the state of biodiversity. And ecological networks turn out to be an effective tool for preserving biodiversity, in particular, they contribute to the regeneration and preservation of natural ecosystems. The studies of different

scientists and researchers, as well as this research, emphasise that ecological networks are an important tool for preserving and restoring the biodiversity of natural ecosystems. Ecological networks can help to ensure the long-term viability of ecosystems and the species they support by providing connectivity between environments, supporting species migration, maintaining genetic diversity and promoting ecosystem recovery. Further research is required to better understand the impact of ecological networks on biodiversity conservation and restoration, and to develop effective strategies for the implementation and management of ecological networks (Ombashi and Løvschal, 2022; Nakamura *et al*., 2020).

In addition, the conducted research is similar to the data of different researchers regarding a significant increase in the number of different plant and animal species in areas with ecological networks compared to control territories without protected areas. Ecological networks provide unique conditions for the preservation of the genetic diversity of plant populations, which is a key factor for their stability and adaptation (Mori et al., 2021; Memmott *et al*., 2006). Research by Markl, Hinneberg and Tarmann (2022) and Loreau *et al*. (2021) also confirmed that ecological networks contribute to the maintenance of genetic diversity in species populations by providing migration routes and genetic exchange between different populations. It was established that ecological networks contribute to increasing the functional diversity of ecosystems by creating diverse environments and conditions for different species and ecological functions.

Another confirmation of the conducted research can be found in the works of the researchers who established that ecological networks contribute to the preservation and restoration of plant biodiversity. The study conducted by Niu *et al*. (2019) and co-authors showed that reserves and national parks that are part of ecological networks have a higher level of species diversity and more stable plant communities compared to territories that are not part of ecological networks. Another study by Rockström *et al*. (2021) and their colleagues confirmed these results, showing that ecological corridors that connect different protected areas facilitate the exchange of genetic material and the preservation of migratory routes for plants. So, the results of these studies reflect the importance of ecological networks in preserving plant biodiversity and maintaining ecologically sustainable landscapes. An analysis of foreign practices in the management of protected areas and sustainable tourism shows that protected areas in the United States are managed by the National Park Service, which has a decentralised approach to management. In Canada, protected areas are managed by Parks Canada, which applies a more centralised approach to management. New Zealand promotes sustainable tourism through the Tiaki Promise initiative, which encourages visitors to respect the natural environment. Costa Rica promotes sustainable tourism through the Certification for Sustainable Tourism (CST) programme, which recognises tourism businesses that meet certain sustainability standards. In Australia, public involvement is a key component of protected area management, where local communities are involved in decision-making and management processes. Public involvement is also important in South Africa, with an emphasis on benefit sharing and community-led conservation initiatives (Hermoso *et al*., 2021; Artemenko *et al*., 2024).

The Carpathian Biosphere Reserve could be improved by implementing a decentralized management approach similar to that used in the US. The reserve could also be improved by promoting a sustainable tourism economy similar to that used in New Zealand and Costa Rica. In addition, public participation is an important component of protected area management, and the Carpathian Biosphere Reserve could be improved by involving local communities in decision-making and management processes similar to those used in Australia and South Africa. This can increase the efficiency of reserve management, improve cooperation between local communities and authorities, and increase the economic benefits of tourism for local residents (Mori *et al*., 2021). Research results confirm that the ecological networks contribute to the increase of overall biodiversity in natural ecosystems, because ecological networks help to preserve and protect the diversity of species, including rare species that are of great importance for biodiversity conservation. The establishment of ecological networks also increases the resilience of natural ecosystems to external stressors such as climate change or anthropogenic pressure. So, the research results made it possible to make a more in-depth and comprehensive analysis of the impact of ecological networks on biodiversity, which opens up new prospects for further research and management of natural resources.

