USING R IN LANDSCAPE ECOLOGY: AN OVERVIEW

Milena Lakićević[1]*,
[0000-0001-8312-0443]

Milan Gazdić[2]
[0000-0002-6965-5529]

[1]University of Novi Sad,
Faculty of Agriculture,
Novi Sad, Serbia

[2]Environmental Protection Agency of
Montenegro,
Podgorica, Montenegro

Abstract:

This paper provides an overview of the use of the R programming language and selected specialized packages in a variety of analytical tasks within landscape ecology. It highlights the broad applicability of R across different analytical domains, from numerical data processing and biodiversity analysis to species conservation and spatial visualization. This study integrates quantitative biodiversity assessment with spatial analysis to evaluate plant diversity and conservation patterns. First, the study provides an example of quantitative biodiversity assessment by calculating alpha diversity through species richness, Shannon, Simpson, Berger–Parker, and Fisher's alpha indices, while beta diversity was evaluated using Jaccard distance and visualized with heatmaps to illustrate compositional differences among sites. Next, the paper presents a mapping of protected areas using the example of Fruška Gora National Park. Finally, an example of species-focused habitat analysis is given through detailed mapping of the endemic species *Ramonda serbica* and *Ramonda nathaliae*, including distribution patterns, habitat overlap, and clustering of *R. serbica* habitats in Serbia. Together, these examples illustrate how R can be effectively applied to a wide range of landscape ecology tasks. By presenting practical case studies across multiple domains, the paper aims to promote the broader adoption of R as a flexible and powerful tool for landscape analysis, research, and conservation planning.

Keywords:

Biodiversity, Mapping, Protected Habitats, Endemic Species, IT Tools.

INTRODUCTION

R is a flexible and powerful programming environment that has become a central tool for data analysis in ecology and nature conservation [1]. As an open-source platform, it provides researchers with a highly extensible framework supported by a large and active scientific community. A defining strength of R lies in its extensive ecosystem of packages, i.e. user-developed libraries that extend the core functionality of the language [2]. These packages cover a wide range of specialized applications, from ecological statistics and biodiversity analysis to spatial modelling and data visualization [3]. Well-known packages such as *dplyr* and *tidyr* facilitate data manipulation, *ggplot2* enables advanced graphical visualization, and spatial packages like *sf* and *raster* support geospatial analyses.

Correspondence:
Milena Lakićević

e-mail:
milena.lakicevic@polj.edu.rs

DOI: 10.15308/Sinteza-2026-201-207

This modular structure allows researchers to tailor workflows precisely to their analytical needs. One of R's key strengths is its capacity for efficient data management. It enables users to import data from diverse sources and formats, including spreadsheets, databases, and spatial files, and provides comprehensive tools for cleaning, transforming, and organizing complex datasets. Such functionality is particularly valuable in ecological research, where data often originate from multiple field surveys, long-term monitoring programs, and remote sensing technologies.

Beyond data handling, R offers an extensive suite of tools for numerical computation and statistical analysis. Researchers can apply a broad range of statistical tests and modelling approaches, from descriptive statistics and hypothesis testing to advanced multivariate analyses, mixed-effects models, and generalized linear models [4]. These capabilities support rigorous quantitative research and enable detailed exploration of ecological patterns and processes.

R is also widely used for spatial analysis and mapping [5]. Through dedicated geospatial packages, it facilitates the processing, visualization, and interpretation of geographic information, allowing researchers to examine species distributions, habitat structures, and landscape-level dynamics [3]. High-quality graphical outputs further enhance the communication of findings, making complex results accessible to both scientific and non-scientific audiences. In addition, R supports ecological modelling and predictive analyses, including simulation techniques and machine learning approaches. These tools allow researchers to model species–environment relationships, assess the influence of environmental drivers, and forecast ecological dynamics under scenarios of environmental change [6]. Consequently, R plays a crucial role in advancing data-driven research and supporting evidence-based conservation planning [7]. This paper presents some of the main features of R and its applications in ecological studies, covering several key domains of analysis. The first section focuses on the calculation of biodiversity indices across different habitat types, demonstrating how R can be used to quantify and compare species diversity patterns. The second section addresses the spatial mapping of protected areas using the example of Fruška Gora National Park. The final section presents the creation of distribution maps for individual plant species, illustrating species-level spatial analyses. All examples are based on real case studies conducted within the territory of Serbia, providing practical demonstrations of R's capabilities in applied ecological research.

