

Article

The Impact of Different Management Scenarios on the Availability of Potential Forest Habitats for Wildlife on a Landscape Level: The Case of the Black Stork *Ciconia nigra* (Linnaeus, 1758)

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Abstract: This study analyzed the effects of various forest management scenarios on habitats of the black stork, which has very specific requirements: it needs extensive forest complexes with a significant proportion of old trees for nesting, and bodies of water for foraging. The relationship between different forest management scenarios and the presence of black storks was examined in a large forest complex (9641 ha of managed stands) surrounded by wetland areas. A simulation of forest development under three management regimes was performed for eighteen 10-year periods. Management scenarios differed in terms of the species composition of stands, rotation age, retention tree areas, and silvicultural treatments. The basic scenario was characterized by a species composition consistent with natural-type stands, but with higher proportions of Scots pine and oak, with rotation ages of 100 and 140 years, respectively, managed by the shelterwood system. The productive scenario featured monospecific stands with a dominance of Scots pine with a rotation age of 90 years, harvested by clearcutting. Finally, the long rotation scenario introduced mixed tree stands with a long rotation age (110 and 180 years for Scots pine and oak, respectively). As compared to the basic scenario, the total harvest volume was greater by 14.6% in the productive scenario and smaller by 16.2% in the long rotation scenario. The availability of habitats for black stork changed as a result of different species compositions and age structures of tree stands. A considerable decrease in rotation age (below 100 years) and the elimination of oak trees from stands in the productive scenario adversely affected potential habitats for black stork. On the other hand, the factors favorable to black stork habitats were a long rotation age, the presence of oak in stands, the application of shelterwood cutting, and the use of retention trees in the long rotation scenario. This scenario would probably also benefit other bird species legally protected under the European Union's Birds Directive.

Keywords: multifunctional forestry; biodiversity; management intensity; rotation age; nesting trees; nesting site; landscape; Natura 2000

1. Introduction

Nowadays there is an increasing demand for multifunctional forestry with the underlying idea of using wooded areas for economic, social, and ecological purposes [1–4]. From an environmental point of view, one of the main tasks of forest management is to ensure habitat availability for wildlife. Due to the very high share of managed forests in the overall area of woodlands, they constitute a critical

element in sustaining biodiversity. The planning and evaluation of forest management and ecological restoration may be aided by various biodiversity indicators, depending on the adopted management scenario. Such indicators may also serve as thresholds for certain characteristics that should be attained or maintained to ensure the successful implementation of a given scenario [5]. Habitat conditions may be described using structural forest indicators, e.g., deadwood quantity and quality, vegetation structure, as well as temporal and other structural indicators (age of canopy trees, forest continuity). Habitat quality is also reflected in the abundance and diversity of species. Diversity indicator groups for European forest ecosystems include not only mammals, reptiles, invertebrates, vascular plants, bryophytes, lichens, and fungi, but also birds [6]. While many bird species are generalist, some can be considered true habitat specialists [7]. These include woodpeckers and raptors, which are deemed efficient indicators of species diversity and of the abundance of co-occurring birds [7–13]. The application of the most exigent species requirements as guidelines for ecosystem management is likely to address the needs of many cohabitants [14]. Thus, some birds have a high potential to function as umbrella species [15,16].

One of such umbrella species is the black stork [17]. This threatened species is internationally protected and listed in Annex I to the EU Birds Directive [18]. Importantly, it shares characteristic biological communities with other threatened taxa [17]. The black stork has specific habitat needs [5,19]. Its nests are located mainly in old stands, in trees with high diameter at breast height (DBH) and well-developed crowns, which are larger than the surrounding ones in a stand. Thus, on lowland sites black storks often choose oaks for nesting trees. They have a preference for stands located near rivers, at a certain distance from the ecotone, and feed predominantly on small fish and other aquatic animals in shallow bodies of water and wetlands [20,21].

Since the second half of the 19th century, the abundance of this species has been in decline, especially in Central and Western Europe [22]. While this trend has been reversed in many countries, it remains negative in many regions [23]. The underlying causes have been identified as intensified forestry and habitat degradation [22,24], including the destruction of nesting habitats, with the result of impaired breeding opportunities [25]. More than 50% of the European black stork population is currently distributed across Eastern Europe [26,27]. In Poland, this species nests in forests throughout the country. Its abundance is estimated at 1400–1600 pairs, which corresponds to 12.8% of its overall European population [28–30].

Due to their mobility, birds tend to react quickly to changes occurring in the environment. While some species possess considerable adaptation capacity and may easily adjust to altered conditions, other species leave the affected areas in search of habitats that would ensure optimal nesting sites, safety, and abundance of food [31]. Furthermore, the same species may use different kinds of habitats for different purposes, in which case certain types of sites must be in close proximity [32]. Since forest management is based on the implementation of certain scenarios, their quality has a direct bearing on habitats. In developing management scenarios, only a few selected forest functions can be taken into consideration. Their influence may be evaluated on the basis of structural indicators serving as proxies for forest biodiversity. In conjunction with knowledge about the ecology of a given species, such indicators may be used to make inferences about the benefits or adverse effects of the adopted solutions. Researchers have developed numerous models for assessing wildlife habitat suitability [5,33–35]. Habitat quality value can be calculated on different spatial scales: an individual stand, a group of stands, an entire forest, or a landscape. To ensure an optimal number of habitats on a landscape scale, especially in the long term, it is necessary to conduct appropriate analyses and simulations when designing management plans as decisions made at that stage (concerning the felling system, rotation age, and species composition) may positively or negatively influence a given type of habitat and its availability. Methods of evaluating the suitability of forest stands for wildlife and ensuring a sufficient share of such stands in managed forests have been discussed, amongst others, by [36–38]. To estimate habitat availability on a landscape level, one needs to conduct spatial analyses using appropriate geographic information system (GIS) tools [39–41].

In adopting management regimes with long-term effects on forest habitats, it is necessary to resolve certain dilemmas, including the volume of wood to be harvested. Using input data describing the current state of forests in a given area, the present study analyzed three management scenarios, which are either currently applied, being introduced, or considered for implementation on lowland sites. Simulation encompassed a period of 180 years. The main aim of the present study was to evaluate the influence of changes in forest management factors, such as (1) rotation age, (2) species composition, (3) felling system, and (4) retention of parts of stands (exclusion from harvesting), on the availability of black stork habitats over a long time horizon on a landscape level. The assessment of scenarios was based on structural forest indicators taking into consideration black stork ecology, such as stand characteristics and location with respect to one another, as well as nesting tree parameters. These data were used to estimate the area of potential nesting sites for black storks. The analyzed management scenarios constitute a gradient from rotation ages representing a predominant production function to periods more closely linked to the ecological functions of these forests.

