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Forests, Nature Protection, and Wild Forested Areas: Premises for Maintaining Nursery Populations and Habitats in Poland

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Abstract

Habitat fragmentation is one of the most pressing issues impacting biodiversity. This concern is highlighted in various regional documents, including, i.a., the Convention on Biological Diversity and Polish Program for the Protection and Sustainable Use of Biological Diversity. Despite the critical importance of biodiversity, large forested areas with natural vegetation are often neither recognized nor protected. In this article, we introduce the concept of wilderness areas for forested regions in Poland, which we refer to as wild forested areas (WFAs). The designation of WFAs is based on three criteria: undisturbedness, naturalness, and size. A total of 34 WFAs have been identified in Poland, covering 0.8% of the country's territory and accounting for 2.7% of its forest area. The findings reveal that all WFAs are located within Natura 2000 areas; however, only half are part of national parks, and just 2.5% are protected by nature reserves. The results suggest that some forest complexes in Poland possess significant potential for biodiversity protection and can serve as a foundation for establishing effective conservation measures. While this study is specific to Poland, the proposed methodology can be applied globally.

Keywords: wild areas; forests; nature protection; Poland

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1. Introduction

Policies aimed at the protection and restoration of wilderness areas are increasingly influenced by scientific evidence and are evolving towards more interdisciplinary and inclusive approaches. Practices that prioritize the preservation of wild ecosystems are crucial for the survival of numerous species and maintaining high levels of biodiversity [1–4]. Sustaining these areas is essential not only for fostering biodiversity but also for enhancing the resilience of ecosystems against the challenges posed by global change.

The importance of wild areas, particularly forests, is being increasingly acknowledged in the context of climate change and habitat loss. These areas function as vital carbon sinks, helping to mitigate greenhouse gas emissions, which is crucial for addressing climate change [5–7]. Findings from Weiskopf et al. [8] further emphasize that maintaining and enhancing biodiversity in wild areas significantly boosts their carbon storage potential, making conserving these ecosystems a critical strategy for climate change mitigation [9,10].

It is well-documented that wild areas demonstrate resilience to pressures that affect biodiversity, making them essential tools for achieving biodiversity goals [11–14]. Protecting the biodiversity of wild areas offers a broad range of ecosystem services and serves as a reserve in the event of ecological disasters. These areas deliver vital ecosystem services by maintaining nursery populations and habitats, ultimately benefiting humans [15,16].

Key international treaties, such as the Convention on Biological Diversity [17], the EU Biodiversity Strategy for 2030 [18], and the EU Forest Strategy for 2030 [19], provide a framework for understanding the complementary nature of wild area protection and biodiversity conservation.

The concept of wild areas lacks legal recognition. While wild areas are not explicitly mentioned in the EU Birds and Habitats Directives [20,21], adopting a wildlife-focused approach to managing Natura 2000 sites aligns with the provisions of these directives. In 2009, the European Parliament passed a resolution to promote Europe's wilderness, which initiated the development of a European Wilderness List. Following this decision, the Wilderness Register [22] and the European Commission's Guidelines on Wilderness in Natura 2000 [23] were established. This resolution was non-legislative and included several recommendations, highlighting the need for further action in key areas such as defining wilderness, mapping these areas, studying the benefits associated with wilderness, developing an EU wilderness strategy, creating new wilderness areas, promoting them, and introducing adequate protections for wilderness areas. The Wild Europe initiative organized the first conference on Wilderness and Large Natural Habitat Areas in the same year (2009) in collaboration with the Czech EU Presidency and various organizations. This conference aimed to establish a program focusing on policy development, raising awareness, addressing information needs, and exploring opportunities to conserve these areas. A key outcome from the conference is the development of the "Message from Prague", which contains 24 recommendations from the participants on policy, research, awareness raising, and partnerships [24].

Another premise for creating and implementing a national restoration plan for wild areas in the European Union countries is related to setting out restoration needs and measures to fulfill the obligations and achieve the targets of the Nature Restoration Law, adapted to the national context and taking into account the diversity of different regions. One of the goals is to achieve a positive trend in a range of biodiversity indicators in forest ecosystems, including an increasing trend for standing and lying deadwood, uneven-aged forests, forest connectivity, abundance of common forest birds, and stock of organic carbon.

Work is currently underway in Poland on preparing the third edition of the Programme for the Protection and Sustainable Use of Biological Diversity. The effects of implementing the action plan for 2007–2013 were assessed at 16%. According to the State Council for Nature Conservation (PROP) [25], the state of implementation of the action plan for 2015–2020 will most likely not be better. In this situation, it is necessary to consider the reasons for the unsatisfactory implementation of subsequent action plans. As PROP [19] points out, it is essential to formulate measurable and specific goals for supplementing the Polish system of protected areas to get closer to achieving the goals of the Kunming-Montreal Global Biodiversity Framework [26] of protecting at least 30% of land areas and 30% of marine areas in the EU, including all primary and old-growth forests. The first step in implementing these protection goals is to select criteria and methods for identifying wild areas, which have not yet been officially designated in Poland. This study aims to identify wild forested areas (WFAs) and evaluate their relationship with forests and nature protection areas in Poland. It can serve as a basis for preserving nursery populations and wild habitats. The study considers three criteria: undisturbedness, naturalness, and size of the forests. Additionally, the designated forest areas are assessed in terms of their composition and patch configuration, which will help evaluate the potential of these forests for biodiversity protection.