2. METHODS OF RESEARCH

In this study, all data processing, statistical analyses, and visualization procedures were conducted using the R programming language (version 4.5.2), a widely used open-source environment for statistical computing and graphics. Analyses were performed within the integrated development environment RStudio IDE (version 2026.01.0), which offers an interactive interface for script editing, code execution, object management, and visualization (Figure 1). RStudio facilitates reproducible analytical workflows and seamless integration with version control systems, enhancing the organization and documentation of analytical pipelines.

A variety of R packages were utilized to support specific analytical tasks. These included packages for calculating biodiversity indices (e.g. *vegan*), spatial data handling and mapping (e.g. *sf, raster, sp*), and graphical visualization (e.g. *ggplot2, tmap*). Packages were selected based on their relevance to the analytical task and their widespread use in ecological research to ensure methodological rigor and comparability with existing studies.

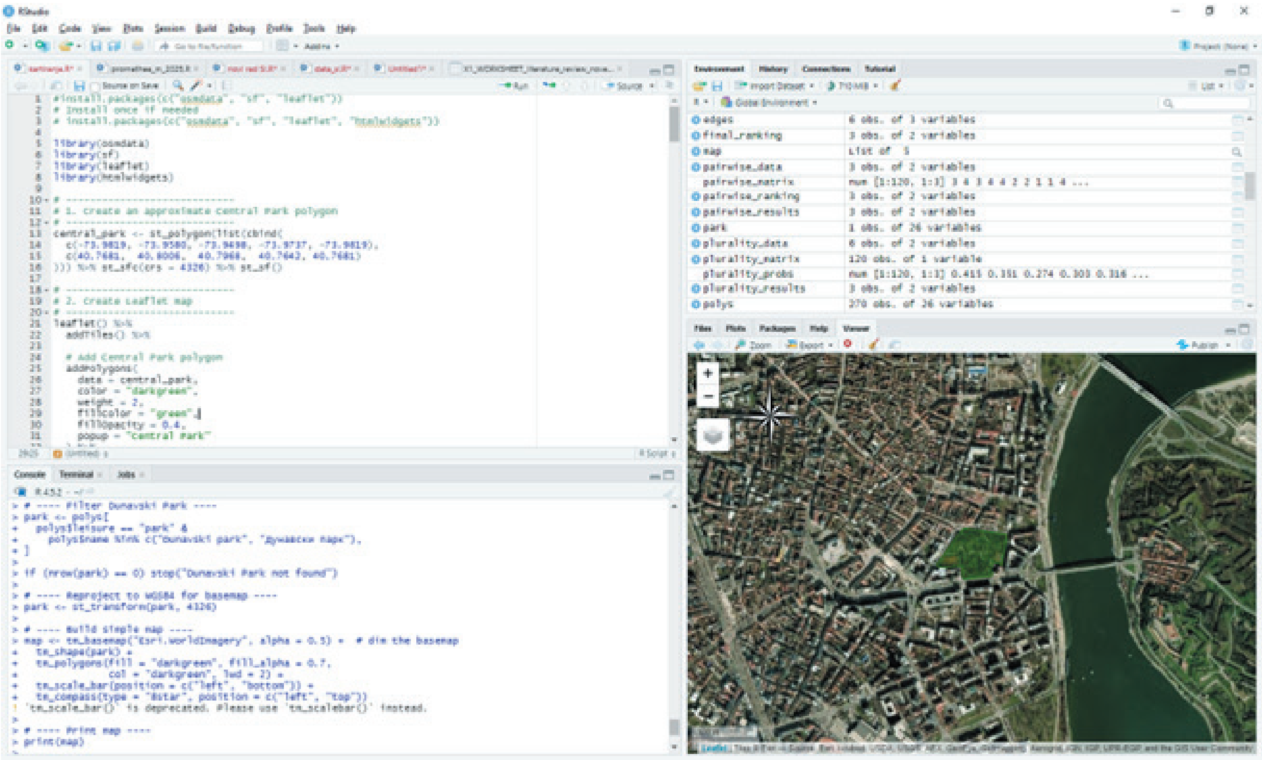
The examples presented in this paper encompass both numerical data processing and mapping, two analytical domains essential to landscape ecology studies. Numerical data processing was used to calculate biodiversity indices and summarize ecological patterns across different habitat types. Spatial analysis and mapping were applied to visualize the distribution of habitats of protected species and generate species-specific distribution maps.