2. Materials and Methods

2.1. Study Area and Input Data

The relationship between different forest management scenarios and the habitat requirements of black storks was examined for lowland stands in southern Poland, on the example of the Niepołomice Forest. The studied forest encompasses sites which largely reflect the trophic pattern characteristic of forest sites in this part of Europe, and so the findings may have wider applications. Polish forests account for a substantial proportion of Central European forests (9177.2 thousand ha), and provide habitats for numerous bird species, including those listed in Annex I to the European Union's Birds Directive and Annex I to the EU Habitats Directive. The vast majority of Polish wooded areas are managed by the State Forests National Forest Holding (SFNFH) (77.3%), and as such are subjected to systematic silvicultural practices. The average age of forests managed by the SFNFH is 58 years, with a stand volume of 272 m³/ha [42,43]. Most of them are found in lowland areas, on soils with low trophic levels. Almost 2/3 of wooded sites in Poland are classified as oligotrophic and mesotrophic sites [44]. The spatial distribution of site conditions is largely reflected in the structure of the dominant species. *Pinus sylvestris* L. is the most abundant species to the north of the Carpathian Mountains. Also *Quercus* sp. plays an important role in the composition of those sites. Upland and mountainous sites are less numerous, being located mostly in the southern part of Poland. Site distribution is the basis for the adoption of specific silvicultural and production solutions. The rotation age of tree stands depends on their species composition, and is defined as that of the dominant species, which is 80–120 years for Scots pine and 120–160 years for oak [45]. However, for economic reasons, the upper limits of the rotation age brackets are rarely used in practice. As a result, the share of stands that are 100 years old or older in all SFNFH-managed forests amounts to only 9.5% [43].

The Niepołomice Forest is a large complex surrounded by wetland areas providing suitable foraging sites for black storks. The forest is located approximately 200 m above sea level, near the largest Polish river, the Vistula (50°08'36"–49°54'08" N, 20°30'40"–01'40" E), in the temperate zone, with an annual mean temperature of 8.2 °C and an annual precipitation of 700 mm. The tree species composition of the Niepołomice Forest has been shaped and maintained by silviculture for approximately 200 years. The Scots pine, as a species of high commercial interest, has been favored on all sites except eutrophic ones, where oak has been used. Tree stands have been typically managed by the clearcut system with a relatively short rotation age (up to 90 years). Since the mid-20th century, recreation and water protection have been considered important forest functions and silviculture and management methods have evolved: more deciduous species have been introduced, the rotation age has been extended, and clearcutting has been partially replaced by the shelterwood system. At the beginning of the 21st century, a Special Protection Area (SPA, designated as PLB120002) was established in the Niepołomice Forest within the European network Natura 2000 pursuant to the EU Birds Directive [18]; it encompasses all

the tree stands included in the present study (Figure 1). The designation of the SPA was motivated by the presence of 29 forest and open-land bird species listed in Annex I to the Birds Directive, of which 8 regularly nest in this area. The Niepołomice Forest is one of the 10 most important breeding refuges for the Ural owl *Strix uralensis* (Pallas, 1771), middle spotted woodpecker *Leipicus medius* (Linnaeus, 1758), and the collared flycatcher *Ficedula albicollis* (Temminck, 1815). Other species of conservation concern are: the black woodpecker *Dryocopus martius* (Linnaeus, 1758), grey-headed woodpecker *Picus canus* (Gmelin, JF, 1788), European honey-buzzard *Pernis apivorus* (Linnaeus, 1758), boreal owl *Aegolius funereus* (Linnaeus, 1758), and black stork *Ciconia nigra* [46]. The abundance of black storks in the Niepołomice Forest SPA is estimated at 3–5 pairs ([46], personal communication). Data about the species of nesting trees and their approximate location (tree stand) were collected from foresters responsible for the various forest divisions comprising the Niepołomice Forest (personal communication from foresters working in the Niepołomice Forest).

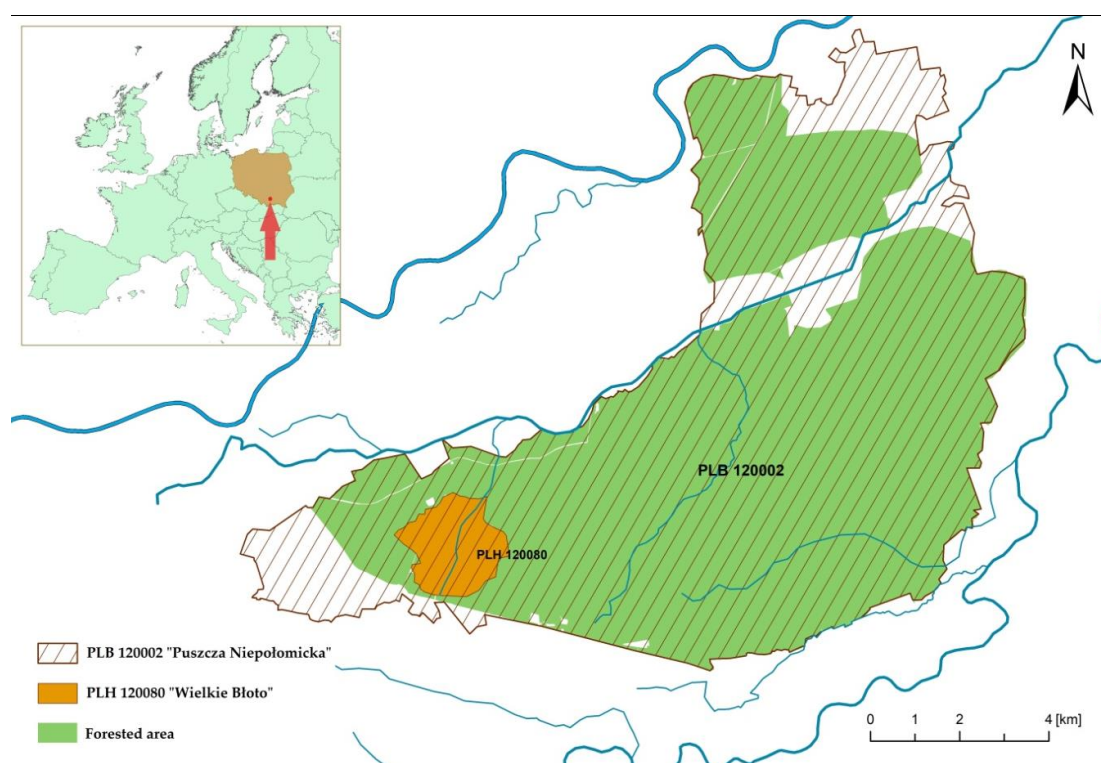


Figure 1. Location of forest complexes and special protection areas within the Natura 2000 network.

In 2011, a new SPA with an area of 347.90 ha was created within the SPA PLB120002; it was designated as PLH120080 “Wielkie Błoto.” In the past, that area was completely devoid of trees. It was used for agricultural purposes with irrigation/drainage ditches; also, peat was extracted. Currently, most of that land is no longer farmed, with a plant succession transitioning towards shrub and shrub-forest assemblages. It predominantly features low-sedge bog-springs, fens, and wet meadows; there are also marshes, bogs, and small bodies of water, including a fish pond [47].

