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Effects of Forestry Transformation on the Ecosystem Level of Biodiversity in Poland's Forests

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Abstract: This paper presents the results of an analysis of the effects of Poland's forest management evolution over the last 75 years on forest biodiversity at the ecosystem level. Forest biodiversity changes in the two politically and economically different eras (socialism and democracy) are interpreted based on four indicators used in assessments of forest stands (naturalness; habitat diversity; forest management system; forest stand age structure). In the era of socialism (1945–1989), there were dynamic increases in the area of semi-natural forests as well as in the proportion of the most fertile habitats, whilst the proportion of the poorest habitats decreased quite dynamically. Then, the clearcutting management system was regularly implemented, with adverse impacts on forest spatial structure diversity. The proportion of old/mature tree stands and the stand average age increased at relatively slow rates. In the era of democracy (1990–2020), there were comparatively more dynamic increases observed in the area of forests undisturbed by man, as well as in the proportions of mixed broadleaved and wetland forest habitats. At the same time, the proportion of old/mature stands and stand average age kept increasing at relatively fast rates. The area of forests managed with the use of the shelterwood system increased and the area of forest plantations substantially decreased. On the other hand, irrespective of the era under study, there occurred a noticeable not-so-favourable decreasing trend in the proportion of the youngest forest stands. All in all, during the analysed period of more than seven decades, the evolution of forest management practice implemented in Poland's forests by State Forests National Forest Holding led to the restoration of/an increase in biodiversity at the ecosystem level. Yet, there have remained unsolved issues, as regards the following aspects: organisational (the assurance of further reconstruction of forest stands, and the restoration of water profiles), political (a lack of up-to-date national forest policy), and financial (the costs of protecting/restoring biodiversity vs. State Forests' self-financing), as well as conceptual (old-growth stands in managed forests, and controversy over clearcutting) and natural/anthropogenic (climate change, and the eutrophication of forest habitats) issues. The solutions may require measures outside the limits of Poland's forestry, if not far beyond national borders.

Keywords: forest spatial structure; habitat diversity; management practices; naturalness; SFM indicator; stand age structure

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1. Introduction

Forest management, dependent upon historical, political, economic and social conditions, determines the shape, sustainability and biodiversity of forest ecosystems [1]. Thus, changes in the goals and principles of forest management result in alterations of forest ecosystems and in their ability to provide services related to biodiversity and its conservation [2,3]. The examination the aforesaid relations at the large spatial and temporal scales is important and informative. In this study, we examined the relationship between changing forest management and the state of forest ecosystems using the example of Poland's forests

(Central Europe), taking into consideration the period from the end of World War II (1945) to the present.

In order to obtain a better understanding of the changes that occurred during the analysed period, it is necessary to go slightly back in time. Of many phases of forest use in Poland, the most significant one for the diversity of forest ecosystems were those which began about 250 years ago. Starting from 1772, Poland was split between the bordering empires (Russia, Prussia and Austria) for over 120 years. At that time, the country's environment was intensively exploited, and in the 19th century, forest coniferous tree species were propagated; this also occurred all over Europe [4–9]. Modelled on agriculture, single-species, single-generation and single-layer spatially ordered forest stands were cultivated, leading to the elimination of the ecosystem and spatial diversity of forests almost completely [10,11].

After Poland regained its independence in 1918, works on a modern model of multi-functional forestry began to emerge. Established at that time (1924) was the Polish State Forests Enterprise who has to date continued functioning, and is now known as State Forests National Forest Holding (the State Forests or the SF, hereafter also referring to Poland's forests managed by this enterprise). Currently, the SF is the EU's largest specialised entity managing national forests [12]. In 1939, the outbreak of World War II abruptly terminated the initial stage of Poland's forestry development and brought on the destruction of national forests due to warfare, military battles and over-exploitation by the occupying forces until 1945 [13,14]. Nevertheless, subsequent generations of Polish foresters have continued to pursue the initial course and to build on the achievements gained before the war, although the extent of the use of former knowledge has changed over time.

On account of historical changes in Poland in the last decades, we divided the period under study (1945–2020) into two stages, which are quite different in terms of Poland's political and economic conditions, i.e., the era of socialism (1945–1989) and the era of democracy (since 1990). The two eras have made their important marks on the shape of forest management in Poland.

Extensive nationalisation and industrialisation were characteristic of Poland under socialist conditions [15,16], resulting in severe environmental pollution, which was every so often followed by the extinction of natural habitats, and which was also recorded in the case of forests [17,18]. The economy was centrally planned and regulated, devoid of market mechanisms, and national forestry was implemented in line with a resource-based economic model [4,7]. Forest management was chiefly focused on industrial wood production and the achievement of commercial goals [19], whereas ecological principles and forest sustainability were of secondary importance [7]. Nonetheless, the managers of state-owned forests undertook a number of measures so as to reduce ongoing biodiversity loss one way or another.

Appropriate measures had a chance to be implemented on a considerable scale only after the transformation of Poland's political (and economic) system into a democratic one which brought about the free market (starting from 1989). This led to the implementation of the concept of sustainable forest management (SFM), with a strong emphasis being put on the protection and restoration of forest ecosystems [20–23], including ecosystem-level biodiversity. A very important factor for the maintenance direction of reforms was to continue the state ownership of forests under the conditions of the transformed economic system [3]. In the meantime, Poland joined several international processes on the protection of, inter alia, forest biodiversity (e.g., the Convention on Biological Diversity, and the Ministerial Conference on the Protection of Forests in Europe—now FOREST EUROPE), and started implementing jointly developed recommendations/guidelines on its own forest industry and management practice.

Two milestone actions undertaken during the era of democracy have boosted the protection of biodiversity in Poland's forests (especially those managed by the SF), i.e., the accession to the European Union (2004) and the implementation of the Birds and Habitats

Directives [24]. The ratification of the Aarhus Convention (2003) [25] resulted in greater-than-before public participation in shaping the rules and ways of forest management, especially in terms of forest nature conservation.

The aforementioned historical, political, economic and social changes (together with the increased awareness of environmental issues) during the period under study have considerably influenced the state of forest biodiversity in Poland. So far, these aspects have been studied based on selected indicators, in relation to biodiversity at the landscape level. The results of Referowska-Chodak and Kornatowska [26] show that in the era of socialism, there were prompt increases in total forest cover, wood resources (total growing stock) and the total area of protective forests essential for biodiversity conservation. In the era of democracy, average growing stock density increased intensively and forest management has put a greater emphasis on reducing forest fragmentation and clearcut logging. Likewise, there was an average increase observed in protected forests' areas in both eras under study. At the crossing point, the area of protected forest in Poland increased most vividly. The changes throughout the study period were considered positive for the forest landscape. Yet, numerous problems and challenges in this have still remained. These include, inter alia, unnecessary beneficial alterations in the ownership structure of Poland's forests; outdated national forest policies; insufficient funding for nature conservation; uneven distribution and ongoing forest fragmentation across the country; climate change impacts (e.g., extreme weather events) [26]. For a more complete picture of the consequences of the evolution of forest management in Poland, there is a need for further comprehensive analyses as regards other than landscape biodiversity levels, including but not limited to the ecosystem biodiversity level.

Considering the above, the main aim of the present study was to evaluate the effects of forestry evolution under Poland's conditions on the state of forest biodiversity at the ecosystem level, in reference to selected indicators. In the perspective of 75 years (1945–2020), the specific objectives were distinguished: (1) to determine the direction and dynamics of changes in forest ecosystems, (2) to identify drivers of the observed changes and their effects, and (3) to identify threats to forest ecosystems and the direction of further actions for the benefit of forest biodiversity at the ecosystem level. The study period comprised the two political eras in Poland (socialism and democracy) with differently formulated forest management objectives. In the era of socialism, forest management was focused on industrial wood production and the achievement of commercial goals whereas in the era of democracy, the emphasis has been put on the implementation of the concept of sustainable forest management (SFM) and the restoration of forest ecosystems. The regulations and guidelines for forest management developed in the eras under study are quite different but in both cases have directly influenced the state and structure of forest ecosystems.

The results of a comprehensive ana"ysis'of relationships between forest management and forest biodiversity at the ecosystem level, carried out in consideration of conceivable conflicts, as well as the long-term perspective and the large spatial scale, can be useful for enhancing sustainable forest management, for example in the regions with historical conditions or forest structures analogous to those in Poland. On a broader scale, such studies can serve as forms of documentation of changes occurring under the impact of human activity on the surrounding nature.

2. Materials and Methods

2.1. Indicators

The indicators used to measure the state of forest biodiversity, such as the set of criteria and indicators (C&I for SFM) developed by FOREST EUROPE [27] often reflect the condition of more than one level of biodiversity. In order to assess forestry evolution effects on different levels of forest biodiversity in Poland's forests (State Forests), we used the criteria/indicators that reflect the studied aspects to the greatest extent.

In the present study, the widely used biodiversity indicators, such as species richness and abundance as well those related to alpha, beta, gamma diversity, were not used as they merely refer to a species level. Our aim was to focus on analysing complex systems composed of various factors and forest management undertakings that shape forest ecosystems—not only in terms of species characteristics, but also spatial and temporal diversity. Therefore, in regard to the ecosystem level, the following proved useful: selected C&I for SFM [27]; selected factors listed by Keller [28] as determinants of biodiversity related to forest ecosystem stability; selected indicators used by Mederski et al. [7] to analyse the effect of "ecological" forestry policy on the landscape change.