3. RESULTS

3.1. BIODIVERSITY INDEX CALCULATION

This section examines the application of the R programming environment, with particular emphasis on the vegan package [8], for the calculation of biodiversity indices in urban parks in Novi Sad, modified from [9]. Three of these parks - Danube, Kamenica, and Futog - are protected as natural monuments, and monitoring their biodiversity status is therefore highly important. Biodiversity indices are typically calculated using alpha and beta diversity indices. Alpha diversity quantifies the diversity of species within a single site or habitat, providing insight into the richness and evenness of local species communities. Beta diversity, on the other hand, measures the difference or turnover in species composition between two sites, allowing for comparisons across habitats and the assessment of ecological variation at the landscape level. Within each park, alpha diversity was quantified through multiple indices to capture different aspects of community structure. Species richness provided a basic count of taxa, while Shannon and Simpson indices accounted for both species abundance and evenness. Berger–Parker dominance highlighted the relative contribution of the most abundant species, and Fisher's alpha offered a parametric measure of diversity that is less sensitive to sample size. Calculations were performed using vegan's *diversity*() function for Shannon and Simpson, *fisher.alpha*() for Fisher index, whereas Berger–Parker index and species richness were derived using dedicated R scripts. Table 1 presents the alpha diversity indices for dendroflora in Danube, Futog, and Kamenica parks.