These research results serve as the foundation for the development of a targeted strategy for the restoration of plant biodiversity in the Carpathian Biosphere Reserve, which includes the following steps:

1. Identification of priority species: carry out an assessment of the diversity of plant species in the reserve and identify those that are under threat or need special attention for recovery.
2. Restoration of the environment: carry out work on the restoration of the natural environment in the reserve area, including the restoration of forests, swamps, mountain meadows and other plant communities.
3. Seeding and transplanting programmes: develop seeding and transplanting programmes of rare or endangered plant species in restored areas. Consider compliance with local conditions and the ecological needs of each species.
4. Monitoring and evaluation: carry out continuous monitoring of plant populations and their environment in order to assess the effectiveness of the measures taken and to make adjustments to the recovery strategy.
5. Community and stakeholder engagement: involve local residents, researchers, environmental organisations and other stakeholders in the process of restoring plant biodiversity through awareness, education and collaboration.
6. Communication and education: conduct information campaigns and educational activities among the local population about the importance of preserving plant diversity and natural ecosystems in the reserve.

This strategy is aimed at creating conditions for the sustainable restoration and preservation of plant biodiversity in the Carpathian Biosphere Reserve, taking into account the characteristics of its territory and ecological needs. In addition, the Carpathian Biosphere Reserve can be improved by implementing innovative technologies such as biodiversity monitoring using drones, satellite sensing and other technologies that can improve the monitoring and management of the reserve's ecosystems. It is expected that the implementation of these measures will improve the

efficiency of management of the Carpathian Biosphere Reserve, increase economic benefits from tourism for local residents, and help to preserve the unique natural heritage of the Carpathian region for future generations.

Therefore, the performed research corresponds to the set goal, and its results emphasize the importance of preserving the ecosystem for maintaining the biodiversity of plant communities. Recognition of the influence of ecological networks on the structure and functioning of plant ecosystems is a step towards ensuring the sustainable management of natural resources and the preservation of biodiversity for future generations. The results of this research emphasize the need to continue measures to expand and improve ecological networks, as well as to implement effective strategies for the management and protection of natural ecosystems.

## Research Limitations

The study was conducted only on the territory of the Carpathian Biosphere Reserve, which may limit the general universality of the obtained results in the context of other regions or ecosystems. This is determined by the unique climatic, geographical and biological conditions of the reserve, which can differ significantly from conditions in other parts of the world. So, in order for the obtained data to be more widely applicable, additional research is needed in different regions and ecosystems, taking into account their specific ecological conditions and diversity types.

## Recommendations

It is recommended to improve the system of monitoring and management of biodiversity in the reserve, in particular, to ensure more effective monitoring with the help of modern technologies, and to develop strategies for preserving the diversity of species. Based on the obtained results, it is recommended to develop programmes for the preservation and restoration of species diversity, in particular, to actively involve the local population and interested parties in nature conservation activities.

## Conclusion

The study showed that the evenness indices for the studied plant species Rhododendron myrtifolium, Leontopodium, Pulsatilla alba Reichen and Erythronium dens-cani remained stable over the years, which indicates a uniform distribution of these species in the vegetation cover. The stability of these indices indicates the balance of the ecosystem of the Carpathian Biosphere Reserve in the period from 2010 to 2023. In addition, there is a general trend towards an increase in the recovery indices for all species, which indicates a positive dynamics of the recovery of populations of these species in the studied areas.To restore plant biodiversity in the Carpathian Biosphere Reserve, it is necessary to apply strategies that include the identification of priority species, habitat restoration, plant sowing and transplanting programs, systematic monitoring and assessment of the state of populations, as well as the involvement of local communities and stakeholders in these processes. These strategies are aimed at ensuring sustainable recovery and conservation of the plant biodiversity of the reserve, increasing the resilience of ecosystems and preserving natural diversity.

This research significantly contributes to understanding biodiversity by confirming the crucial role of ecological networks in preserving and enhancing plant species diversity in natural ecosystems, thereby supporting the development of effective conservation strategies.Research results can be used to improve reserve management strategies, develop species diversity conservation programmes, and support conservation decision-making at the local and regional levels.