The influence of the evolution of Polish forestry on forest biodiversity at the ecosystem level was therefore studied based on the following four indicators:

1. Naturalness—C&I for SFM: Indicator 4.3, *naturalness* [27]. The indicator refers to a degree of alteration of a certain ecosystem classified in the following classes [3]: forests undisturbed by man ("*the natural forest development cycle persists or was restored and show characteristics of natural tree species composition, natural age structure, deadwood component and natural regeneration and no visible signs of human activity*"); semi-natural forests ("*neither undisturbed by man nor plantations but displaying some characteristics of natural ecosystems*"); plantations ("*usually representing ecosystems on their own, established artificially by planting or seeding, often with introduced tree species, and intensively managed*"; "*completely distinct from the original ecosystem*"). In this study, consistent with the methodology adopted in Poland, forests undisturbed by man were considered forests under strict protection in forest nature reserves (area per ha). Forests protected in national parks were not analysed, as institutions other than State Forests are responsible for their management [26]. In the case of forest plantations, we took into account those established for increased timber production in shorter production cycles (ha). Seed plantations (focused on the conservation of gene resources) and Christmas tree plantations (usually established under power lines) were not included in the analysis. The area of semi-natural forests (ha) was calculated as the difference between the total area of forests administered by the SF over the study years [26] and the sum of the areas of other forest categories examined, i.e., forests undisturbed by man and plantations;
2. Habitat diversity: *diversity of habitat conditions* is, as stated by Keller [28], one of the factors that influence forest ecosystem functioning. In the present study, we focused on 4 basic types of forest habitats in Poland (the term considered to represent the physical conditions of forest sites). The habitats under this study were distinguished by forest site fertility from the poorest to the most fertile, i.e., those of (1) coniferous forests, (2) mixed coniferous forests, (3) mixed broadleaved forests and (4) broadleaved forests. Based on available data, we calculated the respective habitat area proportions (%) in each of the study years. In further descriptions, we referred to the habitat moisture gradient through the analysis of changes in the proportion (%) of the wettest habitats in the forests under study;
3. Forest management system: indicator *methods of final felling* [7]. This indicator refers to general principles of forest use and regeneration, as well as to the implementation of specific activities in time and space so as to ensure that the intended production goal is achieved [11]. The management system directly influences forest ecosystem characteristics and *spatial structure*, which, in accordance with Keller [28], is a factor with significant effects on ecosystem stability. In this study, depending on data availability, there are presented figures on forest areas (ha) covered by specific treatments under each analysed management system in a given study year or the total forest area (ha) planned for the application of a given management mode in the long-term perspective;
4. Forest stand age structure: *the age structure of stands*, consistent with Keller [28], influences the formation of specific conditions for an ecosystem's development and its richness, and thus has effects on long-term ecosystem stability. This is also an indicator for SFM (C&I, Indicator 1.3, *age structure and/or diameter distribution* [27]), originally considered in terms of economic aspects and the contribution of forest resources to global carbon cycles [3,27].

2.2. Scope of Analyses

It was assumed that the analyses would include forest areas managed by the State Forests National Forest Holding (SF), and references to all forests in Poland would be made only if information regarding the SF was not available or the analysed data were relevant for the interpretation of the obtained results. This approach was based on the following: (1) almost 77% of the area of all Polish forests is currently under management of the SF [29]; (2) a standardised forest management practice has been implemented in all the forests administered by the SF [12]—this confirms the consistency of the presented results and conclusions drawn; (3) more and more detailed and reliable data (especially historical) concerning the SF are available compared to those on other forests in Poland; (4) State Forests is the entity managing state land, and therefore, it is principally influenced by pressures exerted by the government and decisions on land management policy.

The time scale of the analysis was the period of 1945–2020 (75 years). The influence of the evolution of Poland's forestry on forest biodiversity at the ecosystem level is presented based on data pertaining to 10-year intervals (Figure 1).

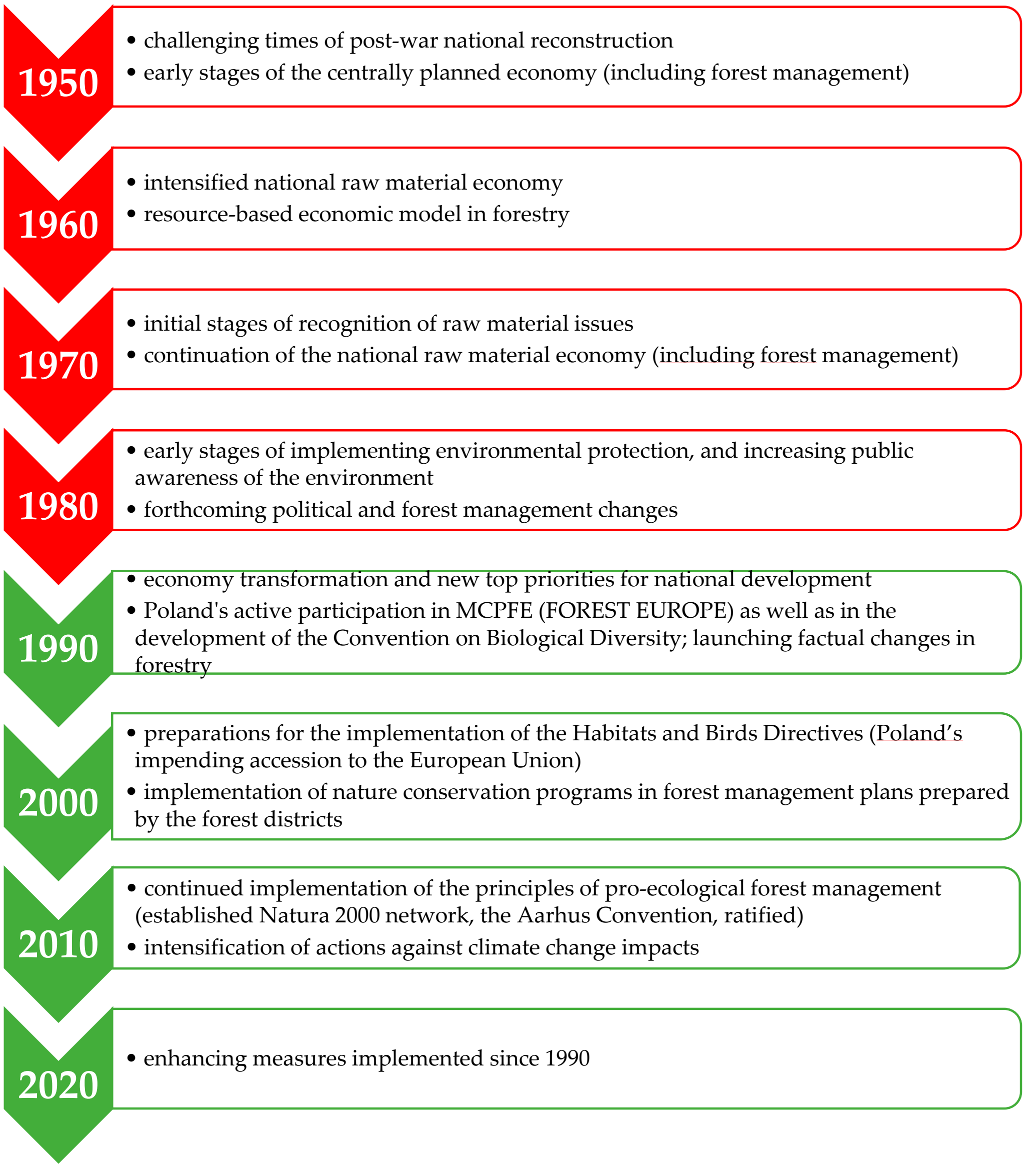

Figure 1. Timeline of developments related to Poland's forestry in 10-year intervals of the period under study (the era of socialism—red; the era of democracy—green).

The year 1990 was assumed as the breakthrough year (the sanctioned start of forest management transformation). The data used for the analyses represented the status at the end of the year given in the tables/figures. In the case of data being unavailable for a given study year, if possible, data from contiguous years were used. Relevant information was then indicated in the footnotes to the tables/figures. Due to the different reporting mode (a marketing year covering the fourth quarter of the previous year and the first three quarters of the following year), the results for the area under different types of forest management systems in the year 1960 was calculated as the sum of $\frac{3}{4}$ of the parameter value for the 1959/1960 marketing year and $\frac{1}{4}$ of the value for 1960/1961.

The substantive scope of the study included the following: (1) evaluating information/data compiled in terms of the characteristics of the analysed feature, taking into account differentiation over time, as well as the direction and dynamics of changes; (2) providing a comprehensive analytical commentary; (3) identifying threats to forest ecosystems and indicating the directions of beneficial actions.

2.3. Sources and Analysis of Information

Once the indicators were selected and the scope of the study was defined, pertinent data for the study years were compiled. The presented numerical data came from reports published by State Forests National Forest Holding (Poland) that included financial/economic information or that regarding the state of forests [30–33]; the Forest Data Bank [34]; statistical yearbooks on forestry and environmental protection published mainly by Statistics Poland (GUS); relevant available monographs and articles. Due to the lack of pertinent studies/reports for some study years (especially, for those at the beginning of the study period), several statistics were not available; nevertheless, the trend and dynamics of changes could still be revealed. For each analysed indicator, the aforesaid trend and dynamics of changes in indicator elements were determined both for the entire study period and the periods of the political eras under study. For the purpose of the discussion of the results, including the description of factors that influence changes in the analysed parameters, we used the results of several articles from the Scopus (Elsevier) database (keyword: Polish forestry), as well as those found using a snowballing approach.

3. Results and Discussion

3.1. Naturalness

The classification of forests according to the degree of their naturalness illustrates the distance between the current and potential natural status of a particular forest and reflects the history and intensity of human interventions in forest ecosystems [3]. In Poland, forests with preserved primeval features (thus with the minimum aforesaid distance) appear very sparsely [11], mainly in the case of outside forests managed by the SF. This is mainly due to forest management being carried out for centuries, which was particularly exaggerated during the period when Poland's territory was split between Prussia, the Habsburg monarchy, and Russia (1795–1918). As a result, there is now a dominating presence of forests with a relatively greater distance between the current and potential natural status, and this distance depends upon local conditions and history; therefore, it is differentiated across the country.