The overall area of the Niepołomice Forest District amounts to 10,596 ha, of which 9641 ha are managed forests, with the rest being unmanaged forests, not included in the presented analyses. Forest sites have been grouped according to the gradient of fertility (Table 1). The data contained in Table 1 are from 2012 and constitute a starting point for further analyses.

Table 1. Area and species composition of tree stands according to site class in the Niepołomice Forest in 2012.

Site Class (Gradient of Fertility)	Area (ha)	Species Composition ¹ by Percent Area	
		(Major Species) Share $\geq$ 5%	(Minor Species) Share < 5%
Oligotrophic	4184.50	SP 78, OK 6,	BI, EL, BE, AR, NS
Mesotrophic	2934.10	SP 56, OK 14, AR 13, BI 7, BE 6	EL, HBM
Eutrophic	2183.39	OK 55, HBM 12, AR 11, AH 8, LI 6	SP, BI, EL, BE, EM
Swamp	338.69	AR 79, AH 8, OK 6	BI, SP, BE, NS
Total	9640.68	SP 51, OK 19, AR 11	BI, BE, EL, HBM, AH, LI, NS, EM

¹ SP—Scots pine, OK—oak (pedunculate and sessile), BI—silver birch, BE—European beech, AR—black alder, NS—Norway spruce, EL—European larch, HBM—hornbeam, AH—European ash, LI—small-leaved lime, EM—common elm.

The largest area (43%) is occupied by oligotrophic sites (with the dominant plant community being *Quercus-roboris Pinetum*), which are naturally suitable for pine with some oak, beech, and birch. Mesotrophic sites, appropriate for mixed oak-pine stands with some lime and hornbeam, cover as much as 30% of the area, with the predominant community being *Tilio-Carpinetum*. Eutrophic sites typical of broadleaved stands with dominant oak and codominant elm, ash, and lime (*Ficario-Ulmetum campestris*), account for 23% of the forest. A relatively small proportion of the area (4%) is covered by fertile, but very wet alder swamp sites (*Carici elongatae-Alnetum*) with dominant alder and some presence of elm. At the beginning of the study (2012), the most abundant tree species in the examined forest was pine (51% of the area), followed by oak (19%), and alder (11%). The overall mean growing stock volume was 270 m³/ha and the mean stand age was 66 years [48].

2.2. Management Scenarios

The selection of management scenarios for modeling was based on current discussions concerning forest functions and their effects on the entire ecosystem. To achieve the research objective, the chosen scenarios range from a simple one focused on timber production to a sophisticated one emphasizing ecological functions, and differ in terms of (1) rotation age, (2) species composition, (3) felling system, and (4) retention of parts of stands (see Table 2). The species composition of stands depends on the dominant forest function in a given scenario taking into consideration site class in accordance with the guidelines given in the Principles of Silviculture [49]. In protective forests, these principles may include limited clearcutting, a higher rotation age, adjusted species composition, and the exclusion of parts of stands from harvesting [50]. It should be noted that the analyzed scenarios are either currently applied, being introduced, or considered for implementation. The following scenarios were considered:

- The Productive (PR) scenario—the objective of this management scenario is to maximize timber production. Rotation ages correspond to the highest mean annual volume increment. This scenario predominantly involves monospecific stands with the dominant species being Scots pine (rotation age of 90 years) harvested by the clearcut method and regenerated artificially by planting. Two-species stands managed by the shelterwood system with a short (10 years) regeneration period are only found on eutrophic sites.
- The Basic (BA) scenario—the objectives include timber production as well as non-production forest functions. In contrast to the PR scenario, BA does not use clearcutting or monospecific stands; instead it relies on two- or three-species stands, preferably containing pine and oak (enabling a high yield of merchantable timber), with a medium rotation age of 100 and 140 years, respectively, managed mainly by the shelterwood system and regenerated by planting.

- The Long Rotation (LR) scenario—in comparison with BA, LR focuses even more on ecological functions by enhancing species and age diversity and increasing the proportion of old stands. This scenario involves multispecies stands with a dominance of deciduous trees and a long rotation age: 110 and 180 years for pine and oak, respectively. The shelterwood system is implemented with different durations of the regeneration period (10–30 years). Regeneration is essentially natural, but in the transition period the desired species absent from the stand are introduced by planting. About 5% of the mature stand area and volume is retained during harvest for natural death as a source of deadwood (retention trees). In addition, swamp sites are entirely excluded from wood production due to their great significance to black storks, their low share in the overall forest area, and difficulties associated with implementing silvicultural activities (implying low economic viability of wood production).

Table 2. Species composition, rotation age, and felling system in different management scenarios.

Management Scenario	Site Class	Species Composition ¹ (%)	Rotation Age (years)	Felling System/ Regeneration Period (years)
Productive (PR)	Oligotrophic	SP 100	90	Clearcut
	Mesotrophic	SP 100	90	Clearcut
	Eutrophic	OK 80, EM 20	120	Shelterwood/10
	Swamp	AR 100	70	Clearcut
Basis (BA)	Oligotrophic	SP 70, OK 30	100	Shelterwood/10
	Mesotrophic	OK 40, SP 30, BE 30	140	Shelterwood/20
	Eutrophic	OK 60, BE 30, EM 10	140	Shelterwood/20
	Swamp	AR 100	80	Clearcut
Long rotation (LR)	Oligotrophic	SP 40, OK 30, EL 10, BI 10	110	Shelterwood/10
	Mesotrophic	OK 40, SP 30, BE 10, LI 10, HBM 10	180	Shelterwood/20
	Eutrophic	OK 50, EM 20, BE 10, LI 10, HBM 10	180	Shelterwood/30
	Swamp	No interventions		

¹ SP—Scots pine, OK—oak (pedunculate and sessile), BI—silver birch, BE—European beech, AR—black alder, EL—European larch, HBM—hornbeam, AH—European ash, LI—small-leaved lime, EM—common elm.

2.3. Simulation of Future Forest Development

The stand area, species composition, and age at the beginning of the study were taken from the forest management plan for the Niepołomice Forest District as of 2012. Calculations were performed for 1875 managed stands with a mean area of 4.81 ha (min. 0.27; max. 40.15 ha). Since felling systems have area constraints, stands with areas exceeding those limits were subdivided in accordance with silvicultural principles into 4 ha patches for clearcuts and 6 ha patches for partial cutting [49]. Species composition and age were simulated for each stand over a planning horizon of 180 years divided into 10-year periods (Figure 2). This horizon was selected so that each stand would be harvested at least once throughout the simulation period. The species composition of the regeneration was adopted in accordance with the principles given in Table 2, depending on the site type and management scenario.

The stands were designated for harvesting if they reached or would reach rotation age for the dominant tree species in a given decade and met the spatial criterion for cutting. It was checked whether the area of stands designated for harvesting (whether individual ones or groups of adjacent stands) was within the harvest area limit in a given management scenario. If a stand adjoined a previously harvested site, it could not be harvested for 5 years since the regeneration of that site. However, there were no quantitative constraints for the Forest Management Unit (FMU) as a whole; if a given tree stand met the criteria for harvesting, it was designated for felling irrespective of the total harvested area in a given decade. The total volume of merchantable timber harvested in final and pre-final felling was calculated for each management scenario using Taksator software (Version 6.0, TAXUS IT, Warsaw, Poland).