2. Conceptual Framework for Designating Wild Areas

The Guidelines on Wilderness in Natura 2000 [23] distinguish two categories of wilderness areas: wilderness and wild areas. A wilderness area is governed by natural processes [6]. It consists of native habitats and species and is large enough to function ecologically effectively in natural processes. It is unmodified and free from human activity, settlements, infrastructure, or visual disturbance. This minimal interference enables the maintenance of intrinsic ecological, biological, and evolutionary mechanisms that foster biodiversity and ecosystem resilience [27,28]. Wild areas are often smaller than wilderness areas. Here, human activity has slightly modified the original natural ecological conditions. These fragmented areas can support natural processes typical of larger areas if they are connected to the surrounding area by functional ecological corridors [29].

According to these definitions, apart from some nature reserves and areas of strict protection in national parks, Poland has no wilderness areas. Apart from that, all such areas are forest areas. The subject of this study is therefore wild forested areas (WFAs), defined as forest areas of a natural character, located far from road infrastructure and buildings, with an area that allows them to be shaped exclusively or almost exclusively by natural biological processes. The primeval nature of the forest is not a necessary condition here; wilderness areas can be transformed by extensive forest management. They are not primary forests in the meaning of the FAO [30] definition: "naturally regenerated forest of native tree species, where there are no visible indications of human activities and the ecological processes are not significantly disturbed".

Considering the presented definitions of wild areas and the subject of the study, wild forest areas, they should be regarded as both a conceptual and a spatial construct [31]. The conceptual approach has a functional dimension, which treats wild areas as crucial for maintaining the integrity and functionality of ecosystems and high levels of biodiversity. They provide habitat for wildlife, facilitate carbon sequestration, and offer recreational opportunities for humans. The spatial dimension is understood as objective spatial characteristics closely related to ecosystems' structure and spatial distribution.

Designing wild forest areas requires integrating a range of quantitative and qualitative metrics and criteria that capture landscapes' ecological, spatial, and human-use characteristics. This process involves evaluating WFAs through multiple dimensions, such as habitat richness and abundance, environmental integrity, and habitat connectivity understood in functional and spatial dimensions [29]. Subsequent approaches focus on assessing the extent of human influence on forested landscapes by using a set of metrics to calculate wild areas, including intensity of land use [32–34], remoteness [35], absence of intensive human infrastructure [31], human access from roads and settlements [36], terrain ruggedness, vegetation types, night-light intensity [36,37], habitat's patch area [38], and livestock density [34].

The criteria listed quantify the human impact of urban sprawl, agriculture, industrial and infrastructure disturbances, and activities that cause wild areas to be rapidly eroded and fragmented [39]. Habitat fragmentation is one of the most significant problems affecting local, regional, and global biodiversity and ecological processes [40–43]. It influences biodiversity through three main interconnected effects: 1. patch and core area sizes, 2. edge length, and 3. patch isolation.

There are fewer and fewer significant habitats away from human infrastructure, and research has corroborated the positive relationship between habitat size and wild areas' biodiversity, population dynamics, and community [44,45]. Within larger and more compact (circular or square-shaped) habitat areas, larger core areas develop. They are characterized by more significant habitat heterogeneity, which facilitates niche diversification and promotes population stability by reducing the risk associated with environmental fluctuations [38,46]. Larger patches tend to provide more extensive, continuous habitats with greater availability of resources, which can support larger, more viable populations, buffering species against local extinctions [46,47]. Patch size is essential because of the indirect consequences associated with habitat connectivity and edge effects, which depend on the ratio of the patch core area to its edge zone [48].

Smaller patches are more susceptible to edge effects, altering thermal regimes, resource availability, and vulnerability to external threats, affecting species behaviors such as foraging and dispersal [49]. Although the number of species in edge areas is usually more significant than in core areas, common and non-specialized species predominate among them. In the depths of the habitat, valuable, rare, and endangered species are more common, and many of them are typical of natural habitats [50–53]. The variability in findings across studies can be attributed to differing habitats and ecological contexts, indicating that the distance of edge effects may vary widely depending on the specific habitats under study [54–56]. An analysis of the edge effect, which considered its impact on the entire biodiversity (plants and animals), indicated that the edge might cover an area ranging from 100 m to as much as 1 km from the edge of a forest [57–59].

In assessing the configuration of patches, in addition to the size of patches and the size of the core zone, the degree of their isolation is essential, as it shapes the rate of migration and local extinction of species. Empirical studies by Kuipers et al. [60] and Broekman et al. [61] on terrestrial habitat have demonstrated that habitat proximity can substantially influence key ecological processes by mediating connectivity, species dispersal, nutrient transfer, and overall ecosystem resilience, which becomes particularly important for protected areas [62,63]. Such findings underscore the importance of including proximity measures in spatial decision-making within conservation initiatives [64]. Furthermore, the role of proximity dimensions extends to animal social interactions. For example, proximity metrics, particularly in wildlife studies, measure spatial and temporal interactions between individuals. Ossi et al. [65] emphasize that quantifying animal contacts using proximity recorders can reveal important patterns of wildlife behavior, contributing to our understanding of species interactions and resource use.