At the beginning of the period under study—just after World War II ended (1945)—there existed no structured network of forest (or other) protected areas [26]. At that time, fast-growing tree plantations were not implemented [35,36]. Therefore, the entire forest area under the administration of State Forests (5408 thousand ha [26]) can be classified as semi-natural forests. In the course of time, forests began to diversify in some measures (Table 1). The values presented in the table below are the result of a long search for the most reliable data or of data interpolation as historical information (especially as regards the era of socialism) were often unavailable or divergent.

Table 1. Different degrees of naturalness in forests under the management of State Forests *.

Year	1950	1960	1970	1980	1990	2000	2010	2020
Forests undisturbed by man (thousand ha)	0.02	<5.0 [1]	<5.9 [2]	<8.7 [2]	1.0	0.9	1.6	10.0
Semi-natural forests (thousand ha)	<5740	6125	6493	~6700	6787	6943	7066	7108
Plantations (thousand ha)	n.a. (>0)	10.0	8.6 [3]	n.a. (>0)	17.0 [4]	8.9 [5]	4.1 [6]	2.5

* sources: [26,35–44]; [1] area of all forest reserves, [2] area of all strict reserves, [3] based on data for 1965 and 1972, [4] based on data for 1987 and 1989, [5] based on data for 1998 and 2003, and [6] data for 2009; n.a.—data not available.

The dynamics of changes in the area of forests of different naturalness degrees. During the period under study, the trends of changes in the area of the examined forests varied depending on the forest category. There was an increase in the area of forests undisturbed by man (which increased in the era of socialism by 1 thousand ha, and by 9 thousand ha in the era of democracy). The area of semi-natural forests also increased (by 1379 thousand ha in the era of socialism, and by 321 thousand ha in the era of democracy). In the case of plantations, after a period of increase in their area (an increase of 17 thousand ha under socialism), a decrease was observed (a decrease of 14.5 thousand ha under democracy). The dynamics of the aforesaid changes varied. The increase in the area of semi-natural forests was more dynamic in the era of socialism (on average 30.6 thousand ha/year) when compared to that in the era of democracy (on average over 10.7 thousand ha/year). This was contrary to the changes in the area of forests undisturbed by man; in the era of socialism the increase rate was on average 22 ha/year, whereas in the era of democracy, apart from an initial downward trend, it was 300 ha/year. The area of plantations was quite variable In the era of socialism (depending on the projects implemented and their success), whereas in the era of democracy, the area of newly established plantations was smaller compared to that of already existing plantations converted into forests with the use of earlier management/reforestation practices.

Forests undisturbed by man. Currently, at any rate, practically every forest in Poland is under indirect pressures, such as industrial emissions [11]. Therefore, it is conceivable to refer only to forests with ceased direct pressures. Polish forests strictly protected under the Nature Conservation Act of 16 April 2004 [45] can be categorised as "forests undisturbed by man" and assessed by means of Indicator 4.3, naturalness [27]. In forests managed by the SF, the area of "undisturbed" forests increased bit by bit (Table 1) and in 2020, it was 0.14% of the total area of State Forests. The low share of strictly protected forest ecosystems was emphasised as an important problem by the Polish State Council for Nature Conservation as early as 2007, and later in 2016 [46,47]. The Council pointed out, inter alia, that undisturbed forest sites can serve as reference plots for improving forest management practice [46]. They can be used to determine the natural stand type characteristic of a region under given habitat conditions [11], as well as to observe and better understand ecological processes [3]. Although the area under strict protection in forest nature reserves designated in the SF has been increasing since 2007 and then since 2016 (Table 1), the area of undisturbed protected forest ecosystems could be considerably enhanced. The value of undisturbed forests is greater the larger and more consistent their area is, as this allows natural ecosystem dynamics to occur [3]. On the scale of European countries, a particularly high proportion of forests undisturbed by man occur in Georgia (17.7%), Bulgaria (18.1%), and Liechtenstein (22.4%). However, the average for Europe as a whole is 2.2%, and in Northern Europe region it reaches a maximum of 3.9% [3].

Semi-natural forests. The majority of Poland's forests were strongly changed due to the long-lasting implementation of the resource-based economic model of forest management [48,49], in the time when the country was partitioned (1795–1918) and later, in the era of socialism (1945–1989). Focusing on timber production turned forests into unstable formations with seriously diminished species, ages and spatial structures. Yet, the forest ecosystem is a living, dynamic natural entity, with great potential for regeneration. Nowadays, the degree of naturalness could be improved if forests were not affected by human interference [11]—as referred to in the paragraph above—or through silvicultural practices.

Already in the early 1980s, the Polish scientific community highlighted a need for the implementation of a "close-to-nature silviculture model", allowing for restoring complexity and increasing the stability of forest ecosystems [48]. However, this concept had a chance to gradually materialise only after the political, economic and social transformation which took place in the late 1980s and early 1990s. Hence, the results presented in Table 1 show data on forests categorised as semi-natural in the era of socialism whose features were considerably less natural when compared to those in the era of democracy (and especially, when compared to present forests). Even so, the classification adopted in this study is fit for its purpose, because forest plantations—if not intensively managed for an extensive period of time—can be considered semi-natural forests [3]. Notwithstanding the resource management approach, "regular" Polish forests were not plantations, and even during the era of socialism, there was harvested no more wood than its annual increase [26].

Plantations. The concept of fast-growing tree plantations flourished in State Forests during the era of socialism. Poplar (*Populus* sp.) plantations were established in the 1950s, with the goal of establishing 50 thousand ha by the year 2000. Over time, the cost of growing poplar plantations on forest lands turned out to be too high, so the project was discontinued in the 1980s, as was the case with failed willow (*Salix* sp.) plantations in the early 1970s. Then, 100,000 ha of spruce (*Picea* sp.), larch (*Larix* sp.), birch (*Betula* sp.) and Douglas-fir (*Pseudotsuga menziesii*) plantations was to be established in 1970–1990, of which only a little over 4000 hectares was realised. In the first decade of the 21st century, there were efforts undertaken to establish plantations of tree species such as bird cherry (*Prunus avium*) and black locust (*Robinia pseudoacacia*) but since 2010, projects of this kind have been given up by State Forests [36]. Even though the current Forest Management Instruction [50] still specifies "fast-growing tree plantations", current plantations (especially in the case of poplar) are usually established on agricultural lands with poor soils, so as to secure and improve subsoil quality and provide income for private land owners [42,51], e.g., from wood sale to paper factories. In view of the above, as far as Poland's forests (State Forests) are concerned, the present role of plantations is quite minor, comparable to that across Europe (3.8% on average [3]), and significantly lesser than, for example, that in the United Kingdom, Ireland and Belgium, where plantations dominate in the total forest area (in proportions of 89.2%, 86.2% and 68.2%, respectively [3]). However, due to the growing demand for timber, plantations of fast-growing trees on agricultural lands (outside of the SF) may be necessary [42].

Naturalness and biodiversity. It is interesting to note that in regard to forest ecosystems, naturalness and biodiversity are not always correlated, as a forest habitat located in environments affected by strong limiting factors can have a considerably high level of naturalness, even if its biodiversity is not high [52,53]. For instance, in Poland, the process of ageing of unmanaged Carpathian beech forests has been accompanied by a decrease in the diversity of the tree and herb layers [54]. Based on data from permanent plots (established in 1936), Brzeziecki [55–57] reports considerable changes in tree species composition and abundance, as well as the low recruitment rates of formerly dominant species, in spontaneously developing tree stands strictly protected for about 100 years in the Białowieża Forest (a unique temperate forest in eastern Poland). There are also observed cases when high biodiversity is observable in less natural forests. For example, the outstanding species composition and physiognomy of Euro-Siberian steppic woods with *Quercus* spp. (Natura 2000 priority habitat 91I0) are attributable to, inter alia, human-dependent cattle grazing [58].

3.2. Habitat Diversity

The potential natural vegetation in Poland was classified as temperate lowland forest (predominant) and mountain forest [59]. Presumably, lowland forests in fertile habitats would be dominated by oak-hornbeam communities [60]. However, this pattern was disrupted as a result of centuries of a gradual takeover of fertile soils for agriculture, leaving forests mainly on poorer soils [61,62]. This essentially translated into then existing structure of forest habitat types. On the other hand, it is important to be aware that forest management per se also affects habitat quality, by changing basic parameters—fertility, water content and pH [1,63]. The planting of Scots pine (*Pinus sylvestris*) stands on fertile soils, which was carried out in Poland in the 1800s, and later, in the era of socialism, had adverse effects on soil fertility, enzymatic activity and physicochemical properties [64,65]. The evolution of the structure of habitats in State Forests in terms of their fertility during the study period is shown in Figure 2.