The table indicates generally high levels of woody plant diversity across all three urban habitat sites. Among them, Futog Park exhibits the highest species richness (99 species) and the highest Shannon (3.752) and Fisher (18.895) indices, indicating the greatest overall diversity and taxonomic richness. Danube Park follows closely, with slightly lower but still high diversity values (Shannon = 3.574; Fisher = 17.143), reflecting a well-balanced species composition. Kamenica Park shows comparable richness (87 species) and diversity (Shannon = 3.514), though its Fisher index (15.625) suggests somewhat lower expected taxonomic richness relative to the other two parks. Simpson index values are consistently high in all parks (0.956–0.964), indicating a relatively even distribution of individuals among species and the absence of extreme dominance. The Berger–Parker index values (0.083–0.094) further confirm low dominance levels, although Kamenica Park shows slightly higher dominance compared to Danube and Futog. Overall, the results suggest that all three urban parks maintain substantial dendrofloristic diversity, with Futog Park demonstrating the highest biodiversity value among them.



```
#install.packages(c("osmdata", "sf", "leaflet"))
# install once if needed
# install.packages(c("osmdata", "sf", "leaflet", "htmlwidgets"))

library(osmdata)
library(sf)
library(leaflet)
library(htmlwidgets)

# ---------------------------------
# 1. Create an approximate Central Park polygon
# ---------------------------------
central_park <- st_polygon(list(cbind(
  c(-73.9819, -73.9580, -73.9498, -73.9737, -73.9819),
  c(40.7681,  40.8006,  40.7968,  40.7642, 40.7681)
))) %>% st_sfc(crs = 4326) %>% st_sf()

# ---------------------------------
# 2. Create Leaflet map
# ---------------------------------
leaflet() %>%
  addTiles() %>%

  # Add Central Park polygon
  addPolygons(
    data = central_park,
    color = "darkgreen",
    weight = 2,
    fillColor = "green",
    fillOpacity = 0.4,
    popup = "Central Park"
```

```
> # ---- Filter Dunavski Park ----
> park <- polys[
+   polys$leisure == "park" &
+     polys$name %in% c("Dunavski park", "Дунавски парк"),
+ ]
>
> if (nrow(park) == 0) stop("Dunavski Park not found")
>
> # ---- Reproject to WGS84 for basemap ----
> park <- st_transform(park, 4326)
>
> # ---- Build simple map ----
> map <- tm_basemap("Esri.WorldImagery", alpha = 0.5) +  # dim the basemap
+   tm_shape(park) +
+   tm_polygons(fill = "darkgreen", fill_alpha = 0.7,
+               col = "darkgreen", lwd = 2) +
+   tm_scale_bar(position = c("left", "bottom")) +
+   tm_compass(type = "8star", position = c("left", "top"))
! `tm_scale_bar()` is deprecated. Please use `tm_scalebar()` instead.
>
> # ---- Print map ----
> print(map)
```

```
edges                 6 obs. of 3 variables
final_ranking         3 obs. of 2 variables
map                   List of 5
pairwise_data         3 obs. of 2 variables
  pairwise_matrix     num [1:120, 1:1] 3 4 3 4 4 2 2 1 1 4 ...
pairwise_ranking      3 obs. of 2 variables
pairwise_results      3 obs. of 2 variables
park                  1 obs. of 26 variables
plurality_data        6 obs. of 2 variables
plurality_matrix      120 obs. of 1 variable
  plurality_probs     num [1:120, 1:1] 0.415 0.351 0.274 0.303 0.316 ...
plurality_results     3 obs. of 2 variables
polys                 270 obs. of 26 variables
```

Figure 1. RStudio integrated development environment (IDE) interface used for data analysis

Table 1. Alpha Diversity Indices of Dendroflora in Protected Urban Parks in Novi Sad

Habitat – urban park	Richness	Shannon index	Simpson index	Berger-Parker index	Fisher i ndex
Danube park	85	3.574	0.958	0.083	17.143
Futog park	99	3.752	0.964	0.087	18.895
Kamenica park	**87**	**3.514**	**0.956**	**0.094**	**15.625**

Beta diversity among all major urban parks was assessed using Jaccard dissimilarity index, implemented via the *vegdist*() function, providing quantitative insight into differences in species composition. To facilitate interpretation, graphical outputs were generated in R, i.e. heatmaps visualized beta diversity, highlighting compositional similarities and differences on different sites. This approach allowed the study to quantify and visualize diversity in a reproducible manner, emphasizing both numerical and graphical aspects of dendrofloristic variation in the protected urban parks. In the paper, the pairwise Jaccard index values between the parks were visualized as a heatmap, with each cell representing the dissimilarity between two parks and color intensity reflecting the magnitude of the value. Numerical values were also included in each cell to aid interpretation. This graphical representation allows for a clear comparison of biodiversity patterns among these ecologically important sites (Figure 2).

The Jaccard dissimilarity results show that Danube Park and Futog Park have the greatest similarity in dendrofloristic composition among the three parks analyzed (distance = 0.414), suggesting these two parks share a relatively high proportion of woody plant species. This could reflect a similar design history, planting practices, and environmental conditions in both parks. In contrast, Kamenica Park differs more substantially in species composition from the Railway park (Jaccard distances ≈0.72), indicating a more distinct set of species. This dissimilarity is likely due to Kamenica's unique location, ecological conditions, and possibly remnants of more natural woodland elements that are less represented in the more centrally located parks. The analyses provide a detailed overview of species diversity within and between urban parks in Novi Sad and inform tailored management and conservation guidelines. By quantifying alpha and beta diversity, key habitats and areas of unique species composition are identified, supporting evidence-based decisions for biodiversity conservation and sustainable urban park management.