There are no officially designated wild areas in Poland, and methodological approaches in this domain are weakly tested. The authors of the Polish Brown Bear Conservation Strategy [66] considered the minimum area and the distance to human infrastructure, but only for the Polish Carpathians. The first and only attempt to recognize the potential occurrence of wild areas within the borders of Poland was made by Jermaczek and Kwaśny [67]. The basis for the study was an analysis using GIS tools, carried out based on a 2 × 2 km square grid. The authors considered only one of the criteria of wildness—the layout of buildings and the communication network.

3. Materials and Methods

3.1. Creation of a Single Database for Forests

The individual steps of the research procedure are described in Figure 1.

Since in Poland a detailed forest map is prepared only for state forests, it was necessary to integrate it with the forest map included in the topographic map. The source of data for forests was the Forest Data Bank [68], and for the vicinity of forests and forests within the boundaries of national parks, the Topographic Object Database BDOT10k [69]. The primary purpose of the Forest Data Bank is to provide information on forest management, forest condition, and their changes. This information is linked to data on nature conservation and the state of the environment. The database has been maintained and systematically expanded since 2014. New applications and services are being created and new data sets are being made available, while at the same time, information previously placed in the resources of the Forest Data Bank is being updated. The data concerns forests throughout Poland and is collected uniformly. The basic spatial unit is a forest subarea, which means the area separated during forest inventory, homogeneous on the habitat basis, or forest survey items. The subarea allows special management treatment for the separated forest units. Its size depends mainly on the habitat diversity, intensity of forest management, and historical factors. In the lowlands, the area is usually 10–35 ha, while in the mountains, it is 10–50 ha. BDOT10k is a vector database containing topographic objects' spatial location and their essential descriptive characteristics. Its content and detail generally correspond to a traditional topographic map at a scale of 1:10,000. The detailed scope of information collected in the database and the arrangement, procedure, and technical standards to create, update, verify, and share this data are governed by the Regulation of the Minister of Development [70].

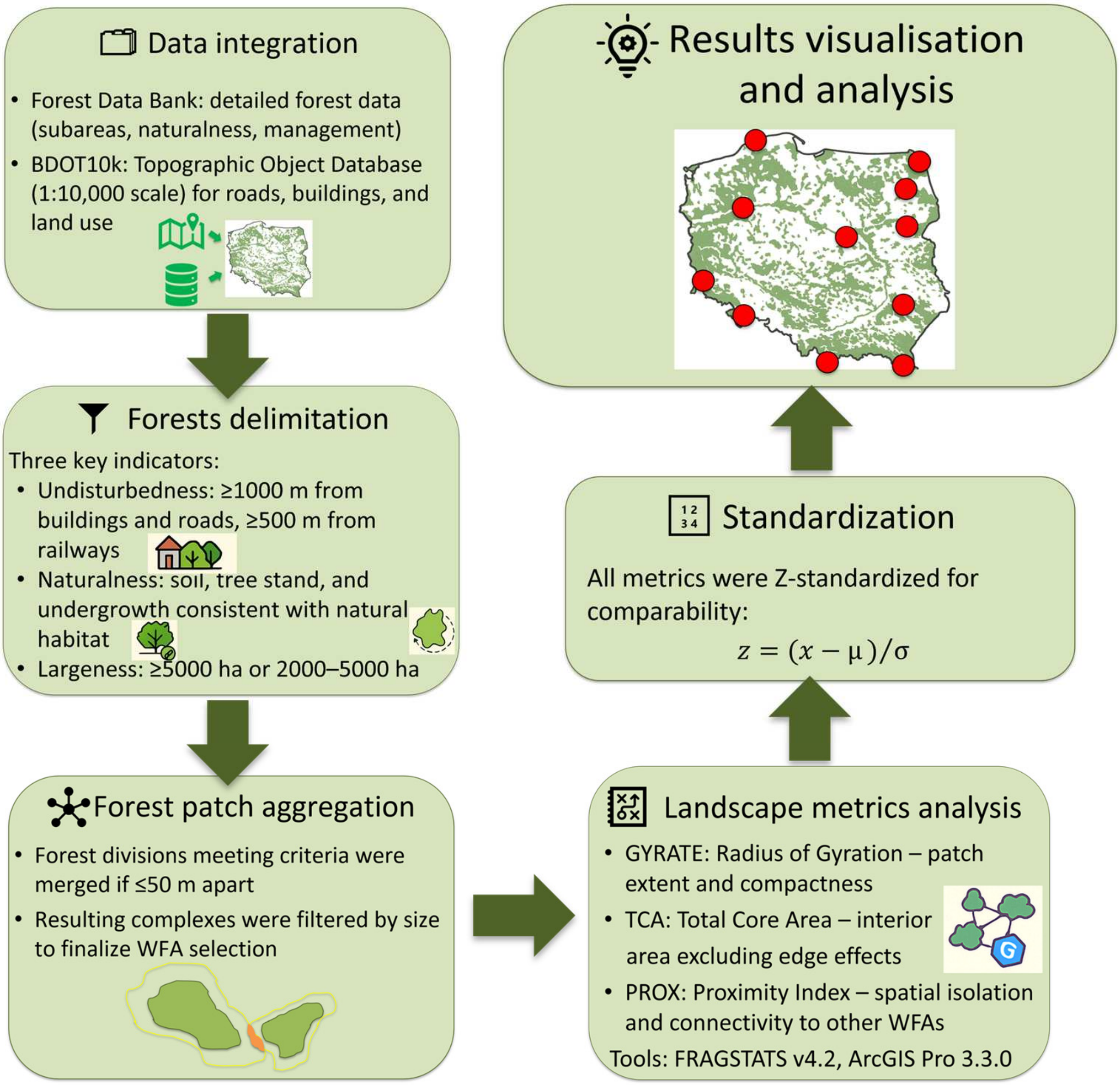

Figure 1. Research procedure used in the study. Source: author's own study.