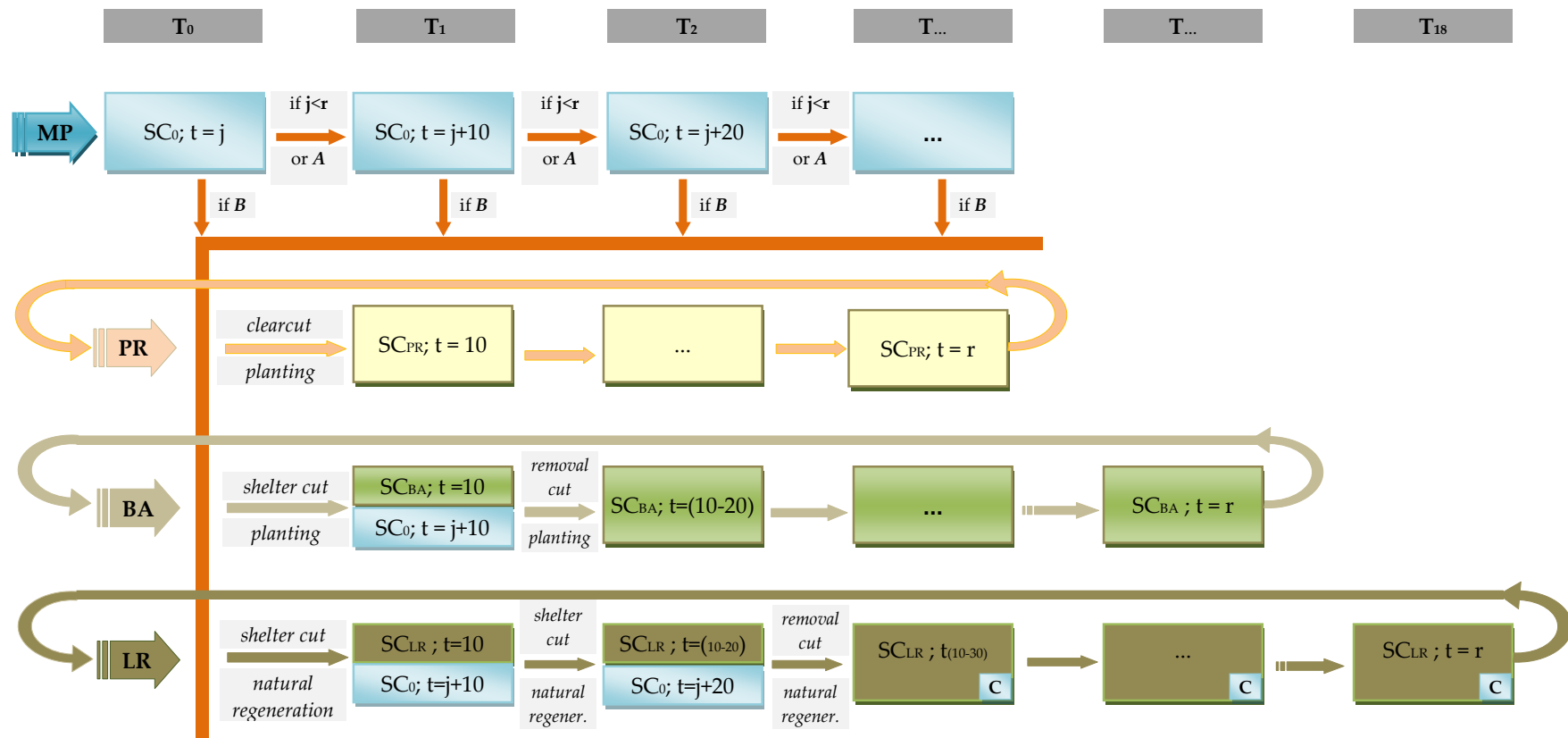


Figure 2. Simulation of species composition and age of tree stands in the various management scenarios. T_0 —Starting point; $T_1, T_2, \dots, T_{18}$ —10-year simulation periods; t —age of stand; j —age of stand at the starting point; r —rotation age for a given SC and management scenario, respectively; MP—data from the current management plan; PR, BA, LR—productive, basic, and long rotation scenarios, respectively; SC_0 —species composition of a stand at the starting point; $SC_{PR}, SC_{BA}, SC_{LR}$ —species composition of stands managed according to the productive, basic and long rotation scenarios, respectively; A—stand age $\geq$ rotation age, but spatial constraints do not allow for cutting; B—stand age $\geq$ rotation age and spatial constraints allow for cutting; C—5% of mature stand area excluded from harvesting. Figure 2 does not pertain to swamp sites.

2.4. Identification of Habitats Suitable for Black Storks

The identification of habitats suitable for wildlife is a hierarchical process based on fulfilling a set of conditions specific for a given species at all landscape scales since disturbances at one level may entirely exclude an area despite compliance at all others [51]. In the present study, habitat factors were evaluated on the following spatial scales (1) nesting zone (macro-habitat), (2) nesting territory, and (3) nesting site.

A nesting zone (NZ) is defined as a forest area offering potential sites for black stork nesting due to its location with respect to foraging sites (rivers, bodies of water, swamps—favorable factors) as well as the forest edge (ecotone), buildings, roads with heavy traffic (non-urban public roads passing through the Niepołomice Forests, except for roads used solely by foresters and closed to other traffic), and places designated for intensive tourism and recreation (excluding factors). A nesting zone is assumed to have the same area throughout the simulation period. It is coextensive with the Niepołomice Forest after subtracting the areas unsuitable for black stork nesting. Studies conducted in different parts of the black stork range indicate some variation in the above factors. In Western Europe adaptation to human activity has been noted, in contrast to a decline in population and continual avoidance of humans in the eastern part of the continent. However, most European black storks are still found in Eastern Europe [52,53]. In Estonia, at the northern extreme of the black stork range, the mean distances from the forest edge, buildings, and roads are 274 ± 60 m ($\pm 95\%$ confidence intervals), 621 ± 99 m, and 1205 ± 183 m, respectively [25]. These literature data are the basis for the criteria adopted in the presented simulation. The nesting zone encompasses forest areas meeting the following criteria: (1) the size of the entire forest complex exceeds 200 ha, (2) the distance from the ecotone between the forest and open land (except for clearings, swamps, and meadows within areas protected by the Natura 2000 network) is at least 100 m, (3) the distance from the nearest buildings (excluding forest management buildings and foresters' lodges near the forest edge) is at least 1 km, (4) the distance from a paved road with heavy traffic is at least 500 m, (5) areas designated for intensive tourism and recreation in the Forest Management Plan were excluded as a potential nesting zone. Thus, a nesting zone is an area within which black storks may potentially build nests as long as additional criteria concerning stand parameters and stork territorialism are met.