## References

Addy, S. and Wilkinson, M.E. (2021). Embankment lowering and natural self-recovery improves river-floodplain hydro-geomorphic connectivity of a gravel bed river. *Science of the Total Environment*, 770(5): 144626. DOI: https://doi.org/10.1016/j.scitotenv.2020.144626.

Artemenko, Y., Hovorov, Y., Maksymova, I., Kostiuk, V. and Zienkin, M. (2024). The impact of conflict on contemporary global dynamics: Integration, globalisation, and polarisation trends. *Multidisciplinary Reviews*, 7: 2024spe030. DOI: https://doi.org/10.31893/multirev.2024spe030.

Atkinson, J., Brudvig, L.A., Mallen-Cooper, M., Nakagawa, S., Moles, A.T. and Bonser, S.P. (2022). Terrestrial ecosystem restoration increases biodiversity and reduces its variability, but not to reference levels: A global meta-analysis. *Ecology Letters*, 25(7): 1725–1737. DOI: https://doi.org/10.1111/ele.14025.

Barry, K.E., Mommer, L., van Ruijven, J., Wirth, C., Wright, A.J., Bai, Y., Connolly, J., De Deyn, G.B., de Kroon, H. and Isbell, F. (2019). The future of complementarity: disentangling causes from consequences. *Trends Ecology & Evolution*, 34(2): 167–180. DOI: https://doi.org/10.1016/j.tree.2018.10.013.

Bhatia, U., Dubey, S., Gouhier, T.C. and Ganguly, A.R. (2023). Network-based restoration strategies maximize ecosystem recovery. *Communications Biology*, 6: 1256. DOI: https://doi.org/10.1038/s42003-023-05622-3.

Bradbury, R.B., Butchart, S.H.M., Fisher, B., Hughes, F.M.R., Ingwall-King, L., MacDonald, M.A., Merriman, J.C., Peh, K.S.H., Pellier, A.S., Thomas, D.H.L., Trevelyan, R. and Balmford, A. (2021). The economic consequences of conserving or restoring sites for nature. *Nature Sustainability*, 4(7): 602–608. DOI: https://doi.org/10.1038/s41893-021-00692-9.

Bullock, J., Aronson, J., Newton, A., Pywell, R. and Benayas, J. (2011). Restoration of ecosystem services and biodiversity: Conflicts and opportunities. *Trends in Ecology & Evolution*, 26(10): 541–549. DOI: https://doi.org/10.1016/j.tree.2011.06.011.

Correia, A. M., & Lopes, L. F. (2023). Revisiting Biodiversity and Ecosystem Functioning through the Lens of Complex Adaptive Systems. *Diversity*, *15*(8): 895. DOI: https://doi.org/10.3390/d15080895.

Fischer, J., Riechers, M., Loos, J., Martin-Lopez, B. and Temperton, V. M. (2021). Making the UN decade on ecosystem restoration a social-ecological endeavour. *Trends in Ecology & Evolution*, 36: 20–28. DOI: https://doi.org/10.1016/j.tree.2020.08.018

Genung, M. A., Fox, J., & Winfree, R. (2020). Species Loss Drives Ecosystem Function in Experiments, but in Nature the Importance of Species Loss Depends on Dominance. *Global Ecology and Biogeography*, *29*(9): 1531–1541. DOI: https://doi.org/10.1111/geb.13137.

Girardin, C. A. J., Jenkins, S., Seddon, N., Allen, M., Lewis, S. L., Wheeler, C. E., Griscom, B. W., and Malhi, Y. (2021). Nature-based solutions can help cool the planet – If we act now. *Nature*, *593*(7858): 191–194. DOI: https://doi.org/10.1038/d41586-021-01241-2.

Gonzalez, A., Germain, R. M., Srivastava, D. S., Filotas, E., Dee, L. E., Gravel, D., Thompson, P. L., Isbell, F., Wang, S., Kéfi, S., Montoya, J., Zelnik, Y. R., and Loreau, M. (2020). Scaling-up biodiversity-ecosystem functioning research. *Ecology Letters*, *23*(4): 757–776. DOI: https://doi.org/10.1111/ele.13456.

