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GIS-BASED SCREENING OF ROAD-INDUCED SPATIAL FRAGMENTATION IN NATURA 2000 SITES IN ROMANIA

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Abstract

Road infrastructure can alter the spatial continuity of protected areas by subdividing habitat blocks and increasing edge-related pressures. This study aims to assess road-induced structural (spatial) fragmentation - derived from GIS analysis rather than from measures of functional ecological connectivity - in Natura 2000 sites in Romania using a GIS-based screening approach focussed on motorways, express roads and national roads. Natura 2000 site boundaries were overlaid with the major road network to identify crossed sites, quantify the number of road segments located within each site, and analyse the spatial distribution and area of the resulting fragments in selected highly affected sites. The analysis showed that 119 out of 232 Natura 2000 sites were crossed by at least one major road segment, while several were traversed by multiple segments. Four sites were selected for detailed interpretation: ROSCI0290 Ialomița Corridor, ROSAC0162/ROSPA0071 Lower Siret Floodplain, ROSCI0206 Porțile de Fier/ROSPA0080 Almăjului-Locvei Mountains and ROSPA0091 Babadag Forest. Although the study does not quantify direct ecological effects, it provides a spatial screening framework that can support field surveys, roadkill monitoring, connectivity assessment and mitigation planning.

Key words: *ecological connectivity, GIS, Natura 2000, road infrastructure, spatial fragmentation.*

INTRODUCTION

Road infrastructure is one of the most widespread forms of linear infrastructure and can produce important changes in habitat continuity. Roads generate direct habitat loss, edge effects, noise, light pollution, wildlife mortality, barriers to movement and increased human access. These effects may extend beyond the physical footprint of the road and can influence the functional integrity of protected areas.

In landscape ecology, fragmentation is not limited to the geometric division of a polygon. It has a structural component, related to the size, number and distribution of fragments, and a functional component, related to species movement, permeability and ecological connectivity. Road networks are therefore frequently treated as drivers of both landscape subdivision and ecological isolation.

Classical road ecology studies have shown that roads may have ecological effects disproportionate to the area that they occupy (Forman & Alexander, 1998; Trombulak & Frissell, 2000). Later reviews emphasised that roads affect species abundance, behaviour and population persistence through multiple pathways, including mortality, avoidance and reduced connectivity (Coffin, 2007; Fahrig & Rytwinski, 2009; Benítez-López et al., 2010).

In protected areas, the issue is particularly important because legal designation does not automatically guarantee ecological coherence. Natura 2000 sites are designated for the conservation of habitats and species of Community interest, but their spatial continuity may be affected where major roads cross or dissect protected landscapes. European studies have used GIS-based approaches to assess the role of roads and roadless areas in protected networks, including Natura 2000 sites (Selva et al., 2011; Votsi et al., 2012; Zomeni & Vogiatzakis, 2014; Kati et al., 2020).

However, these studies have largely addressed roadlessness and road density at continental scale or within individual Mediterranean countries, and have generally treated protected areas as units characterised by an aggregate

pressure index rather than as geometries physically subdivided by infrastructure.
Furthermore, no comparable screening exists for Romania, which hosts one of the largest and most biodiverse Natura 2000 networks in the EU. The present study addresses this gap by quantifying road-induced structural fragmentation across all Romanian Natura 2000 sites and by identifying the most affected sites as priorities for subsequent field-based and functional connectivity assessment.
The present study does not aim to demonstrate direct ecological impacts on species or habitats, because it does not include field surveys, roadkill monitoring, telemetry, species movement data or habitat-quality measurements. Instead, it provides a GIS-based spatial screening of potential road-fragmentation pressure in Natura 2000 sites in Romania. The purpose is to identify where the major road network crosses protected areas and where more detailed ecological assessment may be justified.

MATERIALS AND METHODS

Study scope

The study was designed as a GIS-based screening of road-induced spatial fragmentation in Natura 2000 sites. The analysis focused on the geometric relationship between protected-area boundaries and the major road network. Results were interpreted as spatial indicators of potential pressure and not as confirmed biological impacts.