A potential nesting site (NS) is a tree stand, or a group thereof, located within a nesting zone, having a certain minimum area, species composition and age, with large trees characterized by crowns suitable for nesting. In the Niepołomice Forest, black storks tend to select Scots pines and oaks as nesting trees. These are the most abundant tree species, with higher survivorship levels, greater DBH, and greater height as compared to birch, alder, and ash; they also feature thick boughs in older age. Based on age analysis of stands in which the nests were established and literature data [23–25], the minimum threshold age for NS was adopted at 81 years for stands with at least 10% volume of oak, and more than 100 years for other stands. The minimum NS area was adopted at 4 ha. For stands of less than 4 ha, it was checked whether they adjoined other stands meeting the age criterion and whether the combined area of such a group of stands was ≥ 4 ha [54,55].

A potential nesting territory (NT) is an average area occupied by one pair of black storks defined as a circle with a radius drawn around a nesting tree (corresponding to half the average distance between occupied nests). In publications concerning black stork populations in Lithuania, the length of that radius was reported to be 2.8 km [23], as compared to 3 km in Estonia. In the present simulation, a radius of 2.5 km was adopted.

In the first decade of simulation, NTs were determined in two steps: (1) they were designated around occupied nests, (2) an area outside a radius of 5 km (double the NT radius) around each occupied nest was checked for the presence of tree stands (or a group thereof) fulfilling the NS criteria outside the designated NTs. If such tree stands were found, potential NTs were designated around the center of those stands (Figure 3). In the second and subsequent decades of simulation, the first NT was adopted from the preceding decade at random, with additional NTs established as per the second step in the first decade. No overlap between NTs was allowed. It should be noted that the number of potential NTs reflects the spatial distribution of stands meeting the nesting site criteria within a NZ.

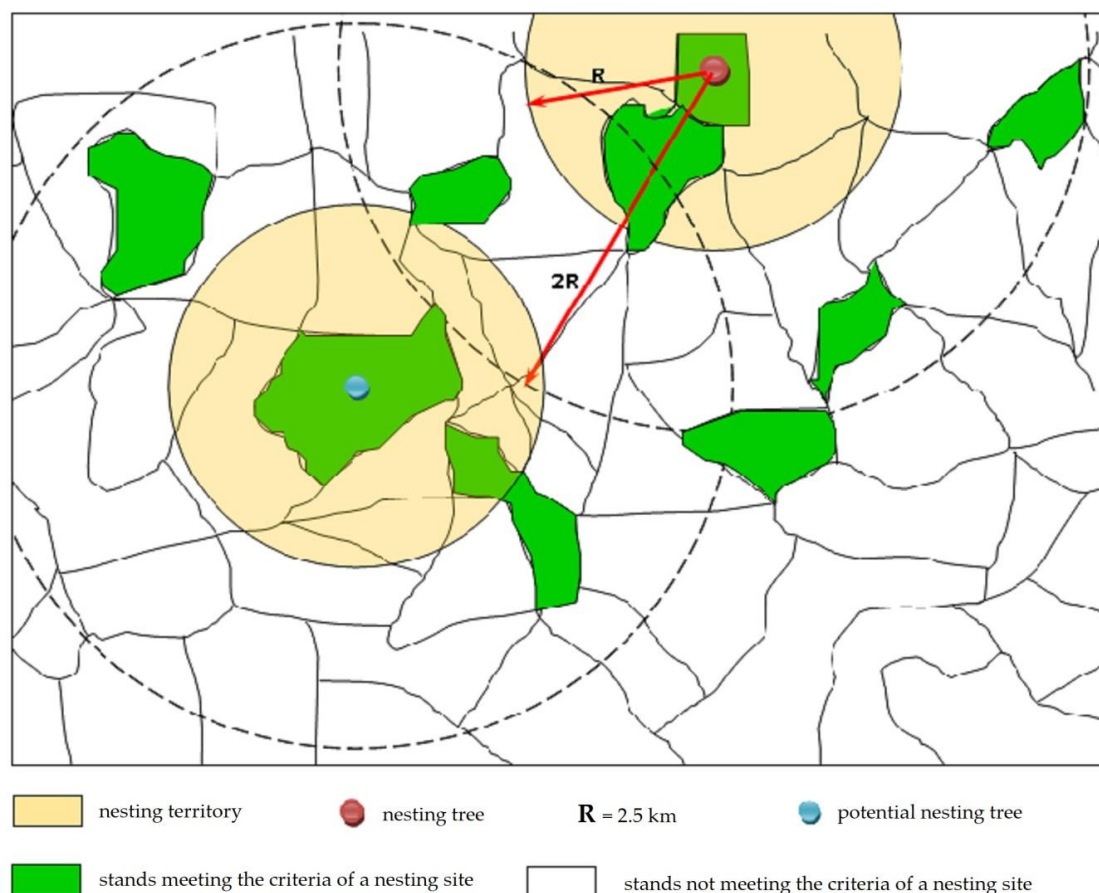


Figure 3. Method of identifying potential nesting territories.

In the study it was assumed that the external factors affecting the suitability of tree stands as potential nesting sites for black storks would remain largely invariant over time, while the internal determinants of stands (species and age structure, tree size, and the relative position of stands with respect to one another) would evolve depending on the management scenario. Thus, the area of the nesting zone remained constant across the entire period of simulation, while the areas of nesting sites and the number of potential nesting territories changed depending on changes in the species composition and age of stands.

2.5. Forest Indicators

Additional characteristics and indices important for biodiversity were calculated based on simulation of future forest development and additional stand measurements.

2.5.1. Overall Area of Black Stork Nesting Sites

In addition to its significance for black storks, the availability of mature stands is beneficial for many bird species as larger trees offer more opportunities, such as excavating nest holes, etc. The simulations conducted for the studied management scenarios revealed changes in the area of stands meeting the criteria of black stork nesting sites. The overall area of such stands was calculated for each scenario in successive decades.

2.5.2. Tree Species Diversity

To provide a more comprehensive evaluation of the management scenarios, tree species diversity (in addition to species composition) in each age class was calculated for each stand, and then for the entire studied area. The species diversity of individual stands was determined by means of Shannon's diversity index according to the formula [56]:

$$H'_j = - \left(\sum_{i=1}^n p_i \ln p_i \right) \quad (1)$$

where: H'_j is the diversity index for j -th stand; p_i —the share of i -th species in the stand, n —the number of species in j -th stand, and $\ln$ —natural logarithm.

Species diversity for the entire forest (H'_F) was calculated as a mean of Shannon's indices for individual stands weighted by the area of those stands, according to the following formula:

$$H'_F = \left(\sum_{j=1}^k H'_j a_j \right) / \left(\sum_{j=1}^k a_j \right) \quad (2)$$

where: a_j is the area of j -th stand and k is the overall number of stands.

