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Spatial Structure and Fragmentation Assessment of Forest Resources of the West Pomeranian Voivodeship and Mecklenburg-Vorpommern Regions

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Abstract:

Purpose: *This study examines the spatial structure and fragmentation of forest resources in two neighboring regions: the West Pomeranian Voivodeship (WP) in Poland and Mecklenburg-Vorpommern (MV) in Germany. The analysis seeks to identify differences in forest cover, property distribution, and the ecological consequences of fragmentation. The aim is to provide insights into the impact of natural and anthropogenic factors on the forested landscapes of these regions.*
Design/Methodology/Approach: *Using high-resolution raster data from the European Environment Agency, the study employed GUIDOS software for analyzing forest fragmentation through methods like Foreground Area Density (FAD) and Morphological Spatial Pattern Analysis (MSPA), identifying structural classes, core areas, and isolated fragments.*
Findings: *WP has greater forest cover (35.4%) compared to MV (24%) and larger contiguous forest complexes with better habitat connectivity. MV, however, is more fragmented, with smaller patches and higher private ownership. Both regions are dominated by small patches (<1 ha), which constitute most patches but cover a minor portion of the area. WP forests are primarily state-managed pine monocultures, while MV features more deciduous species.*
Practical Implications: *Conservation strategies should focus on creating ecological corridors, protecting large forest patches, and managing land use to enhance biodiversity and resilience. These efforts are particularly critical for the more fragmented MV region.*
Originality/Value: *This study provides a novel comparison of forest fragmentation between transboundary regions with shared history but differing management practices, offering valuable insights and a robust framework for forest conservation at multiple scales.*

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1. Introduction

Forest fragmentation, understood as the division of continuous forest areas into smaller fragments with limited connectivity, is a characteristic phenomenon in the modern landscape, and an important ecological and economic problem (Gimmi *et al*., 2011; Jaeger and Fahrig, 2004).

It is a consequence of anthropogenic and natural changes in the structure of land use and it assumed great intensity in central Europe after World War II, as a result of demographic and economic changes, especially due to planned afforestation campaign, which resulted in an increase in forest cover in the second half of the 20th century (Pienkowski and Podlasinski, 2002).

Mecklenburg-Vorpommern (MV) and the West Pomeranian Voivodeship (WP) are neighboring regions in Germany and Poland, linked by a common history of former Pomeranian Duchy. They are also characterized by similar physiographic conditions as young post-glacial areas with varied landscapes .

This article will discuss the spatial aspects of forest cover structure and fragmentation in the neighbouring regions as a result of agricultural activities, development of linear infrastructures and intensive urbanization, which results in the division of forest areas into smaller, isolated fragments (Bohn *et al*., 2000; Gimmi *et al*., 2011).

2. Literature Review

Fragmentation of forest stands is considered one of the most serious threats to forest biodiversity, as it limits the possibility of species migration, reduces their populations and leads to local extinctions, especially among species with specific territorial requirements (Jaeger and Fahrig, 2004).

In the context of changing climatic conditions, the spatial coherence of forest complexes in both regions becomes crucial for the adaptation of species to new conditions and for maintaining the stability of forest ecosystems (Grodzki, 2020). Forest fragmentation in Europe has important ecological consequences.

It leads to the creation of smaller, isolated forest fragments surrounded by non-forest areas, which significantly affects species diversity, migration opportunities, habitat conditions and species interactions (Annals of Forest Science, 2020). In smaller and more isolated forest fragments with reduced biodiversity, landscapes became more susceptible to the emergence of invasive species and ecological degradation (Estreguil *et al*., 2012).

Fragmentation strongly affects the so-called functional diversity of forests, that is, the diversity of traits related to resource use, reproduction strategies and resilience.

Fragmented forests are dominated by plants that prefer edge areas, which show rapid growth and are resistant to changing environmental conditions, limiting the availability of habitat for more specialized or needing core areas forest species (PLOS ONE, 2020). Such an arrangement leads to reduced ecosystem stability and reduced ecosystem services, such as carbon storage, pollination, or soil stabilization, which are typically provided by more diverse and mature forest ecosystems (Estreguil *et al.*, 2012).