3.2. MAPPING OF PROTECTED AREAS

Figure 3 shows shows the borders of Fruška Gora National Park, using ggmap package and satellite as a basemap.

Satellite maps offer high-resolution visual context, which helps in accurately displaying protected areas and geographic features. In addition to satellite imagery, the *ggmap* package in R provides several other map types that can serve as base maps, each with specific characteristics. The "terrain" map highlights natural features such as mountains, forests, and elevation contours, making it suitable for topographic analyses. The "roadmap" type emphasizes roads and urban areas, which is useful for studies focused on human infrastructure. For minimalist or high-contrast representations, stamen maps offer "toner" and "toner-lite" styles, which are ideal for printing or visual clarity. The "watercolor" style provides an artistic and visually appealing background, though it is less precise for quantitative analyses. Finally, "satellite-hybrid" combines realistic satellite imagery with labels, allowing both geographic context and place names to be visible. These options enable researchers to choose the most appropriate base map based on the study's objectives and the desired level of detail.

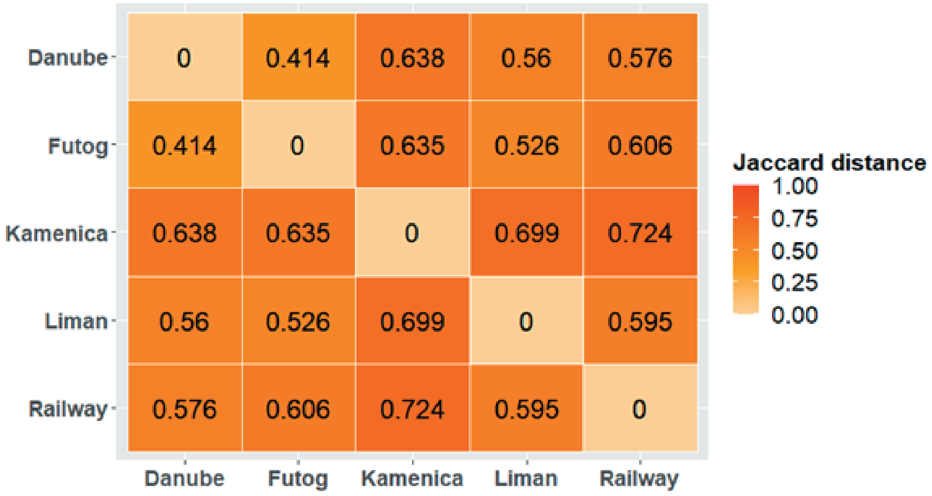


Figure 2. Heatmap of pairwise Jaccard dissimilarity index among urban parks in Novi Sad [9]