2.5.3. Area of Stands Excluded from Harvesting

Under LR, trees occupying 5% area of stands that have reached rotation age are retained for natural death and gradual decomposition, with the remaining 95% subjected to management in accordance with that scenario. The simulation shows a gradual increase in the overall area excluded from harvesting across the studied forest. This indicator has been included in the study as dead trees constitute microsites on which many bird species may live, shelter, or feed. Exclusion from harvesting is not equal to dead trees, but it may be assumed that the probability of having deadwood increases in the set-aside areas. In addition, the LR scenario does not allow for interventions in stands growing on swamp sites.

2.5.4. Large Trees

In order to characterize large trees, which could serve as nesting trees for black storks [57], in 2011 measurements were conducted on sampling plots located in stands with an age of 80 years and older. For that purpose, 430 sampling plots with an area of 0.05 ha were established at random in different species-age layers according to the methodology described by Banaś et al. [58]. On the sampling plots, the DBH of all trees and the height of 2 trees of a given species were measured. If the sampling plots contained trees belonging to different age classes (given an age class bracket of 10 years), the height of trees was measured separately for each class. The collected data were used to calculate the average DBH and height of pine and oak trees, depending on age. Large trees were defined as those exceeding the 95th percentile for height and DBH.

3. Results

3.1. Habitats Suitable for Black Stork

The nesting zone area was determined to be 8668 ha, accounting for 90% of all managed stands (9641 ha). Stands with an overall area of 973 ha were excluded as they did not meet the location criteria for potential black stork nesting sites due to proximity of open areas, buildings, roads, or areas designated for intensive tourist traffic. Assuming these external factors to remain invariant throughout the simulation period, the NZ area was adopted as a constant value.

At the beginning of the study period, the area of nesting sites amounted to 1982 ha, accounting for 21% of managed stands. Over subsequent decades of simulation, the area of NS considerably fluctuated both between the various management scenarios and over time within those scenarios (Figure 4).

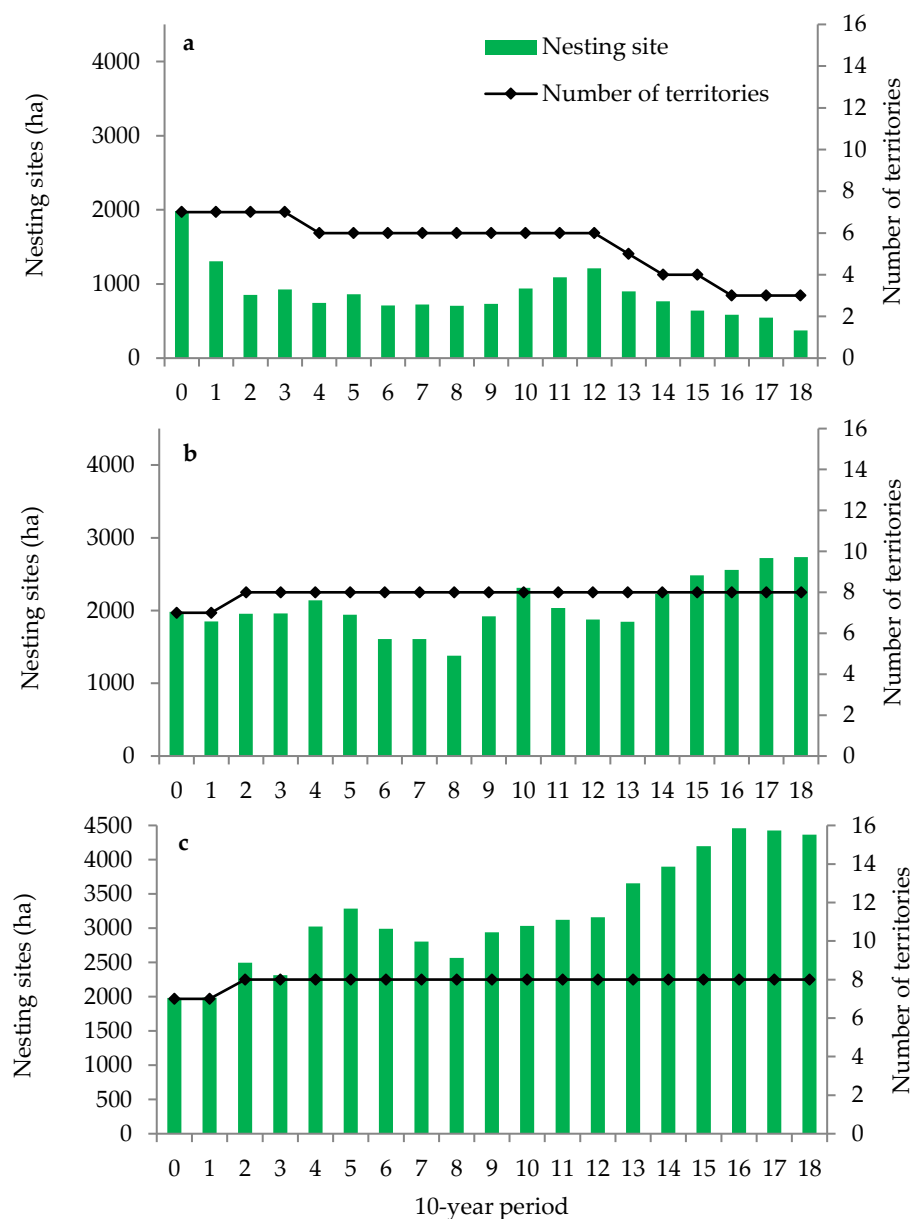


Figure 4. Area of nesting sites (bars) and the number of potential nesting territories (line) in the various management scenarios during 180 years of simulation (a) PR—productive scenario, (b) BA—basic scenario, (c) LR—long rotation scenario).

In the BA scenario, on average 21% of the area of managed stands met the NS criteria throughout the simulated period. The smallest area of such stands (14%) was recorded in the 8th decade of simulation and the largest (28%) in the 17th and 18th decades. The number of nesting territories increased from 7 in the first decade to 8 in the second decade, and remained at that level until the end of the simulation. It should be noted that given the size of the Niepołomice Forest and the adopted assumptions, it is the maximum possible number of nesting territories for this area.

A decrease in oak rotation age from 140 to 120 years and the replacement of mixed stands containing oaks with monospecific pine stands with a 90-year rotation age (PR scenario) reduced the average area of nesting sites over the 180 year simulation period to as little as 9% of all managed stands. Forest management pursuant to the PR scenario substantially limited the potential number of nesting territories, from 7 in the first 3 simulated decades to 3 in the last decades (16–18).

In the LR scenario, an increase in rotation age to 110 and 180 years for pine and oak, respectively, and the introduction of oak as a dominant or codominant species in all stands (except for swamp sites) expanded the area of nesting sites. In that scenario, over the 180-year simulation period, on average 33% of the stands (in terms of area) provided potential black stork nesting sites. The number of nesting territories across the whole 180-year simulation period (except for the initial decade) remained at 8.