Spatial data and coordinate reference system

Two spatial datasets were used. The boundaries of the Romanian Natura 2000 sites (Sites of Community Importance/Special Areas of Conservation and Special Protection Areas) were obtained from Ministry of Environment, Waters and Forests - Romania, https://mmediu.ro/portal-gis/date-spatiale/arii-naturale-protejate-de-interes-national-si-international/, downloaded on 15.01.2025. The major road network of Romania was obtained from geo-spatial.org, https://geo-spatial.org/vechi/download/re-eaua-rutiera-na-ionala-a-romaniei-set-de-date-vectorial, downloaded on 16.01.2025. From the road dataset, only the categories relevant to the present screening were retained, namely motorways, express roads and national roads; county roads, communal roads and forest roads were excluded. The source geometries were not edited, generalised or topologically corrected, in order to preserve the reproducibility of the results against the original datasets. All spatial layers used for area calculations were processed in the Romanian national projected coordinate reference system Stereo 70 (EPSG:3844). This metric coordinate system is suitable for calculating areas and distances on Romanian territory.

Operational definition of fragmentation

For this study, road-induced fragmentation was defined operationally as the intersection of a Natura 2000 site by one or more motorway, express-road or national-road segments, resulting in the spatial subdivision of the protected-area polygon into two or more fragments. This definition captures spatial fragmentation and should not be interpreted as a direct measure of ecological isolation or species-level impact.

GIS workflow

• all spatial analyses were performed in QGIS Desktop 3.12.1.
• harmonisation of spatial datasets in Stereo 70 / EPSG:3844;
• selection of the major road categories: motorways, express roads and national roads;
• overlay of the major road network with Natura 2000 site boundaries;
• identification of sites crossed by at least one major road segment;
• counting of major road segments crossing each Natura 2000 site (i.e. the road sections resulting from the intersection of the road network layer with the site polygon, located within the site boundary);
• spatial subdivision of selected sites into fragments obtained by splitting the site polygon with the major road segments located inside it;
• calculation of fragment areas in hectares;
• selection of highly subdivided sites for detailed cartographic interpretation;
For the selected case-study sites, the conservation-management context was also cross-checked with official Romanian conservation documents, including ANANP Decision No. 125/2022 for the Lower Siret

Floodplain and ANANP Decision No. 144/2021 for the Porțile de Fier site, together with the official ministerial notes on minimum conservation measures for Ialomița Corridor and Babadag Forest (ANANP, 2021, 2022; Ministry of Environment, Waters and Forests, 2021, 2023).

Screening indicators

The analysis was based on four indicators, all derived exclusively from the GIS overlay: (i) the number of Natura 2000 sites crossed by the major road network; (ii) the number of major road segments located within each site; (iii) the number of fragments resulting from the subdivision of the selected case-study sites; and (iv) the area of the largest and smallest fragment in each selected site.

Supporting contextual information

Conservation-status information was not used as a screening indicator. It was consulted only as qualitative background for the interpretation of the four case-study sites and did not contribute to any calculation, to the ranking of sites or to the selection of the case studies. Conservation status was not used to infer causality between roads and species condition.

RESULTS AND DISCUSSIONS

National GIS screening of sites crossed by major roads

The GIS overlay indicated that the major road network intersects a substantial number of Natura 2000 sites in Romania. According to the source dataset, 119 out of 232 analysed sites were intersected at least once by a major road. This result indicates that the spatial overlap between the major road network and the Natura 2000 network is widespread at the national level. The ecological significance of this overlap cannot be inferred from the geometric analysis alone, and the presence of a major road segment within a site should therefore be interpreted as a spatial warning signal rather than as evidence of high ecological impact (Figure 1).

A second GIS layer isolated the road segments located inside Natura 2000 site boundaries, providing a clearer spatial view of the road sections located within protected-area boundaries (Figure 2).