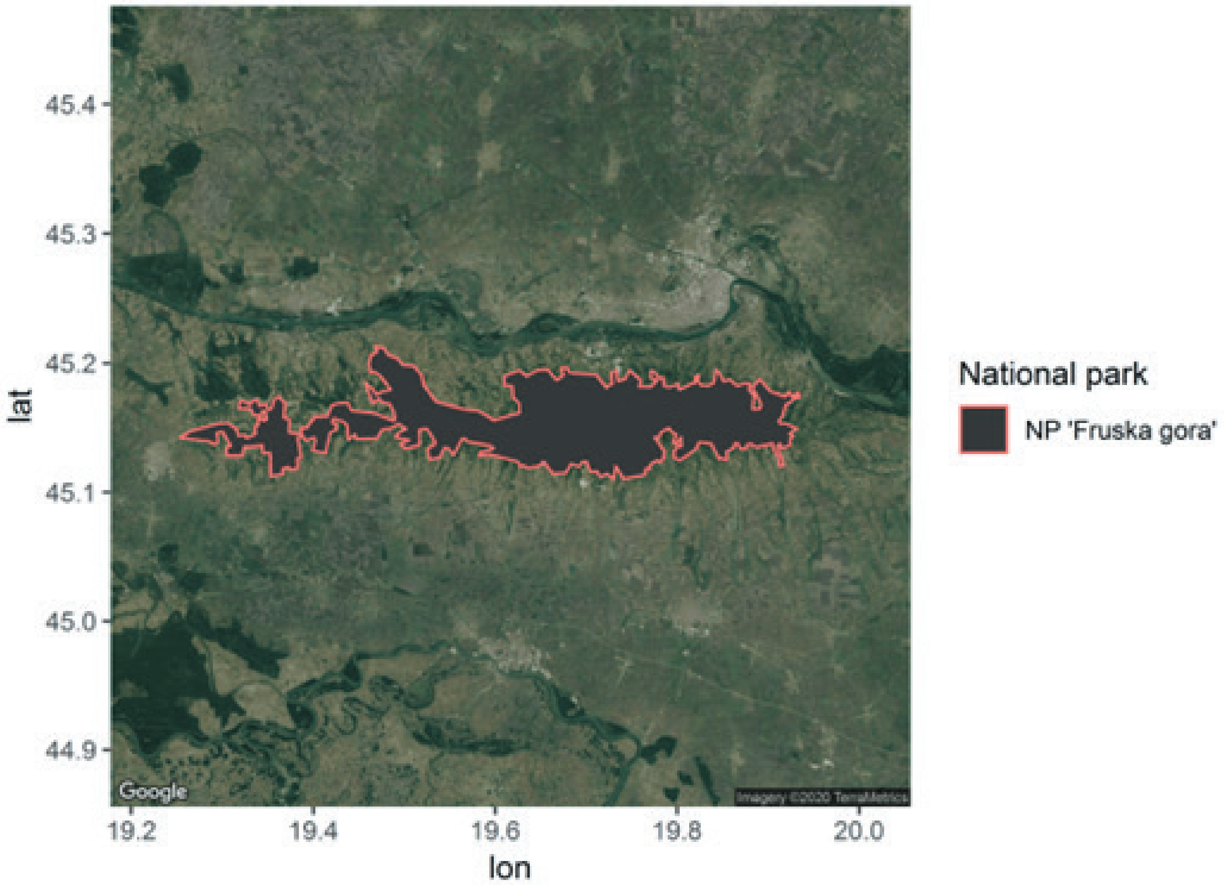


Figure 3. Fruška Gora National Park, *ggmap* Package [10]

3.3. MAPPING OF PROTECTED HABITATS

The analysis performed in one book chapter [11] will be presented here as a clear and practical example of how the R programming language can be applied for spatial visualization in ecological and conservation studies. Focusing on two endemic plant species in Serbia (*Ramonda serbica* Panč. and *Ramonda nathaliae* Panč. et Petrov.), the authors illustrate how species occurrence data can be mapped using manually entered geographic coordinates, without relying on specialized R packages or existing databases. For these analyses, the geographic coordinates of the study species were extracted from published literature sources [12]. This approach is particularly suitable for small datasets and field-collected data, making it relevant for researchers and practitioners working in data-limited contexts. Using the *facet*() function in R, we obtained separate maps showing the occurrence of *R. serbica, R. nathaliae*, and the areas where the habitats of these two species overlap. This approach allows for a clear visual comparison of species distributions and highlights regions of co-occurrence (Figure 4).

The nest analyses performed in R incorporated spatial clustering methods, enabling the identification of distinct geographic population groups based on the proximity of occurrence records. The spatial distribution of *Ramonda serbica* in Serbia reveals two clearly differentiated geographic clusters, corresponding to western and eastern population groups, indicating a pronounced spatial structuring of the species across its national range (Figure 5).

To identify spatial structure within the occurrence dataset, cluster analysis was performed in R using geographic coordinates (latitude and longitude) of recorded populations. R provides robust statistical and spatial analysis tools that allow grouping of sampling points based on geographic proximity. By applying clustering algorithms to the coordinate data, distinct population groups were detected and subsequently visualized on the map using confidence ellipses to highlight the spatial separation between western and eastern clusters.