One of the main effects of forest fragmentation is so-called edge effects, where transitions between forest and open areas increase the exposure of forest interiors to wind, temperature fluctuations and the presence of invasive species. The edges of forest fragments experience different microclimatic conditions than forest interiors, which can lead to changes in vegetation structure and composition. Edge areas experience the development of invasive plant species that displace native flora, further altering forest ecosystems and creating a vicious cycle that exacerbates the loss of biodiversity (Fahrig, 2003).

Landscape indicators, have become a key tool in studies of the impact of fragmentation on forest ecosystems. Studies conducted between 1990 and 2012 have shown that smaller fragments and more isolated portions of forests are associated with significant declines in species richness and ecological connectivity, highlighting the need to implement conservation strategies to maintain ecosystem resilience (Hesselbarth *et al*., 2019).

The conclusions of fragmentation studies underscore the importance of maintaining spatial connectivity and implementing sustainable forest management practices to minimize the negative effects of fragmentation. Effective conservation approaches should include creating ecological corridors and tightening controls on land conversion practices, which can help preserve the spatial integrity and ecological functions of Europe's forests (Zuidema *et al.*, 1996).

The practical implementation of scientific research on fragmentation is perfectly evident in the strategy of establishing a network of protected areas in Europe, especially in the era of the establishment of Natura 2000 areas and the formulation of the principles of national conservation strategies.

3. Research Methodology

Analyses of forest area structure were based on the raster dataset Dominant Leaf Type 2018, prepared by the European Environment Agency, showing the layout of leaf and coniferous forests at 10m resolution (EEA, 2020). The Minimum Mapping Unit for this dataset is 0.5ha, which provides sufficient accuracy for large-scale analyses. The data distributed for each country was trimmed to the borders of the administrative units analyzed: West Pomeranian Voivodeship and the state of Mecklenburg - Vorpommern.

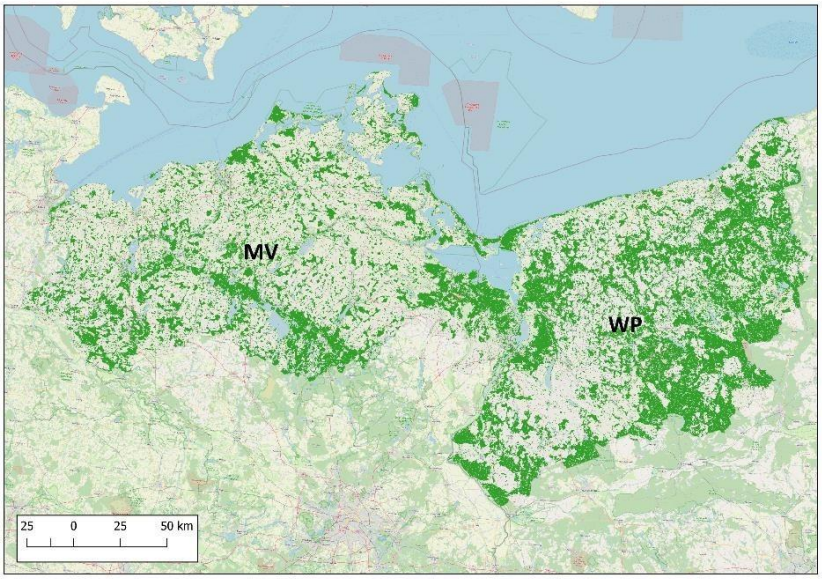
Analyses of the spatial structure of forest areas and fragmentation were performed using GUIDOS software (Vogt *et al.*, 2022), which prepared statistics of the abundance and distribution of forest patches.

Fragmentation analyses were made using the Foreground Area Density method, which used five observation scales for its moving window (with sizes of 70, 130, 270, 810, 2430m), as well as morphological segmentation analysis - MSPA (Soille and Vogt, 2008) with a full variant, distinguishing 4 background classes (background - non-forest areas, core - forest interiors, core opening - mid-forest clearings, border opening - midforest open clearings) and 6 structural classes (islet, perforation, edge, loop, branch, bridge).