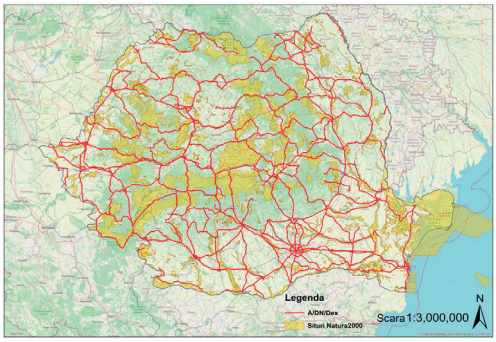


Figure 1. Natura 2000 sites crossed by the major road network in Romania

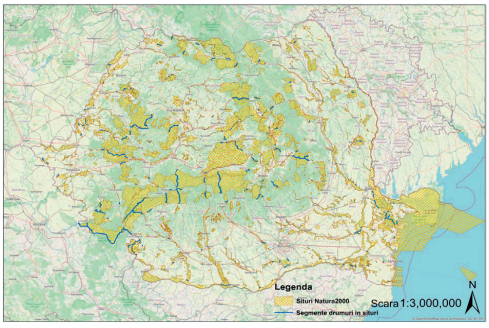


Figure 2. Major road segments located within Natura 2000 sites in Romania

Number of major road segments per site

The frequency distribution shows an uneven pattern of road-induced spatial subdivision. Most crossed sites contain one or two major road segments, whereas a smaller group of sites contains a larger number. Sites containing several road segments should be prioritised for detailed connectivity analysis because multiple crossings may reduce internal continuity and increase edge-related pressures (Figure 3).

Selected case-study sites

Four sites were selected for detailed spatial interpretation on the basis of two combined criteria. First, all four belong to the group of sites showing the highest number of major road segments identified in the national screening. Second, within this group the sites were selected so as to represent contrasting spatial configurations: a corridor-like protected area (ROSCI0290 Ialomița Corridor), a riparian system (ROSAC0162/ ROSPA0071 Lower Siret Floodplain), a large protected-area complex

(ROSCI0206 Porțile de Fier/ROSPA0080 Almăjului - Locvei Mountains) and a forested landscape (ROSPA0091 Babadag Forest). The selection is therefore illustrative of the most subdivided group of sites and of the diversity of geometric situations encountered, and it does not constitute an exhaustive ranking of the most fragmented sites in the national network.

Two distinct quantities are reported for each case-study site. The number of major road segments located within the site boundary was obtained by intersecting the road network layer with the site polygon, whereas the number of fragments was obtained separately by splitting the site polygon with those road lines. The two are not equivalent: a segment that fully traverses a site produces two fragments, a segment terminating inside the site produces none, and two segments intersecting within the same site may produce more than two. On this basis, the GIS screening identified 7 major road segments crossing the Ialomița Corridor, dividing the site into 9 fragments ranging from 59.59 to 11,078.09 ha; 7 segments within the Lower Siret Floodplain, giving 9 fragments of 58.16-17,413.10 ha; 7 segments within Porțile de Fier/Almăjului-Locvei Mountains, giving 7 fragments of 441.52-94,966.59 ha; and 5 segments within Babadag Forest, giving 6 fragments of 29.74-21,258.49 ha. The values reported for each case-study site refer to the number of major road segments located within the site boundary, obtained by intersecting the road network layer with the site polygon.

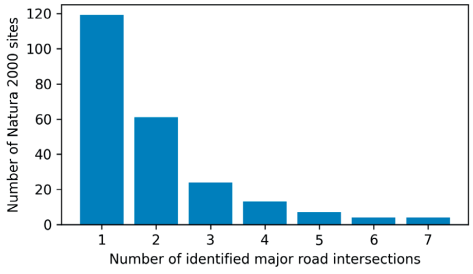


Figure 3. Distribution of Natura 2000 sites according to the number of major road segments located within the site boundary

The cartographic outputs for the selected sites show that multiple road segments may occur both in corridor-like sites and in large protected-area complexes. The maps also indicate strong differences in the spatial distribution of fragments, from narrow riparian sections to large habitat blocks (Figures 4-7).

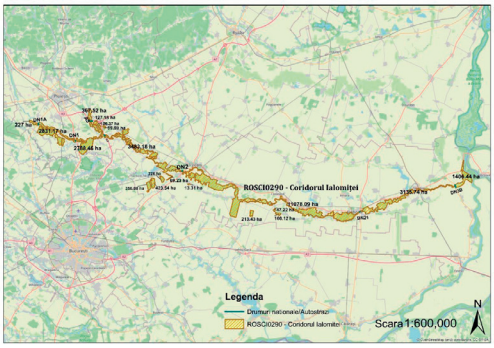


Figure 4. Road-induced spatial subdivision of ROSCI0290 Ialomița Corridor

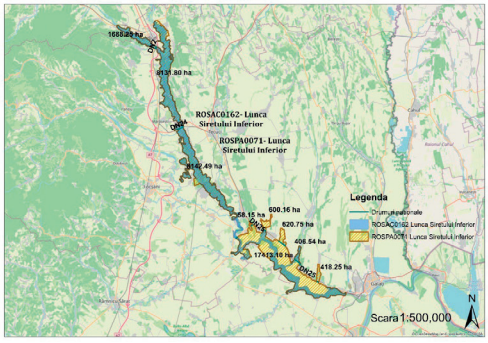


Figure 5. Road-induced spatial subdivision of ROSAC0162/ROSPA0071 Lower Siret Floodplain