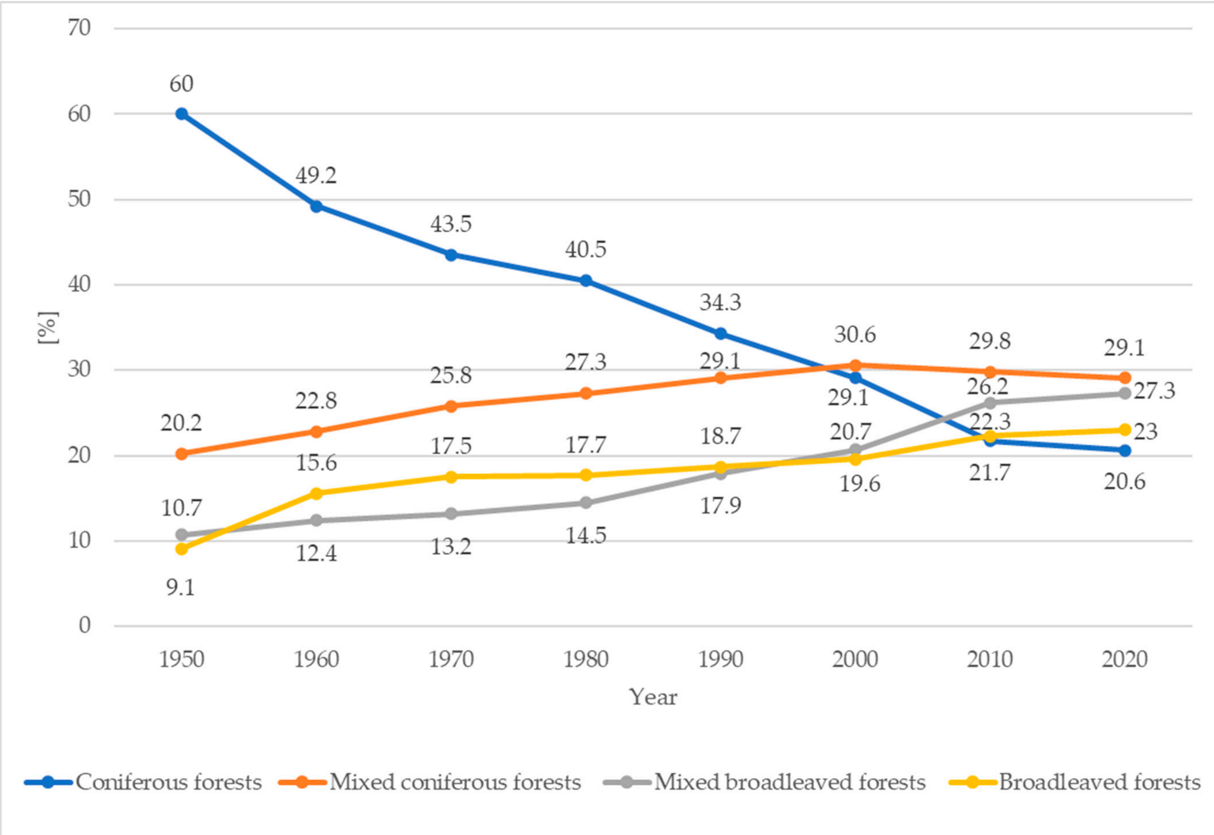

Figure 2. Proportions (%) of the main forest habitat types (distinguished by site fertility) in State Forests. Sources of information: [17,30–33,66–68]. Notes: 1950—data for 1953; 1960—data for 1961; 1970—data for 1968; 1980—data for 1978.

The dynamics of changes in the share of forest habitats of different fertility levels. Over the course of the analysed 75 years (in particular, the 67 years for which data are presented in Figure 2), the structure of forest habitat types underwent a significant transformation: the share of the least fertile habitats decreased three-fold, and the proportion of the most fertile and fertile ones increased two-fold. In the case of the poorest forest habitats (coniferous forests), the decrease rate was higher in the era of socialism (until the year 1990, the average annual decrease was 0.69% of total forest area) when compared to that in the era of democracy (average annual decrease: 0.46% of total forest area). In 2020, the share of mixed coniferous forests in the total forest area was 144% of the value recorded in 1953. A stable increase in the share of mixed coniferous forests was recorded in the era of socialism (average annual increase: 0.24%), whereas in the era of democracy, after an initial increase, the share of coniferous forests decreased to the level recorded in the beginning of this era. More remarkable increases in forest habitat shares were observed in the case of mixed broadleaved forests and broadleaved forests—in 2020, their shares were 255% and 252% of the initial values (1953), respectively. However, a considerable difference can be noted between the eras under study—the increase in the share of mixed broadleaved forests was more dramatic in the era of democracy when compared to that in the era of socialism (an annual increase of 0.31% and 0.19% in total forest area, respectively). This was not the case of broadleaved forest habitats; their share increased annually by 0.26% in the era of socialism and only by 0.14% during the era of democracy.

Causes of changes in habitat fertility. We identified four causes of changes in forest habitat fertility. Firstly, the changes may be due to habitat eutrophication resulting from the deposition of airborne nitrogen compounds [62], which under Poland's conditions is one of the highest in Europe [3]. Even though the total nitrogen content in forest soils in Poland is not high as that in Europe, it is gradually increasing—only in 2009/2012–2015 it increased by 0.1 g/kg, the same value of increase as that in the pH of these soils (by 0.1) [3]. It should be noted that emissions of nitrogen and sulphur are a potential threat to Polish forest ecosystems as the permissible levels of acid depositions are often exceeded [69]. On the other hand, it should be emphasised that the magnitude of air pollution is a factor that is decisively independent of forest management, and depends, inter alia, on national policy in regard to the environment and the country's development.

Secondly, changes in habitat structure within forests managed by the SF may be a result of forest land reclamation, which was carried out since 1955 at a rate of 20–75 thousand ha/year [37,40,70], with a much higher rate in the years 1970–1980 (>100–200 thousand ha/year [68]). As part of forestry undertakings, especially during the era of socialism, mineral fertilisation was applied to forest soils, which directly affected forest resources and related ecosystem services [2]. Over time, however, this form of interference in forest habitats was scaled down, and in the last decades (democracy), fertilisation was applied to soils only in very small areas—for example, in 2010 it was scaled down to 41 hectares of forests under SF management and in 2020, it was scaled down to 15 hectares [41,70]. In addition to fertilisation, certain tree species were planted to enhance habitat fertility [11,64]. The influence of stand species and spatial composition on soil trophic properties was also confirmed by Augusto et al. [71]. An analogous effect was—and still is—achieved via the conversion of stands from conifer monocultures established in too-fertile habitats into mixed broadleaved and broadleaved forests (carried out by SF for about 50 years [7,17]). Admittedly, the crowns of deciduous tree species increase the pH of throughfall precipitation [72].

Thirdly, changes in the habitat structure may be related to afforestation realised in Poland since the end of World War II, which was especially intensive in the period until the late 1970s [26,61,62]. Much of reforested/afforested land was characterised by greater fertility than that found in the forests managed by SF, especially in the period just after the war ended. This was due to the fact that areas with the most fertile soils were formerly deforested for agriculture. For this reason, in post-agricultural areas designated for afforestation, Brunic Arenosols (65.8%) were dominant on the scale of SF. In southern Poland, even more fertile soils were observed—Cambisols and Luvisols. The dominant forest habitat types assigned to these areas include mesotrophic fresh mixed coniferous forest (35.9%) and fresh mixed broadleaved forest (26.5%), covering a total of 62.4% of afforested post-agricultural land [73]. Therefore, the gradual inclusion of afforested land in the acreage of SF has undoubtedly had an effect on the overall structure of forest habitats, causing the proportion of the poorest habitats to decrease (Figure 2).

Fourthly, the documented changes in habitat structure may be a result of the increasingly accurate identification of a habitat's current and potential productive capacity [74]. Pertinent soil physical and chemical analyses and studies on spontaneous natural vegetation, including index plants, have been carried out over the last 20 years [75], with the purpose to improve the precision of forest habitat classification. In this context, pioneer solutions have been implemented in the promotional forest complexes (PFCs) established by State Forests during the era of democracy [76]. PFCs are an original Polish concept of implementing and promoting sustainable forest management.

The share of humid and wet habitats. The grid of forest habitat types in Poland's forests (State Forests) used for forest management planning also takes into account the division of forest habitats listed in Figure 2 in terms of, inter alia, their degree wetness (dry/fresh/humid/marsh) [77]. In 1972, the share of forested humid/marsh (wetland) habitats in the area of state-owned forests was 11.4% [68]. This was the time (the post-war period—socialism) of the implementation of land drainage projects to make wet habitats (forested and non-forested) productive [78,79]. It is worth noting that the draining of wetlands to turn them into pastures and arable fields was carried out not only in Poland, but also in large areas in other parts of Europe [80]. In Poland, a new approach to forest land improvement was assumed after the transformation of the political system from socialism into democracy, which no longer required almost every hectare of land administered by State Forests to be made productive [11,78,79]. As a result of the remedial measures taken (see Section 3.5), the share of forested moist and wet/wetland habitats in SF has increased to 15.8% (calculated based on [33]). This is a positive development in the perspective of preserving biodiversity, as well as increasing the population of trees [81].

3.3. Forest Management Framework

The method of management directly influences forest spatial diversity—the number of forest stories/layers, tree density, and tree size (e.g., differentiated DBHs) as well as the shape of crowns [82–86], the microclimate, insolation that reaches the forest floor at a given stage of stand development, soil moisture and nutrient contents [87]. Forest organisms respond to the specific living conditions shaped by humans; those that can endure can adapt [84].

Polish forestry cultivates high forests almost exclusively [11], with four main management systems being currently in use: clearcutting, shelterwood cutting, selection cutting and special (functional) cutting. The first three systems apply to commercial forests and the last one applies to those with important protective functions [11,50,88]. Under the aforesaid forest management systems, the following can be used: clearcuts, step cuts, group selection cuts and single-tree selection cuts [11,88]. The changes in the way forests have been managed since the end of World War II are shown in Table 2; notably, during the study period, the methods for reporting relevant information/data were modified and data were not always available.

Table 2. Management systems in Poland's forests administered by State Forests *.

Year	1950	1960	1970	1980	1990	2000	2010	2020
Clearcutting system (thousand ha)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3219.0	3190.6
Clearcuts (thousand ha)	16.9	47.8	40.8	34.6	33.5	29.5	26	30.3
Shelterwood cutting system (thousand ha)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3137.5	3378.5
Various types of cuts (e.g., step cuts, group selection cuts) (thousand ha)	58.4	8.3	11.4	8.3	n.a.	n.a.	n.a.	n.a.
Selection cutting system (single-tree selection cuts) (thousand ha)	–	–	–	–	n.a.	n.a.	174.4	110.1
Special (functional) cutting system (thousand ha)	–	–	–	–	n.a.	n.a.	541.6	442.2

* sources: [34,61,62,68,89]; n.a.: data not available; —: no such cutting system.