3.2. Age Class, Species Composition of Stands, and Harvested Volume

The distribution of stands in age classes in the year 2012 was unbalanced with an excess of middle age classes and a shortage of young stands (below 40 years) and old ones (above 90 years; Figure 5a). In terms of species composition, the Scots pine accounted for 63% of the total. The distribution of tree species in age classes was uneven, with the highest shares of pine (more than 60%) in 61- to 110-year-old stands, and oak in stands that were more than 110 years old.

Over the period of simulation, the species composition and age structure of the examined stands underwent considerable fluctuations. In the BA scenario, the proportion of oaks increased, to account for at least 30% of most tree stands (except for swamp sites) after approximately 140 years (rotation age for oak). This means that all stands more than 80 years old (with the exception of swamp sites) located in the nesting zone were potential habitats for black storks. On the other hand, the PR variant entailed changes unfavorable to the availability of potential black stork habitats, that is, a decrease in older stands and an increase in monospecific pine stands. After approximately 120 years (rotation age for oak), monospecific pine stands occupied approximately 74% of the area of all managed stands, while at 90 year rotation, they did not offer any potential habitats for black storks at all. Oak stands occurred on 23% of the area of eutrophic sites. However, those stands were spatially limited and were absent from the main forest complex, due to which the number of NTs decreased to 3 or 4. The LR scenario brought about changes beneficial to the availability of habitat area: an abundance of multispecies stands with a high proportion of oak and a high share of older stands (Figure 5b–d).

During the 180 year simulation period the total harvest volume amounted to 9.40, 8.20, and 6.87 million m³ in the PR, BA, and LR scenarios, respectively.

Gradual transformation of stands over the years is illustrated by Shannon's species diversity index. The increasing value of that index under LR results from the large number of tree species used for regeneration. According to simulation, the index reached 1.3 after approximately 100 years and remained at that level for subsequent decades. On the other hand, in the PR regime that index was reduced to as little as 0.1 after the same period (Figure 6).

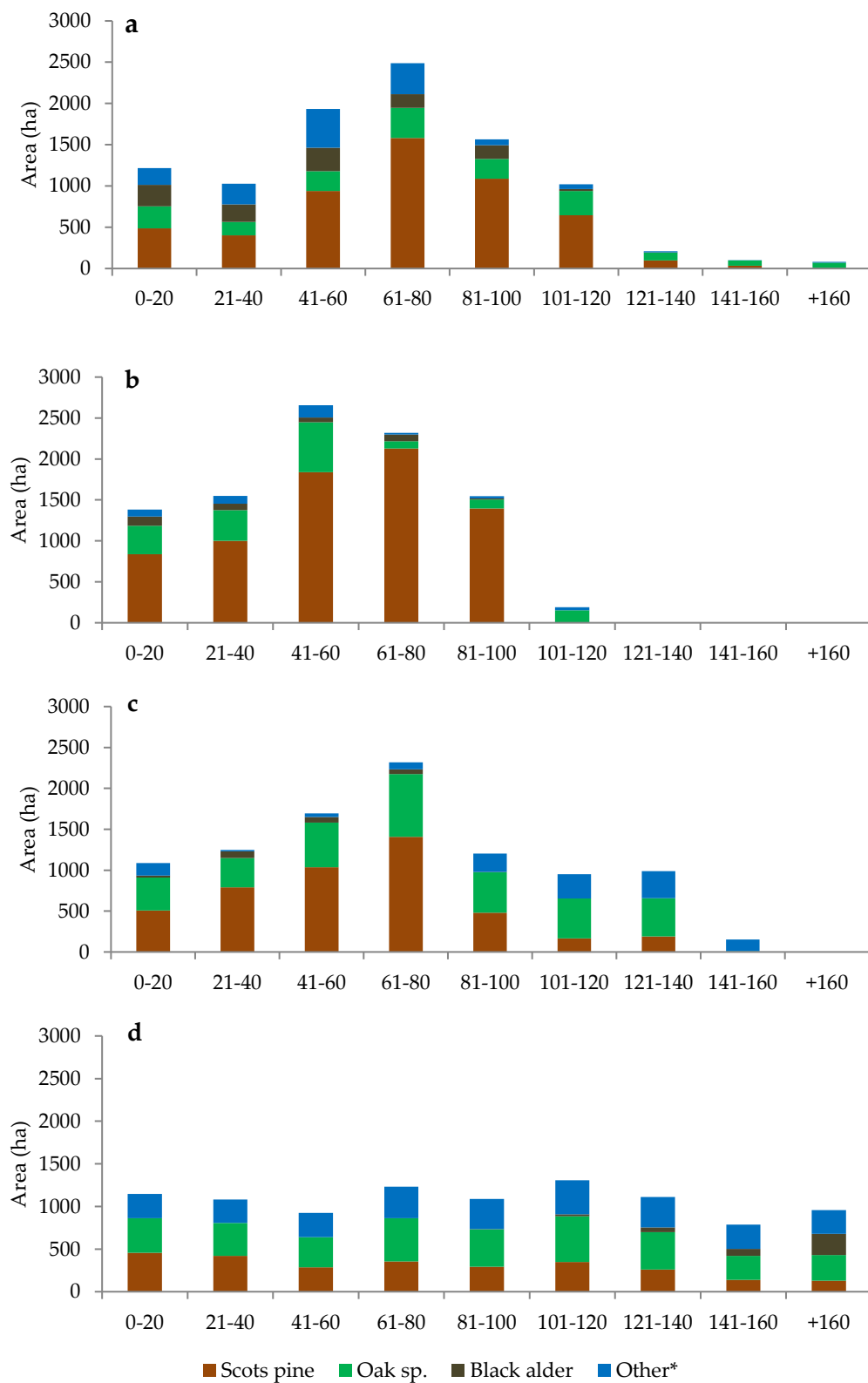


Figure 5. Age class distribution of stands and shares of tree species in the year 2012 (a), and after a 180-year simulation period for the productive, basic, and long rotation scenarios (b, c, and d, respectively). * Other—silver birch, European beech, Norway spruce, European larch, hornbeam, European ash, small-leaved lime, common elm.

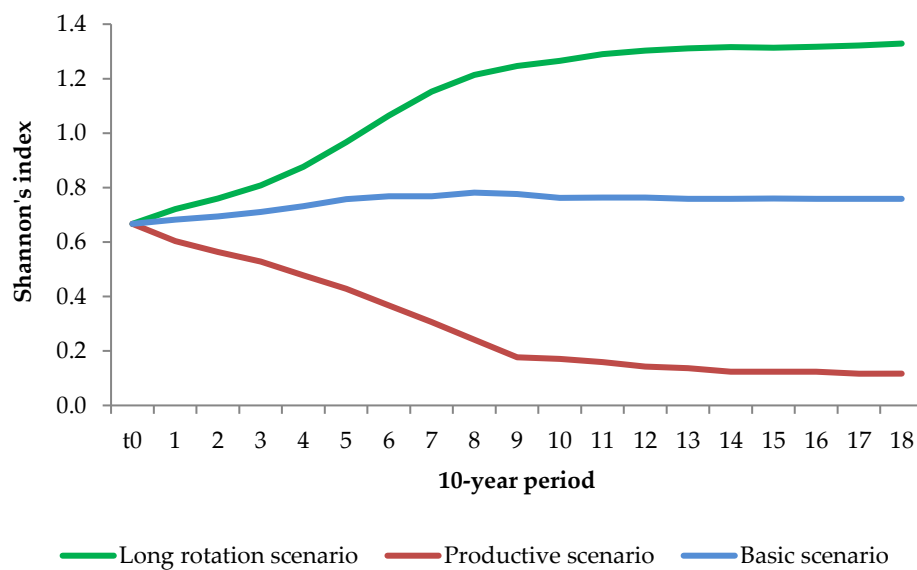


Figure 6. Mean Shannon's index illustrating the average species diversity of stands in the studied management scenarios.