3.2. Delimitation of WFAs

This step includes the extraction of WFAs based on indicators described in Table 1.

Table 1. The indicators used for the delimitation of WFAs. Source: author's own study.

Name of Indicator	Description	Data Source
undisturbedness	distance to built-up areas min. 1000 m, roads min. 1000 m, and railway min. 500 m	BDOT10k ("x code": roads SKDR 1–4, railways SKTR 1–3, built-up areas PTZB 1–5)
naturalness	forests whose top soil layer properties, type of humus, tree stand, and undergrowth are unchanged and consistent with the conditions of the habitat in the natural state	Forest Data Bank (naturalness category N1)
size	all forest complexes with an area of at least 5000 ha and those with an area of 2000–5000 ha, provided their surroundings (1000 m buffer) are semi-natural (only other forests, waters, and meadows)	BDOT10k ("x code": forest PTLZ 1–3, waters PTWP 1–3, meadows PTTR 1)

First, forest divisions meeting the conditions of naturalness and undisturbedness were selected and then combined to create forest complexes. The condition for aggregating individual divisions was that the distance between them did not exceed 50 m. In the last phase, complexes that met the condition of a suitably large area were selected. The exception was forests in national parks. For them, there is no information on naturalness. Hence, only the criteria of undisturbedness and largeness were taken into account. The criteria for selecting WFAs are based on the literature on the subject. Still, from the range of values considered in previous empirical studies [29,60,61], in our analysis, we adopted quantitative parameters (undisturbedness, size) so that the pool of designated WFAs was not too large. The study's assumption was the initial recognition of WFAs in Poland, and the next stage was the selection of those that, subjected to a detailed inventory, provide the potential to create new forms of nature conservation and expand existing ones. The large number in this pool would constitute a barrier to the decision-making process.

3.3. Assessment of the Composition and Configuration of Forests

Landscape metrics describing the composition and configuration of patches have been used in the study of landscape structure [71] and indirectly as indicators of the functioning of the landscape system, including in the study of processes occurring in populations and metapopulations [40] and in the assessment of landscape fragmentation [72–74]. In this study, landscape metrics are intended to show the potential for biodiversity conservation resulting from the structure of forest areas. Three metrics were selected for analysis, showing the size and shape of the patch, the size of its core zone, and the area of other WFAs in the surroundings of a given forest complex. Radius of gyration (GYRATE) is a metric that represents both an area and an edge metric. This is a measure of patch extent (i.e., how far-reaching it is); thus, it is affected by both patch size and patch compaction. The radius of gyration can be considered a measure of the average distance an organism can move within a patch before encountering the patch boundary from a random starting point. The core area metric refers to the interior area of patches after a user-specified edge buffer is eliminated. All other things equal, larger patches with less shape complexity have larger core areas, an essential feature for determining wild areas. The total core area (TCA metric) represents the aggregated patch area greater than the specified depth-of-edge distance from the perimeter. Both metrics were calculated in FRAGSTATS v4.2 [75]. The third metric used in the study was the proximity index (PROX). This metric is used to measure the spatial isolation of forest patches. This index was developed by Gustafson and Parker [76] but modified for this research. PROX is the size of all WFAs whose edges are within a specified search radius (10,000 m) of the focal patch, together with the size of the focal patch itself. The analyses were carried out in ArcGIS Pro 3.3.0 © 2024 ESRI Inc., Redlands, United States of America. To compare the different ranges of indices, the z standardization was used, which can be expressed by Formula (1):

$$z = (x - \mu)/\sigma \quad (1)$$

where z is the non-standardized variable, μ is the population's mean, and σ is the population SD. Z-standardization, often called Z-score standardization, is a vital tool that enables researchers to normalize data, enhance comparability, and improve the accuracy of assessments. This method transforms raw scores into a standardized format, allowing researchers to interpret data relative to a mean and SD. Piazzi et al. [77] emphasize the importance of standardized methods in ecological assessments, suggesting that a uniform approach to calculating scores can improve comparability.

4. Results

In Poland, 34 WFAs were identified. Their location within the provinces of Poland is shown in Figure 2. The numbers of individual forest complexes included in the description of the results refer to the numbering in this figure. Most of the WFAs are located in the lowlands (65.7%). They are present to a lesser extent in the mountains (28.6%), mainly the Carpathians, and two (5.7%) are in the highlands (Table 2). The most significant number, as many as 22 WFAs, are located in the lowlands, mainly in the South Baltic Lake District region. The largest is WFA #20 within Natura 2000 Tuchola Forest, covered mostly with pine, with an area of 209 km^2, which is not part of any national park. A large concentration of WFAs is located in eastern Poland. These are forest complexes located in both national parks and their surroundings (Bieszczady #7, 22, and 31 and Magura National Park #4), as well as outside them (Góry Słonne #23, Lasy Janowskie #24). The largest complex, with an area of 292 km^2, was identified in the Bieszczady Mountains (#7); 80% of its area lies in the Bieszczady National Park. Apart from this, in the Bieszczady Mountains, but outside the border of the national park, there are two other large forest complexes, #22 and 31 (100 and 42 km^2, respectively). Other large WFAs in eastern Poland are located in national parks—Białowieża #14 (75 km^2), Biebrza #18, 19, and 15 (79, 23, and 20 km^2, respectively), and Wigry #17 (33 km^2). The large WFA #21 is located in the Białowieża Forest, but outside the national park borders (142 km^2).