Figure 6. Road-induced spatial subdivision of ROSCI0206 Porțile de Fier/ROSPA0080 Almăjului-Locvei Mountains



Figure 7. Road-induced spatial subdivision of ROSPA0091 Babadag Forest

Interpretation of fragment size and site geometry

The results indicate that the number of road crossings alone is not sufficient to characterise the degree of spatial subdivision of a site. Fragment-size distribution and site geometry are equally important. Corridor-like and riparian sites, such as Ialomița Corridor and Lower Siret Floodplain, may be particularly sensitive to transversal road crossings because such crossings can interrupt longitudinal continuity. Conversely, large protected-area complexes may retain extensive fragments but still require analysis of permeability, wildlife crossing opportunities and roadkill risk (Figure 8).

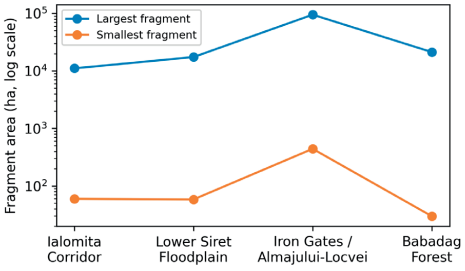


Figure 8. Contrast between the largest and smallest fragments in selected Natura 2000 sites

The contrast between the largest and smallest fragments is relevant for management. Very small fragments may be more exposed to edge effects, human access and functional isolation, even when their contribution to total site area is limited. Therefore, screening outputs should be interpreted together with local habitat maps, species data and field observations.

Conservation-status context

The conservation-status graphs and official conservation context were treated as supporting background, based on the available site-specific documents, including ANANP decisions for the Lower Siret Floodplain and Porțile de Fier sites and official ministerial notes for Ialomița Corridor and Babadag Forest (ANANP, 2021, 2022; Ministry of Environment, Waters and Forests, 2021, 2023). The available conservation-status information was not interpreted as proof of a causal relationship between road fragmentation and species condition. In some sites, the presence of unfavourable or unknown conservation status indicates that spatial fragmentation overlaps with areas already requiring conservation attention, but additional ecological data are necessary to assess biological effects (Figure 9).

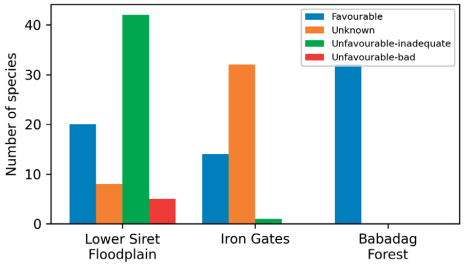


Figure 9. Conservation-status context for selected Natura 2000 sites, based on the values extracted from the existing graphs

Management relevance

The GIS screening can support Natura 2000 management by identifying sites where detailed ecological assessment is justified. Priority actions may include field verification of road-crossing zones, roadkill monitoring, permeability assessment, mapping of existing culverts and bridges, habitat-connectivity modelling and evaluation of the need for wildlife passages or ecological bridges.

The approach is particularly useful as a preliminary planning tool because it is transparent, reproducible and based on spatial layers that can be updated as road networks or protected-area boundaries change. However, it should be complemented by ecological surveys before site-specific mitigation measures are designed.

CONCLUSIONS

This study provides a GIS-based screening of road-induced spatial fragmentation in Romanian Natura 2000 sites. The analysis shows that a substantial number of sites are crossed by the major road network and that several sites are divided into multiple fragments. These findings do not demonstrate direct ecological impact, but identify the sites in which the geometry of the protected area is subdivided by the major road network, and in which a subsequent assessment of habitat continuity and of functional ecological connectivity would therefore be justified. Whether this structural subdivision translates into a reduction of functional connectivity can only be established through species-specific data on movement, permeability and mortality, which fall outside the scope of the present screening.

The selected case studies show that the degree of spatial subdivision depends not only on the number of road crossings, but also on-site geometry and on the size distribution of resulting fragments. The results can support the prioritization of detailed ecological surveys, roadkill monitoring, connectivity modelling and mitigation planning in Natura 2000 management.

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