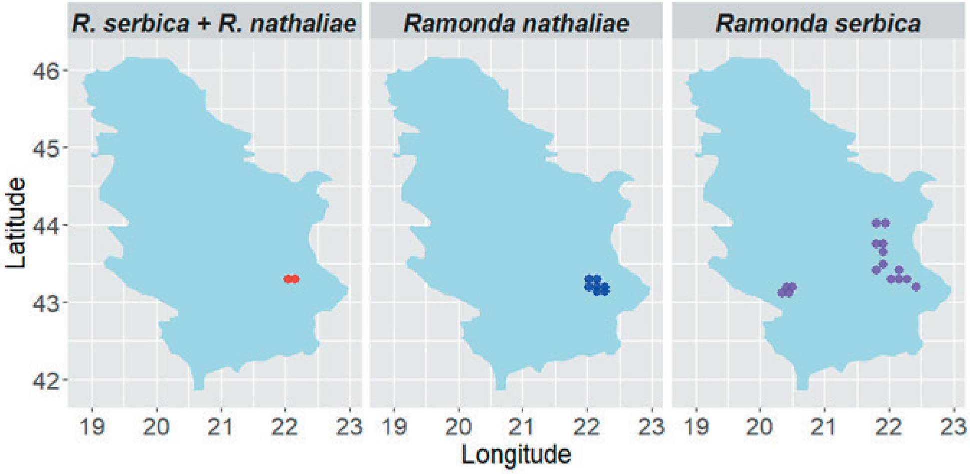


Figure 4. Occurrence maps of endemic species in Serbia: (a) *Ramonda serbica*, (b) *Ramonda nathaliae*, and (c) overlapping habitats of both species [11]

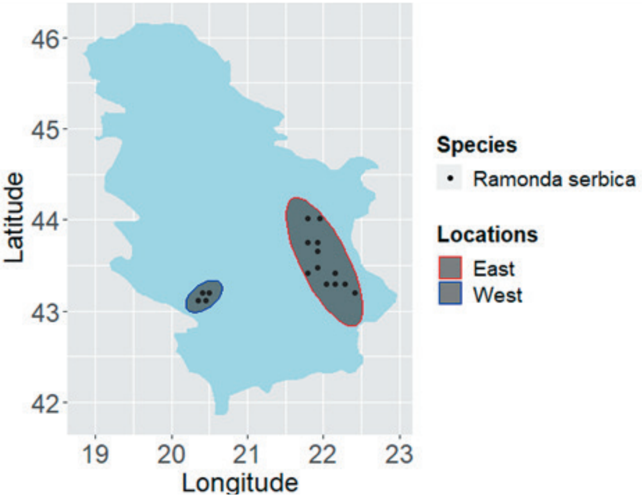


Figure 5. Cluster analysis of *Ramonda serbica* occurrence records in Serbia[11]

4. Conclusion

The use of R for managing protected areas, as well as monitoring habitats of protected species and individual plant specimens designated as natural monuments, is still in the early stages in Serbia. Nevertheless, initial applications have already demonstrated their versatility and strength for spatial and ecological analyses. In particular, R enables the detailed mapping of individual protected plant specimens and the habitats in which they occur, allowing researchers to visualize distributions at multiple scales. Advanced visualization techniques, such as facet maps, make it possible to compare different species or protected areas side by side, while clustering and spatial aggregation analyses can reveal patterns of species co-occurrence, habitat fragmentation, or areas of high conservation value, supporting more targeted monitoring and management. Combined with the calculation of biodiversity indices, these approaches provide a comprehensive toolkit for quantifying species diversity, evaluating ecological patterns, and tracking changes over time, all within a reproducible and flexible framework.