4. Results

The characteristics of the forest cover of the two study regions show significant differences, despite similar physiographic characteristics (Table 1, Figure 1). The Polish region shows significantly higher forest cover and the absolute dominance of stateowned forests, managed by a nationwide institution, which is characteristic of Polish forests.

Figure 1. *Forest areas in Mecklenburg - Vorpommern (MV) and West Pomeranian Province (WP)*



Source: *Own elaboration*

Both regions are dominated by pine monocultures, but the proportion of deciduous stands is significant, with a much higher proportion in MV (Hartmann *et al.*, 2021). The area is dominated by mesotrophic, mixed forest habitats, but the proportion of

dry habitats located on various origins of dry sandy soils is also significant (Bundeswaldinventur, 2022). Dense, extensive forest areas in both regions are found in the lakeside regions: Mecklenburg Lake District, in the southern part of the MV, and Pomeranian Lake District, in the eastern part of the WP. These areas are characterized by the greatest variation in relief, high lakeiness and somewhat more difficult conditions for agricultural development.

Table 1. *General characteristics of forests in the studied regions*

Parameter	**Western Pomerania**	**Mecklenburg-Vorpommern**
Forest area	832,365 ha	600,000 ha,
Forest cover	35.4%	24%
Property	• State forests - 95.4% • Private forests - 2.8% • Communal forests - 1.2% • Other forms of ownership - 0.6%	• State forests (Landeswald) - 48% • Private forests - 40% • Municipal forests - 8% • Federal forests (Bundeswald) - 4%
Species structure	Pine dominance (61.1%), birch (10%), beech (7.9%) and oak (6.4%)	Predominance of pine (about 47%) and beech (35%)
Age stand	younger than 40 years old - 15% aged 40-80 years - 45% aged 81-100 years - 25% over 100 years old - 15%	younger than 40 years old - 15% aged 40-80 years - 48% aged 81- 100 years - 22% over 100 years old - 15%
Annual timber	approximately 4.5 million m³	Approximately 3 million m³
Protected area	8,867 hectares of forests in national parks, additional Natura 2000 areas	Forests in national parks (about 7,000 hectares) and nature reserves and Natura 2000
Changes in stands	An increase in the proportion of deciduous species, including oaks and birches, over the past decades	Increase in the proportion of oak and other deciduous species

Source: *Landesforst Mecklenburg-Vorpommern, 2022; Adamowski and Wrońska, 2022; Rößler & Schmidt, 2022.*

The analysed regions were characterized by significantly different characteristics of the distribution of patch sizes (Table 2). The average patch size in MV was only 1.93 hectares and 3.96 hectares in WP. The smallest sites were on the order of a fraction of a hectare (which was also due to the materials used and the classification algorithm), while the largest patches in MV, which included forest complexes in the Mecklenburg Lake District in the southern part of the area, covered almost 28,500 hectares.