The dynamics of changes in different forest management methods. Irrespective of the political era under study (socialism vs. democracy), two basic forest management systems dominate in the SF: clearcutting and shelterwood cutting. However, there is a fundamental difference between their dynamics, depending on the examined era: the forest area under the shelterwood cutting system has been increasing, and that under the clearcutting system has been decreasing in the era of democracy (Table 2), even though the total area of forests administered by SF has been augmented [26]. The system of selection cutting has as yet been of minor importance, and was established only in the era of democracy, when Polish forestry put a greater emphasis on biodiversity conservation. The outcome of the new approach to forestry in the democratic era is also the method of management dedicated to forests of special importance for, among others, nature conservation purposes (special management—the special cutting system). Over the last decade, selection cutting and special cutting systems have been used in areas decreasing in size.

Clearcutting system/clearcuts. This management method has a strong impact on the spatial structure of forest ecosystems, as an entire mature stand is removed at once, and a succeeding stand—resulting from forest regeneration over a wide-open area—is even-aged (single-generation), single-storey, and most often comprises pioneer or post-pioneer species [11,90]. Due to the dominant share of the Scots pine [33], which is a pioneer species, as well as because of a considerable area of poor habitats being occupied with forests in Poland (see Section 2.2), the clearcutting method was and still is widely applied as a forest management practice (Table 2; [11,91]). It is worth noting that single-generation forests, being a result of the use of the clearcutting management system, have not been a problem only for Poland's forest ecosystems, but also for those in Europe, where about 75 percent of the total forest area is covered by even-aged forests [3]. In Poland, besides being used in coniferous forests, the clearcutting system is currently used in parts of alder forests [11,50,88]. Two aspects of clearcutting management are worth pointing out: the total and unit clearcut area. The total clearcut area has gradually decreased over the years, regardless of the political era under study (Table 2), despite the fact that the overall area of forests administered by SF has increased [26]. On the other hand, however, there were recorded increases in the total area of clearcutting (e.g., in the year 2020—Table 2). In most cases, this was due to the necessity to remove trees because of large-scale wind damage or forest dieback caused by the impacts of biotic factors [2,61,62,92]. Nevertheless, in 2020 (democracy), only 20% of all timber harvested came from clearcutting. In comparison, in the marketing year 1959/1960 (socialism), 55% of timber mass was harvested under the clearcutting management system [26]. In the era of socialism, the unit area of clearcutting was usually 6 ha. This was justified on practical grounds in single-generation Scots pine stands, because the method was the least expensive and time-consuming, which translated into higher income from the forest [7,48]. Until the 1960s, even if ill-chosen, the clearcutting management system was also used in large areas covered by mountain beech forests [84]. In the era of democracy, clearcutting in 6 ha areas has been used only on certain sites, and the forest areas of smaller size are routinely planned for harvesting with the use of this method [22,88], which is considered a manifestation/evidence of the "greening" of Poland's forestry practices [22,61].

Shelterwood cutting system/various types of cuts. This management method interferes with forest spatial structure to a moderate degree; for a certain period of time, two generations of trees coexist, afterwards an older generation is harvested, so forest cover continuity is maintained [11,90]. Currently, this system is used in broadleaved forests and in alder forests not managed under the clearcutting system [11,50,88]. The implementation of the shelterwood management system has become particularly important in the era of democracy, being used as a measure with the purpose of adapting to the changes in the fertility of forest habitats (see Section 2.2). Concurrently, as can be seen in the historical data (Table 2), in the early stages of socialism, the area of forests under the shelterwood management system was much larger than that under the clearcutting system. At that time, foresters attempted to bring back the species composition and spatial structure of Poland's forests—altered in earlier times—to a more natural state. However, due to the soon-to-be-implemented central planning of the economy (characteristic of socialism), as well as various adverse impacts/overexploitation in forests, these attempts had to be abandoned [93,94].

Selection cutting system/single-tree selection cuts. Under selection management—along with forest cover continuity— multi-generation forests have been maintained [11,90]. This kind of management is currently recommended for fir (*Abies alba*) forests and mountain Norway spruce (*Picea abies*) forests [11,50,88]. Forests managed in this manner currently account for only 1.5% of the total forest area administered by SF (the value derived from Table 2). In comparison, in Switzerland, about 8% of the total forest area is managed this way [95]. On a European scale, about $\frac{1}{4}$ of forest area is covered by multi-generation forests [3]. Thus, evidently, in Poland's forests managed by SF, the proportion of unevenly-aged forests is comparatively low, with a noticeable decreasing trend in recent years (Table 2). The downward trend may be due to the process of degradation and resultant reconstruction of artificial spruce monocultures in mountainous areas, which have been proven to have little resistance to adverse abiotic and biotic factors [6].

Selection management as well as various cuts under the shelterwood cutting system have beneficial effects on the diversification of the spatial structure of forests [11,48,54,90]. At a stand level, the multi-layered forest structure allows for a more efficient use of light, water and soil nutrients by forest vegetation [11,86]. Also, the provision of ecosystem services, such as biodiversity maintenance, is generally more advantageous compared to the establishment of single-generation forests, especially young ones [3,48,90,96]. On the other hand, however, the selection cutting system is quite expensive and difficult to implement [11]. It also does not provide solutions to all dilemmas and issues concerning nature. Noted was an increased share of ruderal plant species and increased homogenisation of the undergrowth when this practice was applied [1,54,97]. Nonetheless, analogous phenomena are also observed in unmanaged forests [54].

Special management system. Special management is related to forests with marginalised or excluded commercial functions (e.g., designated nature reserves, and parts of protective forests [11,50,88]). Although such types of forests existed in the era of socialism [26], a special mode of their management has become a part of management planning only in the era of democracy. In the last decade, there has been observed a downward trend in the area of forests under the special management system (Table 2). Nevertheless, in the same decade, the overall area of forests in nature reserves and that of protective forests generally increased [26]. The indicated inconsistency can be explained by the less-restricted nature conservation measures undertaken in some protective forests (under the management of SF). Another reason behind this could be the relinquishment of some of constraints—initially introduced under requirements related to forest management certification. In light of the imperative to respect Poland's nature conservation law, less-restricted nature conservation measures would be unlikely in the case of nature reserves [45,98].

3.4. Age Structure of Forest Stands

Forest biodiversity is determined, inter alia, by the age structure of stands [3,28]. Forest age structure can be considered at a stand level (to which a reference was made in Section 3.3: a single- or multi-generation stand, depending on the forest management system used at the site), or at the scale of the entire country. Under the present study, forest biodiversity was determined at the scale of national forests managed by SF (Table 3). It should be noted that the co-presence of stands of different ages—combined with open spaces—shapes a mosaic of the environments valuable for maintaining the diversity of different groups of organisms, for instance bats [10,91,99].

Table 3. The proportion of area covered by stand age classes in forests managed by SF *.

Year	1950 [1]	1960	1970 [2]	1980 [3]	1990	2000	2010	2020
Age class I (1–20 years old) (%)	23.2	29.4	24.4	21.6	14.2	12.0	10.8	10.9
Age class II (21–40 years old) (%)	22.8	23.1	21.6	21.2	24.7	20.1	15.0	13.4
Age class III (41–60 years old) (%)	18.5	18.0	19.1	21.5	20.5	22.7	24.4	19.2
Age class IV (61–80 years old) (%)	13.1	13.6	14.6	16.0	18.1	19.4	19.1	20.8
Age class V and older (>80 years old) (%)	14.3	13.4	14.1	15.2	18.1	20.9	23.0	24.0
Stands under the selection cutting system (uneven-aged) and those in the restocking class (with distributed age classes) (%)	n.a.	n.a.	3.0	3.1	3.3	4.1	6.2	9.5
Felling sites, blanks and irregularly stocked open stands, and not reforested/afforested forest land (%)	8.1	2.5	3.2	1.5	1.1	0.8	1.5	2.2

* Sources: [30–33,75,89,94]. [1] data for 1948; [2] data for 1967; [3] data for 1978; n.a.—data not available.

The dynamics of changes in the age structure of forest stands. In the period 1948–2020, the age structure of Poland's forests administered by SF meaningfully changed (Table 3). The proportion of the area covered by younger stands (of up to 40 years old) decreased from 46.0% to 24.3%, with a lower decrease rate in the era of socialism (approx. 0.16%/year) compared to that in the era of democracy (approx. 0.49%/year). As for the other age classes, the proportions of their areas increased over the entire period under study—with differentiated dynamics: lower proportions for 41–80-year-old stands (middle-aged, age classes III and IV) and higher proportions for those that were older (age class V and higher; tree stands under the selection cutting system and those in the restocking class). The area covered by middle-aged stands, in age classes III and IV, increased from 31.6% to 40.0%. The increase rate was lower in the era of democracy (about 0.05%/year) than that in the era of socialism (about 0.16%/year). In contrast, the area of forest stands containing older trees increased from 14.3% to 33.5%, with a lower increase rate (approx. 0.17%/year) in the era of socialism compared to that observed in the era of democracy (approx. 0.40%/year). A natural consequence of the evolution described above is the change in the average age of forest stands. During the period under study, the average age of forest stands increased by about 20 years. Initially, reaching the average increase of 10 years took about 45 years (the era of socialism), whereas the duration of the next average increase of 10 years was 30 years (the era of democracy).