Table 2. The quantity and size of WFAs in various provinces in Poland. Source: author's own study.

Province	Number of WFAs	Area of WFAs [km^2]
Carpathians and Subcarpathia	9	957.5
Sudetes	1	69.5
Lowlands	22	1395.6
Highlands	2	57.3
Sum	34	2480.0

All WFAs cover 2367 km^2 and constitute 0.8% of Poland's territory and 2.7% of Poland's forest area (Table 3). All WFAs are protected as Natura 2000 PLB, and 26% as PLH. Slightly more than half of the WFA area (53.3%) lies within national parks, and 2.5% within reserves. The share of WFAs in all national parks in Poland is 35%, and in the area of nature reserves, it is almost 3%.

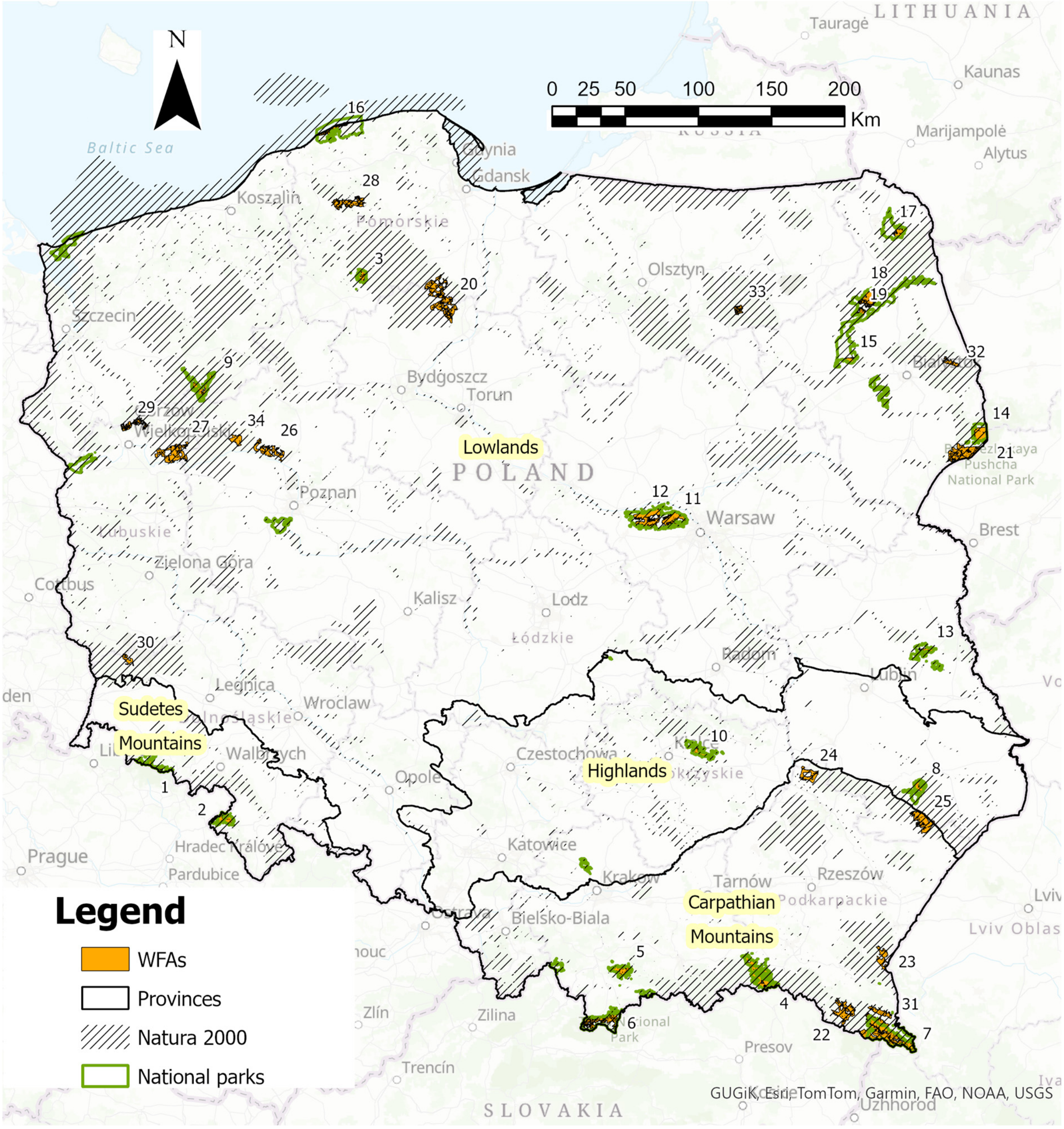

Figure 2. Location of wild forested areas in Poland in relation to provinces, national parks, and Natura 2000 sites. Source: author's own study.

Table 3. Location of wild forested areas in relation to nature conservation areas and other forests. Source: author's own study.