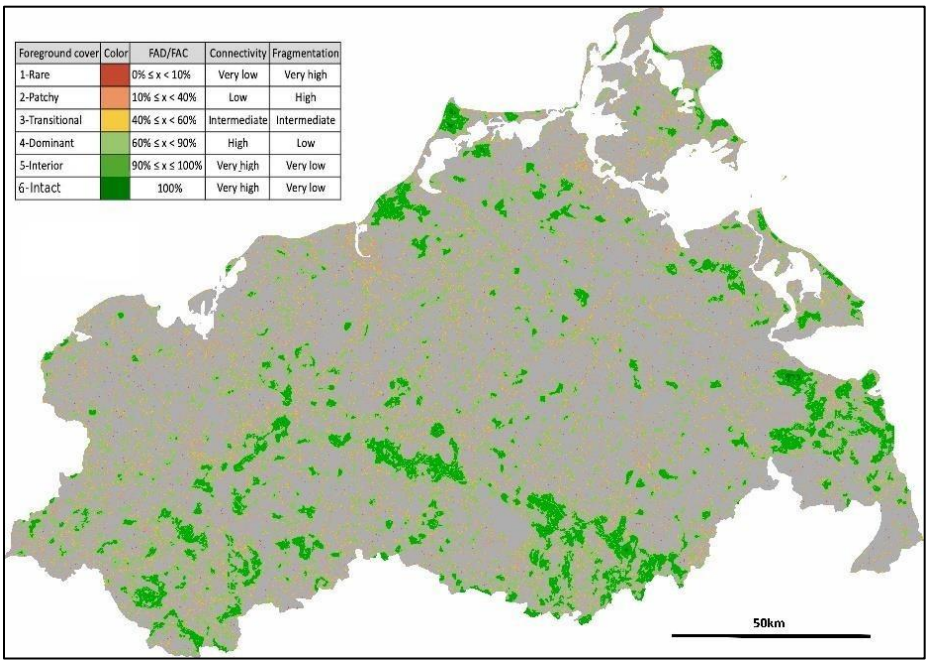
Largest fragments in WP region amounted to more than 433,000 hectares covering most of the complex seminatural forest complexes in the eastern part of the area. The fragmentation of forest stands is very high. Forested areas in MV included 322145 patches with a forest cover of about 24%, while in WP 23897 with a forest cover of about 36%.

Table 2. *Indicators describing the distribution of patch sizes in the studied regions (MV - Mecklemburg Vorpommern, WP - Western Pomerania).*

Size class [ha]	# Objects		Area [ha]		% of all objects		% of total forested area		
	MV	WP	MV	WP	MV	WP	MV	WP	
0.01 - 1	303439	223843	31013.2	23384.5	94.2	94.1	5.0	2.5	
1 - 5	13527	10603	28771.5	22591.0	4.2	4.5	4.6	2.4	
5 - 10	2172	1566	15136.6	10942.7	0.7	0.7	2.4	1.2	
10 - 50	2038	1376	42594.6	28737.5	0.6	0.6	6.8	3.0	
50 - 100	387	195	27167.0	14083.2	0.1	0.1	4.4	1.5	
>100	582	314	479715.2	842886.9	0.2	0.1	76.8	89.4	

Source: *Own elaboration.*

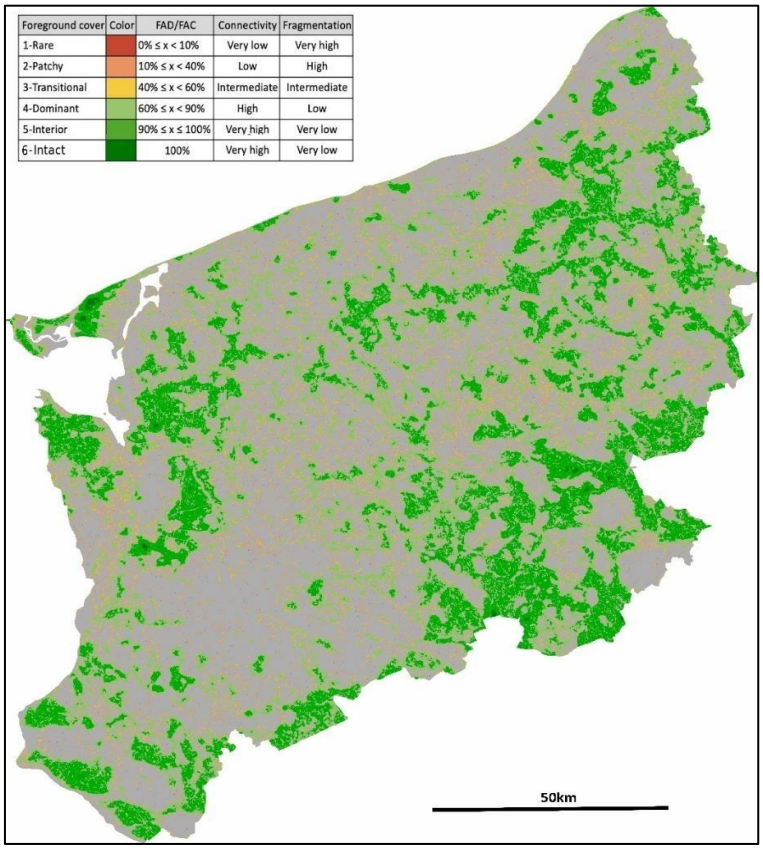
Figure 2. *Results of multiscale moving window Foreground Area Density (FAD) analysis for Mecklemburg-Vorpommern*