Young stands (1–40 years old). The initial dominance of forest stands classified in younger age classes (in the era of socialism until the early 1980s) was related to forest restoration activities, which were undertaken for the regeneration of the forests over-exploited during World War II, as well as actions carried out with the purpose of intensive post-war reforestation/afforestation [17,26,62,100]. Nowadays, at the European level, only in Iceland, there is a relatively large proportion of forests in the regeneration phase being recorded [3]. In Poland, due to the shrinking of reforestation/afforestation areas, and also restrictions regarding clearcutting management introduced in the era of democracy (including the reduction of the size of clearcut areas—see Section 3.3)—the proportion of area covered by younger stands has considerably decreased, particularly that covered by the youngest stands (1–20-year-old trees). In this regard, it is worth noting that in Table 3, the area covered by this generation of trees is also included in the category "Tree stands under the selection cutting system..."; for the most part, these stands appear in multi-generation forests [33]. A continuous reduction in the area covered by the youngest stands may pose a future risk to forest sustainability and the proper age class structure [61,62]. The diversification of forest age structure is a key driver of biodiversity, as it enriches habitats with a range of species associated with each stage of the successional forest cycle [10]. In Poland, the arrangement of the areas covered by trees in certain age classes (a comparative level, yet not necessarily optimal) is considered "normal" if stands of the age classes I and II cover about 18% (each) of the forest area [33]. The values presented in Table 3 evidently differ from those.

Middle-aged stands (41–80 years old). The slowed-down afforestation/reforestation process has influenced a successive increase in the proportion of the area covered by middle-aged forests (with various fluctuations in age class III forests). At the turn of the 20th and 21st centuries, age classes II and III showed a dominant trend, and since 2010, age classes III and IV have prevailed (41–80 years old) (Table 3). The current proportion of stands of this age slightly exceeds the average. This is considered "normal" in the system of age classes in Poland's forests, where stands in age classes III and IV should each cover about 18% of the forest area [33]. Available data show that in the majority of European countries, forests in the intermediate development phase also prevail and cover considerably large areas [3]. It is worth noting that forest stands composed of species such as pine, spruce, birch (common in Poland's forests) in the intermediate development stage (50–100 years old) are characteristic of the highest biomass production, as was reported in Sweden [101].

Old stands (>80 years old; tree stands under the selection cutting system and those in the restocking class). After the collapse of Eastern European socialism, old-growth forests were defined as threatened by the major socio-economic restructuring processes that occurred in the transition of the economy from state-led to market-oriented [2]. However, this has not been the case of Poland's forests as they have mostly remained state property [102,103]. Currently, 81–100-year-old tree stands constitute 15.2% of the forest area under the administration of State Forests. Under the "normal" arrangement of the age classes, they should account for approx. 18% [33]. Stands older than 100 years of age (tree stands under the selection cutting system and those in various stages of regeneration) constitute another 18.3%, even though their assumed share under the "normal" arrangement of the age classes amounts to approx. 9% [33]. Thus, a noteworthy over-representation of the oldest stands in relation to the aforesaid "normal" pattern is observed. The increase in the proportion of older stands in managed forests, related to the process of management transformation towards SFM has been observed not only in Poland, but also throughout Central Europe [49,63,104]. In several European countries (the Netherlands, Norway and Portugal), the proportion of forest stands in the mature phase of development is considerably higher (in terms of the area covered) compared to that of stands in other developmental phases [3]. This is related, for example, to an increase in the rotation age of forest tree species [63]. Currently, in Poland's forests managed by SF, depending on the geographical region and habitats, the rotation ages are 70–140 years for Scots pine (typically 110–120 years); 80–130 years for Norway spruce; 90–140 years for fir (*Abies* sp.); 100–140 years for beech (*Fagus* sp.); 120–240 years for oak (*Quercus* sp.) [50]. Apart from the adopted rotation age, the presence of older stands may be achievable thanks to the designation of many protected areas throughout forests administered by SF [26,98,105]. In general, mature forests provide ample ecosystem services related to, inter alia, biodiversity, which are more favourable compared to the presence of young forests [3,10,101]. Older forests are characterised by greater spatial diversity and the presence of specific microhabitats (which is an element of diversity at the ecosystem level) and support the existence of numerous species, often appearing in greater abundance than they do in younger forests [10,96,101,106]. Of these species, some appear only in older stands [87]. The presence of old trees (even individual specimens) has great aesthetic value, as they shape the diversity of forest landscapes [11].

Average age of stands. The gradual increase in the average age of forest stands managed by SF (more intensive in the era of democracy—Figure 3) reflects the general direction of changes in Poland's forests.

The average stand age (64 years) in forests under SF management is higher than that that in privately-owned forests (58 years [107]). The value of the calculated average age of privately-owned forests results from, among other factors, the afforestation of private lands at the beginning of the era of democracy. As a result, considerably large areas covered by young forests contributed to the lowering of the calculated average value. At the same time, the average stand age of forests managed by SF is of a lower value than that determined for protected forests in national parks (92 years [107]). This is due to long-term strict protection (for example, via taking them out of use). With the current average age of 64 years (Figure 3), older stands in state-owned forests (those administrated under SF) are dominated by fir *Abies* sp. (which are on average 81 years old), hornbeam *Carpinus* sp. (77 years old) and beech *Fagus* sp. (73 years old).A lower rotation age (40–80 years) results in an age below the average for all SF-administered forests (64 years—Figure 3) for poplar *Populus* sp. (52 years) as well as alder *Alnus* sp. and birch *Betula* sp. (58 years) [33,50]. It is worth emphasising that in the period 1950–2010, the average age of stands in Poland's forests administered by SF increased by 18 years (Figure 3), whilst in Europe as a whole, it decreased by 7 years [108].

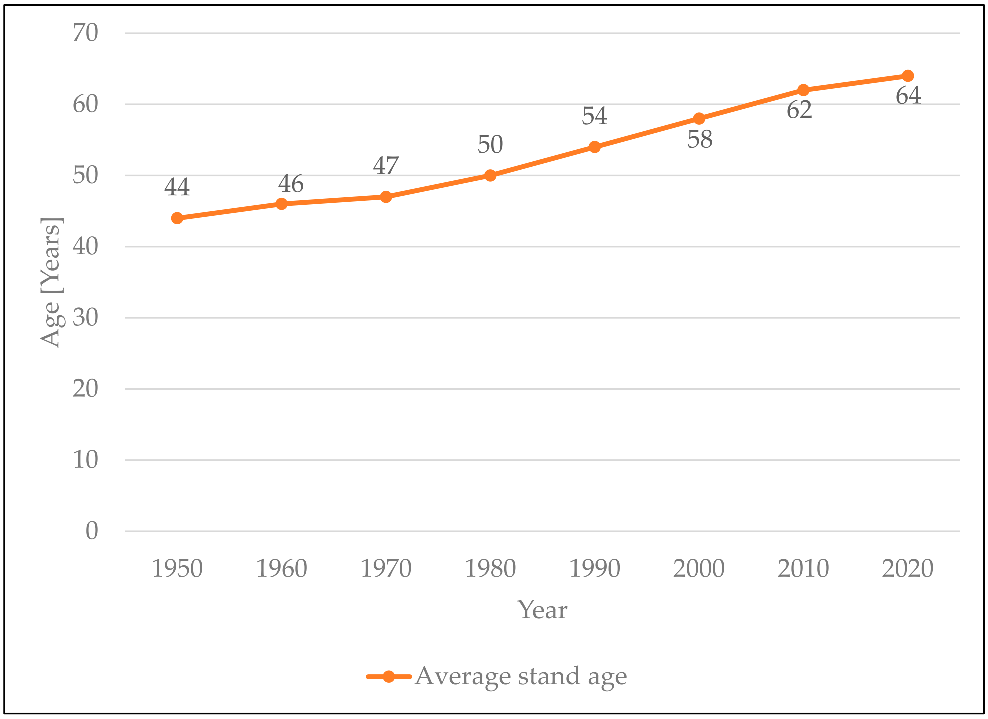

Figure 3. Average stand age (years) within state forests. Sources of information: [30–33,75,89,94]. Notes: 1950—data for 1948; 1970—data for 1967; 1980—data for 1978.

3.5. Issues and Directions of the Protection of Forest Ecosystems in Poland

In the field of the protection of biodiversity at the ecosystem level in Poland's forests, there still remain problems and dilemmas to be solved (Figure 4).

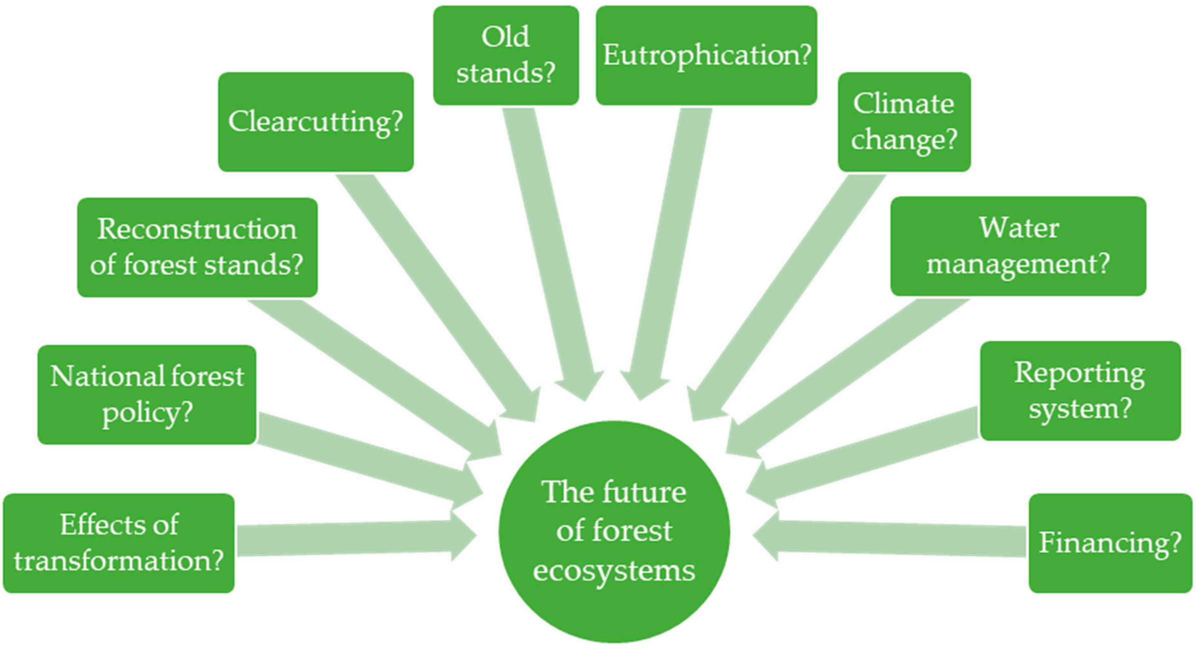

Figure 4. Problems and dilemmas of enhancing forest biodiversity at the ecosystem level in Polish forests/forests administrated under State Forests.