Hermoso, V., Regos, A., Morán-Ordóñez, A., Duane, A., and Brotons, L. (2021). Tree planting: A double-edged sword to fight climate change in an era of megafires. *Global Change Biology*, *27*(13): 3001–3003. DOI: https://doi.org/10.1111/gcb.15625.

Herrero-Jáuregui, C., and Concepción D. (2023). Effects of counter-urbanization on Mediterranean rural landscapes. *Landscape Ecology*, 38: 3695–3711. DOI: https://doi.org/10.1007/s10980-023-01756-1.

Hogan, A., Blomqvist, E., Cochez, M., D'amato, C., De Melo, G., Gutierrez, C., Kirrane, S., Gayo, J. E. L., Navigli, R., Neumaier, S., Ngomo Ngonga, A.-C., Polleres, A., Rashid, S. M., Rula, A., Schmelzeisen, L., Sequeda, J., Staab, S., Zimmermann, A., and d Amato, C. (2022). Knowledge graphs. *ACM Computing Surveys*, 54: 1–37. DOI: https://doi.org/10.1145/3447772.

Li, P., Li, D., Sun, X., Chu, Z., Xia, T., and Zheng, B. (2022). Application of ecological restoration technologies for the improvement of biodiversity and ecosystem in the river. *Water*, 14(9): 1402. DOI: https://doi.org/10.3390/w14091402

Litvak, O. A. (2014). Environmental assessment of land resources structure in the region. *Actual Problems of Economics*, *159*(9): 287–294.

Loreau, M., Barbier, M., Filotas, E., Gravel, D., Isbell, F., Miller, S. J., Montoya, J. M., Wang, S., Aussenac, R., Germain, R., Thompson, P. L., Gonzalez, A., and Dee, L. E. (2021). Biodiversity as insurance: From concept to measurement and application. *Biological Reviews*, *96*(5): 2333–2354. DOI: https://doi.org/10.1111/brv.12756.

Ma, F., Zhang, F., Quan, Q., Song, B., Wang, J., Zhou, Q., and Niu, S. (2021). Common species stability and species asynchrony rather than richness determine ecosystem stability under nitrogen enrichment. *Ecosystems*, *24*(1): 686–698. DOI: https://doi.org/10.1007/s10021-020-00543-2.

Markl, G., Hinneberg, H., and Tarmann, G. (2022). Drastic decline of extensive grassland species in Central Europe since 1950: Forester moths of the genus Jordanita (Lepidoptera, Zygaenidae) as a type example. *Ecology and Evolution*, *12*(9): e9291. DOI: https://doi.org/10.1002/ece3.9291.

Memmott, J., Alonso, D., Berlow, E., Dobson, A., Dunne, J., Sole, R., and Weitz, J. (2006). Biodiversity loss and ecological network structure. In M. Pascual, J. A. Dunne (Eds.), *Ecological Networks: Linking Structure to Dynamics in Food Webs* (pp. 325–371). Oxford University Press. DOI: https://doi.org/10.1093/oso/9780195188165.003.0014.

Ministry of Environmental Protection and Natural Resources of Ukraine (2024). Available online at: https://mepr.gov.ua/ (accessed on 21 February 2025).

Mori, A. S., Dee, L. E., Gonzalez, A., Ohashi, H., Cowles, J., Wright, A. J., Loreau, M., Hautier, Y., Newbold, T., Reich, P. B., Matsui, T., Takeuchi, W., Okada, K.-I., Seidl, R., and Isbell, F. (2021). Biodiversity-productivity relationships are key to

nature-based climate solutions. *Nature Climate Change*, *11*(6): 543–550. DOI: https://doi.org/10.1038/s41558-021-01062-1.