Source: *Own elaboration.*

Both regions were dominated by small forest patches with area of less than 1 ha, which accounted for about 94% of all patches, occupying only 5% of the forest area in MV and 2.5% in WP. In contrast, patches larger than 100 hectares covered a fraction of a percent of the abundance, but accounted respectively for 76 and 89% of forested area. Thus, for both regions, the results indicate the existence of a huge number of small forest patches (or rather, mid-field woodlots), representing a negligible percentage of the forested area, but making up the absolute majority of functioning patches.

Figure 3. *Results of multiscale moving window Foreground Area Density (FAD) analysis for Western Pomerania.*

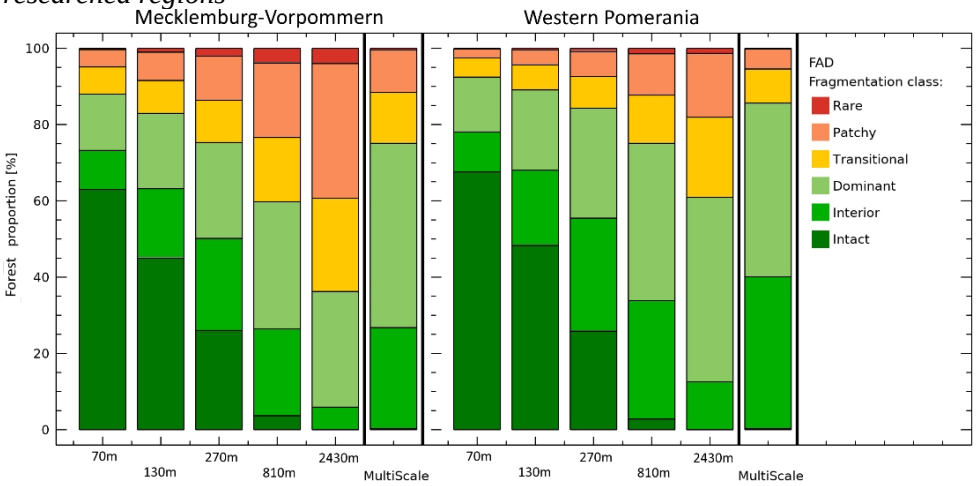


Source: *Own elaboration.*

The distribution of forest area classes indicating the degree of isolation (multiscale FAD analysis) is shown in Figures 2 and 3. The classes of patches here reflect the percentage of forest cover in the area of a moving window (umbrella) of a certain size (fig. 4) in the study area. What is noteworthy here is the structure of the location of forest areas in the three higher classes (dominant, interior, intact) in both study regions. In MV, they are located in the southern, lakeside part of the region, the eastern areas of the Uckerheide Forest and the island areas, with the great

fragmentation of tiny patches in the centrally located agricultural areas being equally important. . Western Pomerania, on the other hand, could be described by areas of the high value forests around the Szczecin metropolitan area (Wkrzanska, Goleniowska and Bukowa Forests) and the lakeside areas of the Drawa Forest. The distribution of classes here is strictly dependent on the scale of the survey and the size of the moving window, but the isolation of small forest patches is noticeably apparent, especially in MV region.