Type of WFA	Area [km^2]	Share in All WFAs [%]	Share in Nature Protection Form [%]	Share in Forests [%]
WFAs outside of national parks	1158.4	46.7	0.00	1.25
WFAs within national parks (without buffer zones)	1321.6	53.3	35.4	1.43
WFAs in nature reserves	62.7	2.53	2.96	0.07

Considering the landscape metrics values, i.e., size, shape, and location relative to other WFAs, the most valuable forests in Poland are in forest complex #7 in the Bieszczady Mountains (Table 4). It is the largest compact forest complex in Poland (292 km^2). Although its patch extent is low (GYRATE), the most significant core area (TCA) and the proximity of other large natural forest complexes (PROX) make its potential the most important for biodiversity protection in Poland. This and two nearby forest complexes (#22 and 31) in the Natura 2000 PLC180001 area should be entirely protected as a national park. Another valuable WFA is also located in the Carpathian Mountains (#4). It has an area of 156.5 km^2 and is entirely covered by the Magurski National Park. Almost 40% of its area is the core zone. In the lowlands, the most valuable forests are the neighboring complexes of WFA #21 with an area of 142 km^2 and #14, with an area of 75 km^2. These are forest complexes in the Białowieża Forest. Only this smaller complex is protected as a national park. These forests have higher than average scores on all three assessed parameters. Due to the patch extent (GYRATE) in the Carpathians, the forest complex in Gorce (#5) should also be mentioned. It is entirely protected within the Gorce National Park. Complexes #26 and 27, which are part of the Natura 2000 site Puszcza Notecka, are also worth mentioning in the lowlands. The first has a high GYRATE index, and the second has PROX and TCA. National parks do not cover these forests. Only in WFA #27 are there five nature reserves, but their area is 1.2 km^2, which is only 0.9% of the WFA area. Large forest complexes are also located near the capital of Poland, Warsaw. WFA #12 and the neighboring complex #11 are valuable forests due to their large core zone and patch extent. Kampinoski National Park entirely protects both complexes. The problem here is the provincial road, which separates these forest complexes.

Table 4. WFAs' composition and configuration metrics. Source: author's own study using FRAGSTATS 4.2 and ArcGIS Pro 3.3.0.

No. ×	Area [km^2]	GYRATE		TCA		PROX		Mean Standardized Value
		Raw Data [m]	Standardized Data	Raw Data [ha]	Standardized Data	Raw Data	Standardized Data	
13	24.4	452.7	−1.0	212.0	−0.9	24.4	−0.9	−0.9
31	41.5	586.6	−0.9	652.0	−0.6	20.7	−0.9	−0.8
15	20.4	573.1	−0.9	772.0	−0.5	20.4	−0.9	−0.8
32	24.7	724.9	−0.7	118.0	−0.9	44.5	−0.6	−0.7
3	36.9	599.7	−0.8	758.0	−0.6	36.9	−0.7	−0.7
28	83.3	742.5	−0.7	1039.0	−0.4	22.4	−0.9	−0.7
17	32.6	663.3	−0.8	1077.0	−0.4	32.6	−0.8	−0.6
19	22.5	590.5	−0.8	123.0	−0.9	77.7	−0.1	−0.6
16	34.6	1674.8	0.4	75.0	−0.9	34.6	−0.7	−0.4
23	53.4	869.2	−0.5	1568.0	−0.1	53.4	−0.5	−0.4
2	44.4	1123.6	−0.2	1408.0	−0.2	44.4	−0.6	−0.3
29	42.7	565.0	−0.9	34.0	−1.0	149.3	1.0	−0.3
6	94	1273.5	0.0	292.0	−0.8	94.0	0.1	−0.2
24	59.8	1054.6	−0.3	1692.0	0.0	59.8	−0.4	−0.2
33	20.7	2078.5	0.9	1.0	−1.0	42.7	−0.6	−0.2
1	25.2	2318.0	1.2	285.0	−0.8	25.2	−0.9	−0.2
30	22.4	2420.7	1.3	424.0	−0.7	24.7	−0.9	−0.1
18	78.9	404.8	−1.1	2974.0	0.7	101.3	0.3	0.0
9	78.5	1367.3	0.1	1601.0	−0.1	78.5	−0.1	0.0
34	39.3	1353.7	0.0	1686.0	0.0	83.3	0.0	0.0
22	99.5	1132.9	−0.2	2013.0	0.1	109.2	0.4	0.1
11	70.1	655.0	−0.8	2395.0	0.3	137.2	0.8	0.1
8	33.5	2644.8	1.6	1375.0	−0.2	33.5	−0.8	0.2
20	95.7	1270.8	−0.1	2647.0	0.5	95.7	0.2	0.2
25	102.7	847.4	−0.5	3367.0	0.9	102.7	0.3	0.2
10	21	3463.7	2.5	391.0	−0.8	21.0	−0.9	0.3
27	132.9	1328.3	0.0	2661.0	0.5	132.9	0.7	0.4
12	120.3	302.5	−1.2	4604.0	1.6	167.6	1.2	0.5
26	84	2889.5	1.8	1271.0	−0.3	87.8	0.1	0.5
5	60.5	3478.4	2.5	1272.0	−0.3	60.5	−0.4	0.6
14	75	1697.6	0.4	4585.0	1.6	119.6	0.5	0.8
21	142.4	1736.4	0.5	2321.0	0.3	216.6	2.0	0.9
4	156.5	1237.5	−0.1	6189.0	2.4	156.5	1.1	1.1
7	292.4	574.5	−0.9	8123.0	3.5	344.3	3.9	2.2

× Numbering as in Figure 1.