Nakamura, F., Watanabe, Y., Negishi, J., Akasaka, T., Yabuhara, Y., Terui, A., Yamanaka, S., and Konno, M. (2020). Restoration of the shifting mosaic of floodplain forests under a flow regime altered by a dam. *Ecological Engineering*, 157: 105974. DOI: https://doi.org/10.1016/j.ecoleng.2020.105974.

Niu, Q., Xiao, X., Zhang, Y., Qin, Y., Dang, X., Wang, J., Zou, Z., Doughty, R. B., Brandt, M., Tong, X., Horion, S., Fensholt, R., Chen, C., Myneni, R. B., Xu, W., Di, G., and Zhou, X.. (2019). Ecological engineering projects increased vegetation cover, production, and biomass in semiarid and subhumid Northern China. *Land Degradation and Development*, *30*(13): 1620–1631. DOI: https://doi.org/10.1002/ldr.3351.

Ombashi, H., and Løvschal, M. (2022). Anthropogenic heathlands in prehistoric Atlantic Europe: Review and future prospects. *European Journal of Archaeology*, *26*(3): 341–358. DOI: https://doi.org/10.1017/eaa.2022.42.

Qiao, X., Hautier, Y., Geng, Y., Wang, S., Wang, J., Zhang, N., Zhang, Z., Zhang, C., Zhao, X., and von Gadow, K. (2023). Biodiversity Contributes to Stabilizing Ecosystem Productivity across Spatial Scales as Much as Environmental Heterogeneity in a Large Temperate Forest Region. *Forest Ecology and Management*, *529*(43): Article 120695. DOI: https://doi.org/10.1016/j.foreco.2022.120695.

Rasshyvalov, D., Portnov, Y., Sigaieva, T., Alboshchii, O., and Rozumnyi, O. (2024). Navigating geopolitical risks: Implications for global supply chain management. *Multidisciplinary Reviews*, 7: 2024spe017. DOI: https://doi.org/10.31893/multirev.2024spe017.

Red Book of Ukraine. 2024. https://nature.land.kiev.ua/red-book-96.pdf

Rockström, J., Beringer, T., Hole, D., Griscom, B., Mascia, M. B., Folke, C., and Creutzing, F. (2021). We need biosphere stewardship that protects carbon sinks and builds resilience. *PNAS*, *118*(38): 2115218118. DOI: https://doi.org/10.1073/pnas.2115218118.

Solé, R., and Levin, S. (2022). Ecological complexity and the biosphere: The next 30 years. *Philosophical Transactions of the Royal Society B*, *377*(1857): 20210376. DOI: https://doi.org/10.1098/rstb.2021.0376.

Špulerová, J., Piscová, V., and Matušicová, N. (2023). The contribution of scientists to the research in biosphere reserves in Slovakia. *Land*, *12*(3): 537. DOI: https://doi.org/10.3390/land12030537.

State statistics service of Ukraine (2024). https://www.ukrstat.gov.ua/

Strymets, H., Gorban, L., Khomyn, I., and Ferents, N. (2018). Monitoring of the state of transformation and preservation of ecosystem biodiversity in the conditions of the Roztochcha nature reserve. *Scientific Bulletin of UNFU*, *28*(10): 57–61. DOI: https://doi.org/10.15421/40281012.

Sudmeier-Rieux, K., Arce-Mojica, T., Boehmer, H. J., Doswald, N., Emerton, L., Friess, D. A., Galvin, S., Hagenlocher, M., James, H., Laban, P., Lacambra, C., Lange, W., McAdoo, B. G., Moos, C., Mysiak, J., Narvaez, L., Nehren, U., Peduzzi, P., Renaud, F. G., and Walz, Y. (2021). Scientific evidence for ecosystem-based disaster risk reduction. *Nature Sustainability*, 4(9): 803–810. DOI: https://doi.org/10.1038/s41893-021-00732-4.

Terpay, V. (2021). Watercourses of the Carpathian Biosphere Reserve as a habitat, reproduction and conservation of fish gene resources. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Agricultural Sciences*, *23*(95): 160–166. DOI: https://doi.org/10.32718/nvlvet-a9524.