Effects of transformation of forest management model. Forest management objectives, adopted in Poland at the beginning of the era of democracy and thereafter amended, have rendered the realisation of forest production functions conditional on the needs of ecosystem preservation being taken into account [109]. This is a meaningfully different approach to that implemented in the era of socialism, where the production function played a distinctive, superior role resulting in considerable anthropogenic changes in forest ecosystems [48]. Not without significance for the course of changes in Polish forestry is the fact that SF, as the organisation managing the majority of the country's forests, has been the most important forest policy maker at a national level [76]. Many positive changes have already been achieved; nevertheless, the full effect of forest management transformation on the enhancement of forest ecosystems is still to be seen. Considering the now-existing alteration of some forest ecosystems, the model of a semi-natural forest with a diversified species and spatial structure [11,48,49] is not always possible to implement in the time of one generation of a stand [48]. In view of this, it is necessary to ensure future, legal, organisational and financial measures, for continuing the instigated processes, as they are necessary in boosting the diversity and security of Poland's forests.

Lack of revised national forest policy. In Poland, the policy on forests and forestry in force was adopted in the year 1997 [21]. This means, inter alia, that there have been no solutions included that were developed afterwards, as part of the process of FOREST EUROPE (e.g., the resolution "Conserving and Enhancing Forest Biological Diversity in Europe", MCPFE 2003 Vienna Resolution 4), or those related to Poland's accession to the European Union (2004) and the implementation of a network of nature protection under Natura 2000 [110]. The decisions/recommendations adopted under the framework of these processes address the issues of the protection, conservation and management of forest ecosystems in practice. Even though in the forests administered by SF or those protected in national parks (designated as state-owned lands) many consecutive endorsements have been already implemented [50], there are forests under other forms of ownership, where the situation is not as promising. This is because of the lower requirements for forest management documentation [20] as well as unsolved organisational management issues. Consequently, in view of safeguarding the richness of all forest ecosystems in the country, a national forest program (NFP) should be legitimately established, which is not the case in Poland, even though comprehensive works on the NFP proposal were carried out in 2013–2016, with a wide range stakeholders participating. One of the issues debated was the better recognition of the necessity to safeguard forest biodiversity.

The reconstruction of tree stands. The first, initial component of the forest management transformation model, implemented as early as in 1970s (under socialism) [7,17], considered a gradual replacement of coniferous stands artificially planted on fertile forest sites in the 1800s and in the era of socialism, by mixed and broadleaved stands made of species indigenous to a given forest habitat [5]. Therefore, in the years 1948–2020, the proportion of forest area covered by coniferous tree species decreased from the initial 87.1% to 75.6% [33,94]. This approach enabled the application of more complex forest management systems (see Section 3.3), which enhanced the differentiation of the forest's spatial structure [11]. On the other hand, however, recovering the spatial (and species) structure of forest ecosystem may not be welcomed by society, with expressions of dissatisfaction and low acceptance due to their individuals' own preferences when it comes to the forest landscape. The results of the study by Edwards et al. [111] revealed that from the perspective of the surveyed persons, the forest should be full of light, dry and of low density. Dense understorey vegetation is not appreciated, as it reduces visibility and causes a loss of the sense of safety. Poland's State Forests are in general accessible to the public, who contributes to shaping the forest ecosystem through the mechanism of public consultations on draft forest management plans [112]. In consideration of the conflict of interests between forest management practices implemented towards forest restoration and public expectations, as for forest appearance, it is important to increase public awareness of the reasoning behind the naturalisation of forest spatial (and species) structure, e.g., through educational campaigns carried out by SF.

Dilemmas of the clearcutting forest management system. The clearcutting management system (which in Poland concerns a forested area of over 3 million ha—see Section 3.3) is considered to strongly and negatively interfere with the forest ecosystem [11,113]. The assumption is that the greater the clearcut area, the greater the adverse impact [96,114]. Clearcutting results in local climate changes followed by, e.g., the fast decomposition of forest litter and the leaching of plant nutrients from the soil [11,90]. At the same time, the pioneer stage of forest regeneration is consolidated, and forest age, species and layer structures are most often in decline [11,48], which decreases forest resistance to damage from biotic and abiotic factors [11]. In order to limit the negative consequences of clearcutting, since 1995, it has been recommended (by State Forests) to leave behind old-growth tree groups with all the lower layers [11,22]. Apart from the above, the clearcutting system remains one of the elements of forest management which evokes negative emotions in Polish society [115]. However, it should be noted that there are a number of forest species for which the presence of open spaces is essential for proper functioning. For example, studies on bat activity carried out on Poland's Scots pine stands showed the beneficial effects of clearcuts (and 1 m high young forests as well) on bats [91], which was confirmed via the study results obtained outside Poland [116,117]. Likewise, a considerable increase in undergrowth vegetation diversity after cutting trees in coppice stands was noted by Decocq et al. [87]. Hence, the use of clearcuts should not be completely abandoned, especially if the restrictions regarding their maximum area are respected.

Large areas covered by old stands. Apart from the beneficial effects of old-growth forests (see Section 3.4), the ageing of forests may be associated with certain problems of forest management. An increased stand age and volume leads to a greater susceptibility of stands to disturbances [118,119], resulting in damage due to abiotic factors [62], such as strong winds [11,120], biotic factors such as insect outbreaks [120] and anthropogenic factors, such as pollution [121]. The ageing of beech stands, for example, may lead to top soil acidification, lower nutrient concentrations, and consequently, to plant species homogenisation in the undergrowth, which means that older stands do not always generate better conditions for the conservation of species richness [63,84]. In view of forest management, wood from old-growth trees is not profitable enough as it depreciates with time, thus implying economic losses [61,62]. The profitability of wood production is an important issue. If the optimal economic rotation age was taken into account, then, e.g., for Scots pine (the dominant species in forests managed by SF), it would range between 75 and 91 years, rather than 110 and 120 years—as is currently the case in Poland's forests [122,123]. Decreasing the rotation age was postulated by the authors of the above calculations, in order to meet legal requirements as regarding SF's self-financing [123]. It is important to note that the large area of old-growth forests will at some point require regeneration; thus, there will be established young forests. Young forests do not yield good profits from large-size timber and require considerable maintenance expenditures. In Poland, there is very high demand for wood, which is first of all due to its advanced wood processing industry [29]. Mature wood is very valuable for the furniture industry (juvenile wood is used by the paper industry). Timber and its products manufactured in Poland have been exported to European and non-European markets [29], so a reduction in the supply of wood from state forests will result in lesser wood availability not only in Poland, but also in other countries. The presented issues/dilemmas require further analysis and the development of pertinent procedures in order for the optimal solution to be chosen for a specific place, time and in relation to the needs of people and nature now and in the future.

The gradual eutrophication of forest habitats. The risk of eutrophication concerns about 60% of Poland's area, mainly its central part, but also the north-eastern part (the latter is a region with a low level of atmospheric pollution) [62]. A soil nitrogen surplus can lead to nutrient imbalances, growth reduction, nitrogen leaching and groundwater pollution [3]. Gradual eutrophication (see Section 3.2) may therefore pose a threat to the sustainability of forest ecosystems [61,62] and lead to forest homogenisation [124]. Negative changes in the undergrowth can be partially reduced by controlling the species composition of the stand [125]. Eutrophication poses a particular threat to rare habitats on sites with unfavourable fertility conditions, e.g., the Central European lichen Scots pine forests (communities of *Cladonio-Pinetum* association) that appear in Poland and that are protected under the Natura 2000 program (code 91T0) [126]. Solving the eutrophication problem can be very challenging due to the nature of its causes which are beyond the control of forest managers, and therefore require the comprehensive, interdisciplinary cooperation among many different institutions.

Ecosystem diversity and climate change. One of the most important contemporary problems of biodiversity protection is climate change [127]. The habitats most dependent on water resources are particularly vulnerable to climate change impacts [128]. In Poland, amongst the forests in marshy and wet habitats, floodplain forests comprise the richest ecosystems of broadleaved forests [81]. Higher mean temperatures (these every so often being extremely high) and recurrence of droughts increase the risk of habitat overdrying [80]. As a result, forest trees are more and more vulnerable and threatened by dieback [62,127,129]. Global warming also poses the risk of frequent fires [29,53]. Furthermore, every so often, forests experience extreme weather events and their impacts [127]. In response to it all, some counteractive actions have been implemented by SF, with a scope and scale that changes over time. In the whole period under study, there have been fire protection measures undertaken, in light of the expanding scale, especially in the 21st century, due to a greater fire risk attributable to prolonged drought periods caused by climate change. In addition to technical solutions that allow a reduction in the risk of fire/fire damage, such as the forest fire detection system that enables the relevant actors to take quick actions towards fire control [62,70,80,130], over the years, there was a fire hazard map for forests (that is open-access) that was developed and is updated twice a day in the period from 1 April to September 30 [131].With the use of this tool, some forest areas can be periodically restricted or closed for use by the general public [20] so as to protect forest ecosystems against accidently set fire. All these solutions should also be implemented in the future. Faced with uncertainty about the conditions for the further development of a given forest, in Poland's forests there is a complex cutting system that has been implemented [11,48], and that includes shelterwood or selection cuttings. These forest management methods contribute to the improvement of forest spatial structure. The diverse and rich structure of forest ecosystems increases forest continuity, resilience and stability [48,54,84,132], as well as compensating for the mortality observed after the perturbations [86]. Since the transformation of Poland's political and economic system, complex cuttings have been more frequently implemented compared to the era of socialism (see Section 3.3), which has contributed to the shaping of multi-aged forests, as well as natural ones [63]. The process of transformation from a regular into an irregular form of forests develops gradually [11,132] and should be continued in the future. An element supporting the diversification of forest spatial structure (also biodiversity) is the planting of trees which form a lower layer of crowns as well as plants that form an underlying layer of vegetation (understorey) [11]. In the case of the understorey, the extent of planting has been quite small in the last two decades [29,75]. This may be related to the lower level of needs for such activities (many tasks have been already accomplished), and also to the requirements of the Natura 2000 program. Planting additional trees and shrubs may lead to the degradation of protected habitats, such as Central European lichen Scots pine forests (code 91T0), thermophilous oak forests *Potentillo albae-Quercetum* (91I0) or habitats of the most valuable and threatened plant and animal species. Therefore, care should be taken when introducing additional vegetation. Supporting forest ecosystems under climate change includes enhancing natural water retention in forests (so-called small water retention) which has been implemented for some time in the era of democracy and needs to be continued, bearing in mind that Poland's forests were subject to destructive drainage operations in the 1800s and 1900s.