5. Discussion

This study presents the national-level WFA selection in Poland based on structural and ecological assessments. According to previous work on wild area mapping (e.g., [78–80]) and other studies cited in chapter 2 of the manuscript, structural criteria related to human influence and fragmentation processes, such as road density, proximity to developed areas, human access from roads and settlements, and terrain ruggedness, are considered key to wild areas. While Kuiters et al. [22] adopted a high level of formal protection as a criterion for delimitation, we rather searched for unprotected areas, which, due to the composition and configuration of the forest, should be included in the analyses for potential protection. Hence, we identified a larger number of wild areas occupying a 4.5-times-larger area. The single attempt to identify wild areas in Poland undertaken by Jermaczek and Kwaśny [67] considered only the criterion of the location of buildings and communication networks. The authors identified 5454 2 × 2 km squares without infrastructure. They conducted their analysis in squares, which made it impossible to assess the connectivity of wild areas. Another problem is the availability of data at an appropriate spatial scale. The studies of Kuiters et al. [22] and Jermaczek and Kwaśny [67] were based on general geographic maps at a scale of 1:250,000, making the assessment very difficult, especially concerning connectivity. We used very detailed data for forests at the level of the smallest forest units and a scale of 1:10,000 for the land cover in the vicinity of forests. Better quality of data was used by Strus and Carver [34], who used Google Earth Engine to construct the Wilderness Quality Map for Europe index. Our study has the advantage that we were able to assess the degree of vegetation transformation. In the mentioned study of Kuiters et al. [22] and Strus and Carver [34], as in most analyses of this type, the naturalness criterion refers to land cover types. In our analysis, we linked naturalness with habitat status, where the tree stand and undergrowth are unchanged and consistent with the habitat conditions in the natural state. Such a criterion was necessary to separate WFAs from large areas of forest monocultures (mainly pine) resulting from afforestation, which are noncongruent with potential natural vegetation in our region [81]. Characteristics such as continuity of woodland existence and species composition reflective of natural vegetation are essential for fostering a high degree of forest naturalness [82] and supporting native biodiversity [83]. This aligns with the growing recognition in forestry practices that embracing natural attributes can lead to more resilient ecosystems. Unfortunately, due to a lack of data, our study, like others of this type, does not consider forest management practices, especially logging intensity. In addition, wilderness studies should also consider connectivity between large forest complexes. As a proxy for wildlife refuges, called stepping stones in landscape ecology, we used the land use intensity within 1 km of the WFA. This should be expanded in future studies. Of course, wild areas are not only forests but also, e.g., wetlands. However, in Poland, based on only two criteria, undisturbedness and size, we have designated only one non-forest area with an area larger than the assumed area—the Biebrza wetlands [84], which is entirely covered by a national park. On this basis, we decided to analyze only forest areas. The shortcoming of our study is that the analysis was conducted only within the borders of Poland. Some large forest complexes intersect with these borders, and the external parts are not included in the study. However, the eastern border of Poland and the EU are exceptional cases. The barriers there make migration very difficult, and in the case of larger mammals, completely impossible. In such cases, the research methodology should be adapted to local conditions.

In our study, we applied an extended approach in which anthropopressure was weighed equally with the naturalness of forest ecosystems and the surface of their patches, emphasizing the importance of the functional dimension in designing wild areas. Additionally, we used landscape metrics to assess the potential for biodiversity protection resulting from the structure of forest areas. The proposed method, which incorporates structural and functional evaluation criteria and the development of WFA, provides a robust framework for evaluating wilderness quality. It also corresponds to understanding wild areas as crucial for maintaining the integrity and functionality of ecosystems, as they provide habitat for wildlife and promote resilient landscapes. The method and criteria are universal and could be adapted as a design draft of WFAs. However, the methods proposed here must be verified in the geographical context of the region where they will be applied, especially in terms of forest ownership, data availability, and legal systems.

The extent and character of wildness are context-dependent, influenced by natural conditions, cultural perceptions, and the prevailing policy frameworks that determine how these areas are valued and managed [31]. A reference could be a relationship between the patch core area and the edge effect (TCA). Research has shown varying distances where edge effects can be prominently observed. The variability in findings across studies can be attributed to differing habitats and ecological contexts, indicating that the distance of edge effects may vary widely depending on the specific habitats under study [54–56]. An analysis of the edge effect, which considered its impact on the entire biodiversity (plants but also animals), indicated that the edge might cover an area that can range from 100 m to as much as 1 km from the edge of a forest [57–59]. Similarly, in the case of the forest size criterion, from an ecological point of view, it can be argued that a wilderness area should meet minimum size features, i.e., be large enough for the effective ecological functioning of natural processes [85], but this will be largely dependent on the ecosystem types involved. The IUCN guidelines do not use any minimal size limit for a wilderness area. PAN Parks, the leading European wilderness protection organization, assessed Wilderness Partners' ecologically unfragmented wilderness area of at least 1000 hectares (with the potential to grow up to 3000 hectares) and "Certified PAN Parks" with a wilderness area of at least 10,000 hectares [86]. The Wilderness Act [87] mentions a minimum size of 5000 acres (about 2000 ha). As mentioned above, the context of Poland's afforestation policy was also crucial in our study for establishing the criterion of naturalness of WFA.