Figure 4. *Fragmentation classes as results of multiscale FAD analysis for researched regions*



Source: *Own elaboration.*

Table 3. *Results of Morphological Simplified Pattern Analysis (MSPA) classification of forested areas*

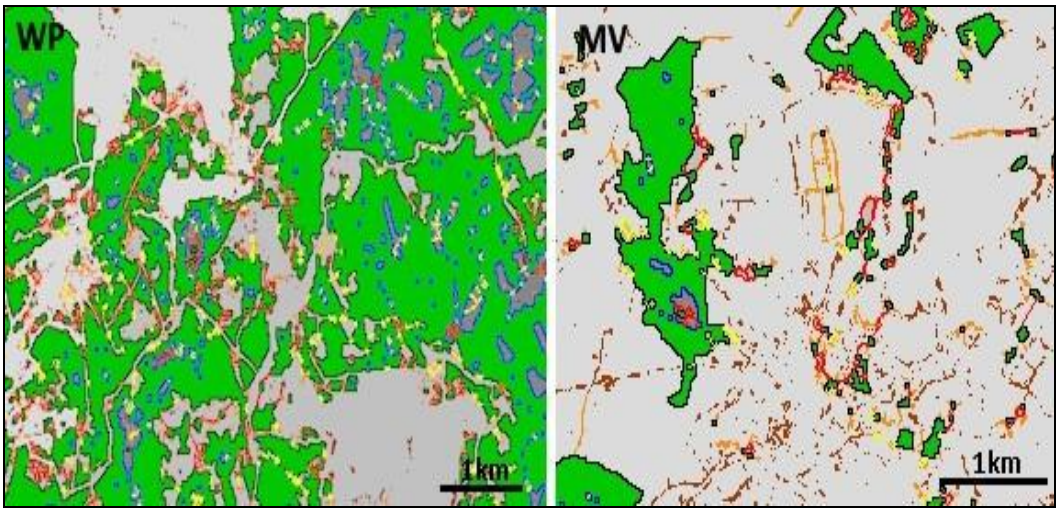
Morphological type and map color	MV	WP
	% of forested area	
Core:	68.36	73.47
Islet	6.49	2.92
Perforation:	3.00	6.52
Edge:	15.06	11.58
Loop:	0.92	0.94
Bridge:	1.51	1.21
Branch:	4.66	3.36

Source: *Own elaboration.*

Fragmentation processes are also reflected in the results of the MSPA morphological forest area type classifications (Table 3). They indicate a higher proportion of core areas in West Pomerania (less fragmentation, presence of many large patches) and a higher proportion of islet, edge, branch, bridge classes in Mecklenburg, indicating the existence of very numerous areas with shapes suggesting dynamically occurring

fragmentation processes (Figure 5, MV). The results of this analysis also reveal a number of spatial processes happening concurrently that have a significant impact on landscape processes. These include: the formation of mid-forest islands as a result of forest management operations , the formation of dissected forest areas as a result of the construction of linear investments (roads and power lines), the formation of small forest patches as a result of abandoned farming and planned afforestation (Figure 5, WP).

Figure 5. *Examples of morphological classification of patches (MSPA) for an area of high forest cover in the West Pomeranian region (WP) and an area of high fragmentation in the Mecklenburg-Vorpommern region. Colour scale as in Table 3.*



Source: *Own elaboration.*

5. Conclusions

Despite many similarities resulting from natural conditions and a common management history, the spatial structure and degree of forest fragmentation of the studied neighboring regions differ significantly. Western Pomerania is characterized by greater forest cover, but also by the presence of still dense and extensive forest complexes.

They are fragmented, cut by numerous cuts and perforations, but still retain functional connections. Small patches of less than 5 hectares (this is the statutory boundary formally defining forest areas as a legal category of space) make up the overwhelming majority of patches here (98.6%), but their distribution is limited to typically agricultural regions of bottom moraines and former stagnant areas. Vast areas of the region here still have a historically traditional forest character. Similar landscape characteristics were found in the southern part of Mecklenburg-Vorpommern.

The landscape character of the northern and central parts of Mecklenburg is significantly different. In the dominant landscape of open farmland, we find mainly small wooded areas and forest fragments of less than 1ha. Such a picture of forest cover suggests a significant impairment of patch structure, a reduction in biodiversity and declining habitat diversity and resilience.

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