Van Der Plas, F. (2019). Biodiversity and Ecosystem Functioning in Naturally Assembled Communities. *Biological Reviews of the Cambridge Philosophical Society*, 94(4): 1220–1245. DOI: https://doi.org/10.1111/brv.12499.

Wang, S., Isbell, F., Deng, W., Hong, P., Dee, L. E., Thompson, P., and Loreau, M. (2021). How complementarity and selection affect the relationship between ecosystem functioning and stability. *Ecology*, *102*(6): e03347. DOI: https://doi.org/10.1002/ecy.3347.

World commission on protected areas (2024). https://www.iucn.org/our-union/commissions/iucn-world-commission-protected-areas-2021-2025

Yan, P., Fernández-Martínez, M., Van Meerbeek, K., Yu, G., Migliavacca, M., and He, N. (2023). The Essential Role of Biodiversity in the Key Axes of Ecosystem Function. *Global Change Biology*, 29: 4569–4585. DOI: https://doi.org/10.1111/gcb.16666.

Yang, Q., Weigelt, P., Fristoe, T. S., Zhang, Z., Kreft, H., Stein, A., Seebens, H., Dawson, W., Essl, F., Konig, C., Lenzner, B., Pergl, J., Pouteau, R., Pysek, P., Winter, M., Ebel, A. L., Fuentes, N., Giehl, E. L. H., Kartesz, J., and van Kleunen, M. (2021). The global loss of floristic uniqueness. *Nature Communications*, *12*(1): 7290. DOI: https://doi.org/10.1038/s41467-021-27603-y.

.

## Authors' Declarations and Essential Ethical Compliances

*Authors' Contributions (in accordance with ICMJE criteria for authorship)*

| *Contribution* | *Author 1* | *Author 2* | *Author 3* | *Author 4* | *Author 5* |
|---|---|---|---|---|---|
| Conceived and designed the research or analysis | Yes | No | Yes | No | No |
| Collected the data | No | Yes | Yes | Yes | Yes |
| Contributed to data analysis & interpretation | Yes | Yes | No | No | No |
| Wrote the article/paper | Yes | Yes | Yes | Yes | Yes |
| Critical revision of the article/paper | Yes | No | No | Yes | Yes |
| Editing of the article/paper | No | Yes | Yes | No | No |
| Supervision | Yes | No | No | Yes | Yes |
| Project Administration | No | Yes | Yes | Yes | Yes |
| Funding Acquisition | No | No | No | No | No |
| Overall Contribution Proportion (%) | 20 | 20 | 20 | 20 | 20 |

*Funding*
No financial support was received for the research and writing of this article.

*Research involving human bodies or organs or tissues (Helsinki Declaration)*
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

*Research involving animals (ARRIVE Checklist)*
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

*Research on Indigenous Peoples and/or Traditional Knowledge*
The author(s) solemnly declare(s) that this research has not involved Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

*Research involving Plants*
The author(s) solemnly declare(s) that this research has involved the plants for experiment and field studies. Some contexts of plants are also indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

*Research Involving Local Community Participants (Non-Indigenous) or Children*
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

*PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)*
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

*Competing Interests/Conflict of Interest*
Author(s) has/have no competing financial, professional, or personal interests from other parties or in publishing this manuscript. There is no conflict of interest with the publisher or the editorial team or the reviewers.

*Attribution and Representation*
All opinions and mistakes are the author(s)' own and cannot be attributed to the institutions they represent. The publisher is also not responsible either for such opinions and mistakes in the text or graphs or images.

*Declaration of the Use of AI*
During the preparation of this work, the author used no AI tool to assists the script translation and proof reading.

## Rights and Permissions



***

To see original copy of these declarations signed by Corresponding/First Author (on behalf of other co-authors too), please download associated zip folder [Declarations] from the published Abstract page accessible through and linked with the DOI: https://doi.org/10.33002/nr2581.6853.080140.