Based on our study, we recommend the integration of landscape metrics into methodological frameworks for wild area mapping as a tool, which, combined with undisturbedness, size, and naturalness, can facilitate the identification of areas of high conservation value and strengthen naturalness criteria as a guiding principle for qualifying forest areas as wild. Because one of the primary contributions of landscape metrics is their ability to evaluate the ecological processes that underpin wild areas, numerous landscape metrics can be used to assess forest quality, including measures of patch size, shape, and connectivity, as well as measures of edge density and landscape diversity [88,89]. The metrics used in our study (GYRATE, TCA, PROX) provide quantitative tools to evaluate characteristics of landscapes, respectively, patch extent (landscape continuity), core area size (habitat availability), and patch isolation, which are crucial for determining the structural and ecological integrity of wilderness areas [90–93]. Such metrics can be derived from remotely sensed data, permitting robust assessments of forest habitat loss and fragmentation and identifying priority areas for conservation and restoration [94,95].

Our study shows that the number of extensive, remote forests with natural vegetation in Poland is small, and these forests are unevenly distributed within the country. Forests in the eastern part of the country and Western Pomerania dominate. The central part of Poland is devoid of WFAs, except the Kampinos Forest, which is unfortunately divided by a provincial road. The small number of WFAs in the mountains, especially in the Sudety Mountains, is also worrying. The Bieszczady, Low Beskids, Gorce, and Tatras are the most important refuges for brown bears (*Ursus arctos*), gray wolves (*Canis lupus*), and Eurasian lynxes (*Lynx lynx*), the Białowieża Forest and Bieszczady for European bison (*Bos bonasus*), and the Bieszczady and Low Beskids for golden eagles (*Aquila chrysaetos*) [96].

In Poland, Natura 2000 covers 20% of the area (62,535.8 km^2) and includes various types of ecosystems, of which forests cover 25,014.32 km^2 (40%) [97]. Among the forests, according to our analysis, those that meet the criteria for wild areas are 2480 km^2 (3.97%). Still, Natura 2000 aims to preserve specific types of natural habitats and species and habitats considered valuable and endangered on a European scale. It means a high protection regime for these selected species and habitats, but not entire ecosystems, such as the WFAs defined in our analysis. The problem is that not all Natura 2000 areas are formally designated by national regulation. Many lack the definition of protection objectives and the introduction of appropriate protection measures (in Poland, plans of protective tasks). There are no planning tools and, above all, political will, allowing for at least a gradual evolution of spatial management aimed at formal and legal protection against investment and, ultimately, the protection of wild areas. No mechanisms effectively limit investment and various management forms, including intensive forest management, in Natura 2000 areas not protected by national parks or reserves. The best tool to effectively protect WFAs is the creation of reserves and national parks, as forms of protection with the highest regime. According to our analysis, only half of WFAs are protected as national parks and 2.5% through a nature reserve. In Poland, 80% of forests are state forests managed by the Polish Forest Holding-State Forests (PGL-LP). Theoretically, this method of management provides excellent opportunities for protection. Unfortunately, this company enjoyed great freedom in forest management for many years, and any attempts to influence forest management by the social side and even by the government were ineffective. Since 1995, no national park has been created in Poland; the main obstacles were PGL-LP and local authorities, who did not see the benefits of protecting nature in their area. Since 2024, the situation has changed; the Polish government has been working on various projects and initiatives to preserve Polish forests. One of the most important is the moratorium on logging the most valuable forests, which came into force in January 2024. It assumes the exclusion of 20% of the most valuable forest areas from logging. The reduction in logging results from the needs and conditions of nature, law, economy, and above all, social conditions. In the first stage of work, 10 forest complexes were designated where logging is to be limited. Some of them, including the Bieszczady Mountains and the Carpathian Forest, overlap with those selected in this study.

Additionally, the government is introducing a reform of forest management planning to ensure social supervision over forest management and increase judicial control of the compliance of plans with the law. The government is also working on the creation of new national parks. The State Forest National Holding has taken the initiative to create 1000 reserves, and we can already see the first effects of these activities. Unfortunately, there is much to be done. The introduction notes that Poland lacks a current Program for the Protection and Sustainable Use of Biological Diversity. In addition, under the Nature Conservation Act, the Polish government should prepare protection programs for endangered species of plants, animals, and fungi. Poland has such documents only for five species of birds and one mammal [98].

Wildlife conservation within wild areas is a significant area of scientists' focus, especially for threatened species. Effective management practices that preserve these key habitat components can enhance biodiversity and contribute to overall ecosystem resilience. Furthermore, ensuring habitat connectivity through managed corridors is vital for dispersing various species, ensuring genetic diversity, and maintaining population sustainability [29]. Studies prove that imposing strict regulations on wilderness areas regarding their use is critical for conservation [99]. In Poland, such protection is provided by the highest forms of legal protection, i.e., national parks and reserves. It is postulated that the protection of the indicated WFAs in Poland should be strengthened by giving them the status of national parks or reserves. This means considering the creation of new national parks or expanding with adjacent Natura 2000 areas. Examples are WFAs close to Bieszczady National Park or WFAs close to Białowieża National Park. However, de facto wilderness areas, apart from adequate protection, are not only a problem in Poland. They still constitute a significant part of the total wilderness, which raises concerns about their conservation status, considering that they may not have formal protections [99,100]. The postulated significant spatial congruence between wilderness and protected areas emphasizes the importance of appropriate spatial planning and conservation and management strategies to enhance ecosystem conservation while maintaining wilderness characteristics [41].

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