Looking ahead, the application of multi-criteria (MC) analysis in R offers a promising avenue for advancing landscape ecology research and conservation planning. In particular, MC approaches can help integrate spatial data, ecological variables, and management objectives to evaluate trade-offs, prioritize areas for protection, and guide landscape-level decision-making [13]. Packages such as *RMCDA* provide tools for systematic decision support, which, when combined with R's capacity for spatial and statistical analysis, can enable more holistic assessments of landscapes, species habitats, and ecological networks [14]. Incorporating MC analyses in future studies could thus enhance conservation strategies by providing structured, data-driven frameworks for prioritizing interventions and optimizing resource allocation across complex ecological landscapes.

5. ACKNOWLEDGEMENTS

The research funds were provided by the Ministry of Science, Technological Development and Innovation under Contract No. 451-03-34/2026-03/200117, dated 5 February 2026.

REFERENCES

[1] J. Lai, D. Cui, W. Zhu and L. Mao, "The use of R and R packages in biodiversity conservation research," *Diversity*, vol. 15, no. 12, p. 1202, 2023.

[2] M. Gao, Y. Ye, Y. Zheng and J. Lai, "A comprehensive analysis of R's application in ecological research from 2008 to 2023," *Journal of Plant Ecology*, vol. 18, no. 1, p. rtaf010, 2025.

[3] M. H. K. Hesselbarth, J. Nowosad, J. Signer and L. J. Graham, "Open-source tools in R for landscape ecology," *Current Landscape Ecology Reports*, vol. 6, p. 66–79, 2021.

[4] A. J. Davis and S. Kay, "Writing statistical methods for ecologists," *Ecosphere*, vol. 14, p. e4539, 2023.

[5] M. Lakićević, "Creating maps in R (Case study: National Park 'Fruška Gora')," *Contemporary Agriculture*, vol. 70, no. 1-2, p. 41–45, 2021.

[6] S. Vignali, A. G. Barras, R. Arlettaz and V. Braunisch, "SDMtune: An R package to tune and evaluate species distribution models," *Ecology and Evolution*, vol. 10, no. 20, p. 11488–11506, 2020.

[7] J. Lai, D. Cui, W. Zhu and L. Mao, "The use of R and R packages in biodiversity conservation research," *Diversity*, vol. 15, no. 12, p. 1202, 2023.

[8] J. Oksanen, F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs and H. Wagner, "vegan: Community Ecology Package. R package version 2.6-4.," https://CRAN.R-project.org/package=vegan, 2022.

[9] M. Lakićević, K. M. Reynolds, S. Orlović and R. Kolarov, "Measuring dendrofloristic diversity in urban parks in Novi Sad (Serbia)," *Trees, Forests and People*, vol. 8, no. doi: 10.1016/j.tfp.2022.100239, p. 100239, 2022.

[10] M. D. Lakićević, "Program R in mapping of protected natural assets in Serbia," *Zbornik Matice srpske za prirodne nauke*, vol. 139, p. 115–122, 2020.

[11] M. Lakićević, N. Povak and K. M. Reynolds, Introduction to R for terrestrial ecology: basics of numerical analysis, mapping, statistical tests and advanced application of R, Cham, Switzerland: Springer, 2020.

[12] T. Rakić, M. Lazarević, Ž. S. Jovanović, S. Radović, S. Siljak Yakovlev, B. Stevanović and V. Stevanović, "Resurrection plants of the genus Ramonda: prospective survival strategies – unlock further capacity of adaptation, or embark on the path of evolution?," *Frontiers in Plant Science*, vol. 4, no. doi: 10.3389/fpls.2013.00550., p. 550, 2014.

[13] B. A. Esmail and D. Geneletti, "Multi criteria decision analysis for nature conservation: A review of 20 years of applications," *Methods in Ecology and Evolution*, vol. 9, no. 1, p. 42–57, 2018.

[14] A. Najafi and S. Mirzaei, "RMCDA: The comprehensive R library for applying multi criteria decision analysis methods," preprint, [Online]. Available: https://arxiv.org/abs/2502.08677, 2025.