Water management in forests. In forests managed by State Forests, the estimated area of forest drainage was about 13% [11], i.e., 850 thousand ha [79]. Polish foresters tried to avert this practice [133], as wherever drainage works were carried out, large, sometimes irreversible hydrological changes were observed in forest ecosystems, especially those situated in forest swamps and peat bogs [134], resulting in biodiversity loss [135]. A decrease in water resources in forest habitats is particularly hazardous. In view of long periods of drought due to ongoing climate change, bearing in mind the above considerations, as well as the transformed priorities of forest management [11,78,79], in the era of democracy, as early as in the second half of the 1990s, the first works began towards the restoration of water resources in forests [79]. The devices used included gates, river bars, dikes, fords, overspills, fish ladders, ditches and small retention reservoirs. Other solutions involved the implementation of soft engineering elements, such as the introduction of woody, shrubby, and/or herbaceous vegetation to enhance water retention potential and to contribute to the protection of riverbanks [80,81]. In the 21st century, these works were intensified and financially supported by the EU's funds [61,62,81]. The total level of retention achieved as a result of the actions taken in 2007–2015 exceeded that planned at approx. 32.3 million m^3 of water, and the actions taken in the period 2016–2020 resulted in the retention of another 2.5 million m^3 of water [70,136]. Notwithstanding the unquestionable successes at the scale of State Forests, it should be noted that the situation in Poland is still quite unfavourable—Poland ranks as one of the last countries in Europe in terms of available water resources [80,81]. Therefore, it is necessary to continue the activities towards water retention, which will benefit both forest ecosystems and non-forest ecosystems spatially and hydrologically. These are first and foremost water bodies, swamps and peat bogs. Urgent works related to water retention should also be undertaken outside the area administered by State Forests. The described above measures concerning small retention are especially recommended due to their low cost [81]. It is important to stress that restoring water retention largely contributes to the protection and restoration of ecosystems, especially those dependent on hydrogenic habitats, and supports the implementation of the Sustainable Development Agenda in terms of, inter alia, halting biodiversity loss (Goal 15, [137]). On the other hand, it should be noted that so far achievements in water retention in Poland's forests (and beyond) have been in part due to the work of beavers, the population of which in Poland has considerably increased from approx. 200 specimens in 1960 [37] to about 142,000 specimens in 2020 [43].

Reporting systems. Poland has been reporting on the state of forests under the framework of FOREST EUROPE. In the submitted reports, Polish forests that are strictly protected, compliant with the Nature Conservation Act [45], are referred to as "forests undisturbed by man". Yet, this approach does not take into account all the nuances of Polish forest management and its impact on the naturalness of forest ecosystems. It is estimated that at the beginning of 2020, at least 530 000 ha of forests managed by State Forests (7.5% of the SF area) was completely excluded from timber harvesting. Apart from forest nature reserves, this area comprised other types of strictly protected forests, the protection zones for selected species, xylobiont refuges, wetland habitats, some protective forests and FSC reference forests, all designated in line with national law or internal instructions and good practices, and applicable only within SF [138]. In comparisons with the average percentage of forests undisturbed by man in Europe (2.2% [3]), the aforesaid value of 7.5% of the SF area excluded from logging seems to be a good result. This value reflects the reality of Poland's forests undisturbed by man better than that obtained by means of the method used in the reporting system of FOREST EUROPE. The method for determining the area of forests undisturbed by man could be verified in the future. This might improve the social perception of forest management in a situation where more and more people expect foresters to focus on the protective functions of forests (and not those related to wood production). It should be emphasised that at least 23% of Poles believe that the primary task of State Forests should be nature conservation [139].

Financing the protection of biodiversity. The main source of income for State Forests is sale of felled timber [12,136]. Supporting the non-productive functions of forests, in particular the function of biodiversity safeguarding, can increase the costs of management and result in lower profits [140]. Currently, State Forests management is profitable, which should allow for the maintenance of the course of positive changes in regard to biodiversity, recorded step by step since the end of World War II. This trend may also be influenced by the considerably strong social pressure focused on protecting the country's natural resources that arose along with transformation of Poland's political system and economy. Increasing the area of Natura 2000 sites that are under strict protection, as planned in the EU Biodiversity strategy for 2030 [141], is also relevant. A consequence of expanding the area of protected forests may be a lower supply of timber, as well as a reduction in employment in the forest wood sector. Now, it is of great social importance and provides employment for almost 0.5 million people in Poland [29]. It is necessary to anticipate a scenario in which profitability comes to a halt, so as not to lose the so-far-attained effects of foresters' work in the field of biodiversity protection and restoration in Polish national forests. Within this context, the aforesaid social considerations are not without significance.

4. Conclusions

The effects of the evolution of management of Poland's forests carried out by State Forests National Forest Holding (SF) in the period 1945–2020 on forest biodiversity at the ecosystem level were analysed with the use of selected indicators (naturalness; habitat diversity; forest management system; forest stand age structure). Regardless of the deficiency of precise data or any statistics for the years considered in this study, in some situations, it was possible to determine the trends and dynamics of changes in particular parameters related to ecosystem diversity in Polish forests. Such results were interpreted on the basis of a comprehensive literature review, even if not all possible sources of information were analysed. Nonetheless, the sources used allowed us to look at the analysed parameters and problems from different angles.

Even though the period of 75 years does not seem as a long time in view of a forest ecosystem's lifespan and functioning, the obtained results indicate improvements in the ecological condition of ecosystems in the examined forests which, over the study period, were intensively influenced by political, economic and social changes at a national level. During the time of a centrally planned socialist economy (the era of socialism: 1945–1989), there were dynamic increases observed in the area of semi-natural forests and in the share of broadleaved forest habitats. The proportion old forest stands, as well as the stand average age, increased at a relatively slow rate. The proportion of poor coniferous forest habitats dynamically decreased. The clearcutting forest management system prevailed, and as a result the spatial structure of the forest was depleted. Along with a transition from a centrally planned economy to a market economy (the era of democracy—ongoing since 1990) and forest management transformation, in Poland's forests, there have been observed increases in the area of forests undisturbed by man, and the shares of mixed broadleaved forest habitats as well as wet and wetland/swamp forest habitats. The proportion of older stands and the average age of stands have also increased at a relatively fast rate. The area of forests managed under the shelterwood cutting system has expanded, which can help maintain biodiversity within the forest ecosystem through boosting a forest's spatial structure. The area of forest plantations has considerably decreased. In general, regardless of the era under study, there has been a decreasing trend observed in the proportion of the youngest stands, which is particularly unfavourable in view of forest sustainability.

All in all, the evolution of forest management in Poland's forests/those administered under State Forests during the whole study period has led to the restoration of/an increase in forest biodiversity at the ecosystem level, which was also perceptible in the era of socialism, when Poland's forestry had to face barriers related to the centrally planned and regulated economy. Thanks to the gradual change in forest management priorities towards treating forest as an ecological system performing multiple functions as well as the implementation of closer-to-nature forestry, it was possible to enrich the species, ages and spatial structures of forests and enhance their diversity and sustainability. Further studies are needed on long-term relationships between forest management and forest plant communities, which will require a compilation of comprehensive data (not available at the moment). Likewise, in the future, it would be useful to carry out analogous smaller-scale (regional-level) studies on the diversity of habitats and other analysed parameters, so as to capture their specific trends, the threats they face and the need to counter the risks. Problematic, however, is the lack of comprehensive information related to forest management development in Poland right after 1945. Additionally, changes in the administrative boundaries of individual regional units of the state forests introduced over time affect the consistency of the study's results.

Even with the accomplishments referred to in the present study, in the field of the protection of the ecosystem-level biodiversity in Poland's forests, there still remain unsolved problems, such as organisational (ensuring the further reconstruction of forest stands, and improving water relations), political (revising the national policy on forests), financial (bringing together costs of biodiversity protection/restoration and State Forests' self-financing), conceptual (addressing the issue of old-growth stands, and the pros and cons of clearcutting) and natural and anthropogenic (related to climate change and the eutrophication of habitats) issues. In some cases, actions beyond Poland's forestry, and even beyond the country's borders, will be necessary to carry out meet these challenges.

In times of urgent necessity to protect biodiversity on a local, national, continental and global scale, the method of forest management, adopted objectives, priorities and solutions are of great importance. The basis for their arrangement should be, inter alia, long-term experience and comprehensive knowledge gained worldwide, which—under similar or changing external conditions—will make it possible to avoid evident mistakes or provide the right solution. The results and their interpretation presented in this paper provide useful information that can be used to improve forest management with regard to its impact on biodiversity at the ecosystem level.

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