3.3. Large Trees and Area of Stands Excluded from Harvesting

The size characteristics of Scots pines and oaks older than 80 years are given in Table 3. In older tree stands (>80 years), oaks revealed both larger DBH and height. For instance, the DBH of 101- to 110-year-old trees was 40.0 cm (standard deviation (SD) 7.7) and 50.8 cm (SD 12.1), and their height was 26.1 m (SD 3.4) and 27.4 m (SD 3.7), for pine and oak, respectively. Even greater differences were found between trees above the 95th percentile (the largest 5% of trees), at 53.1 cm and 71.1 cm for pine and oak, respectively. Table 3 shows the current age classes and tree dimensions for trees older than 80 years in the studied area. Additionally, in the LR scenario some trees would grow to be older and larger than any of those found in the forest now.

Table 3. Diameter at breast height (DBH) and height of Scots pines and oaks in old stands.

Tree Age (years)	Species	DBH (cm)			Height (m)		
		Mean	Standard Deviation	95th Percentile	Mean	Standard Deviation	95th Percentile
81–90	SP	36.6	7.4	49.1	25.3	3.1	30.5
	OK	37.2	11.2	53.3	24.0	4.1	29.0
91–100	SP	39.3	7.3	52.1	25.7	2.9	31.0
	OK	46.4	10.5	65.3	25.7	4.9	32.6
101–110	SP	40.0	7.7	53.1	26.1	3.4	31.0
	OK	50.8	12.1	71.1	27.4	3.7	33.0
111–120	SP	42.1	8.0	55.3	25.7	3.0	31.0
	OK	49.9	16.0	74.4	26.8	4.6	33.4
121–140 *	SP	44.3	8.5	57.6	26.8	4.0	33.6
	OK	60.4	13.8	83.9	28.6	4.1	33.5

SP—Scots pine, OK—oak (pedunculate and sessile), * some individual trees are older than 140 years.

Management under LR led to a gradual increase in the area excluded from harvesting (retained trees), including not only swamp sites, but also depending on the area of stands reaching rotation age over time. Since no interventions are allowed on swamp sites, at the beginning of simulation the set-aside area was equal to the size of those sites. Subsequently, that area gradually increased due to the fact that 5% of the area of the remaining stands that reached rotation age was retained. After

50 years, the total set-aside area amounted to approximately 5.5% of the overall area of the Niepołomice Forest, and to approximately 7.7% after another 50 years. Finally, the overall set-aside area reached approximately 8.3% of the total wooded area and remained at that level (Figure 7).

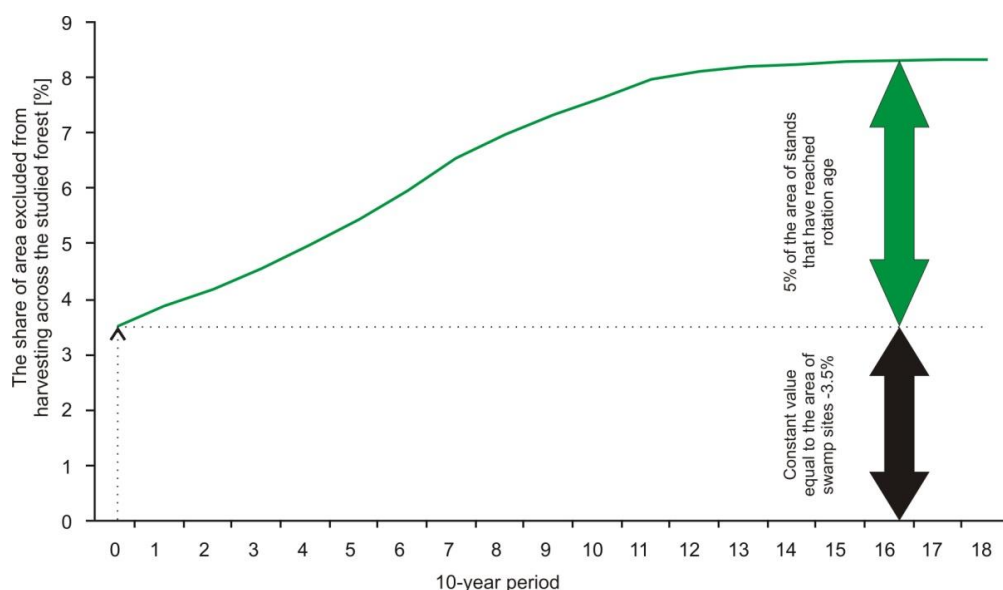


Figure 7. Share of area (green line) excluded from harvesting as a source of retention trees in the long rotation scenario.

4. Discussion

The condition and abundance of the black stork population is affected by factors associated with breeding habitats, migration routes, and wintering grounds [59,60]. Locally, of importance is landscape structure including the relative shares of woodland, open land, and swamps [5,23]. The selection of nesting sites is influenced by stand parameters, such as species composition and tree size distribution (in addition to safety and the availability of food). The above factors are largely shaped by human activity as more than 95% of European forests are under human management [61]. Among them, 80% are forests designated for more or less intensive timber production. Excessive forest exploitation, unchecked sprawl of suburban areas, and heavy recreational use make forests vulnerable to degradation. Therefore, it is all the more important to be able to predict the long-term effects of large-scale management practices. According to research, the decline in black stork abundance is associated with the intensity of silvicultural treatments [19,22]. Nevertheless, it should be noted that forestry is not the only underlying cause of the loss of black stork breeding habitats [25,62,63]. Black storks avoid open and fragmented stands, e.g., resulting from group cutting, as well as sites hydrologically disturbed by drainage. Protection recommendations for this species include maintaining closed tree stands around the nests and high moisture levels in surrounding areas [62].

Comprehensive evaluation of biodiversity is difficult due to the large number of organisms associated with a given ecosystem and the multitude of factors affecting it [64,65]. Forest biodiversity is often assessed using three measures: forest composition, structure, and function [66]. The assignment of certain functions to a given forest site has implications for the silvicultural solutions used [67]. The management scenarios adopted in the present work differed in terms of management intensity and significantly affected the black stork habitat area. The applied gradient of rotation ages and species compositions had a major bearing on the total area of nesting sites. The use of a simplified management regime resulted in very low Shannon's diversity indices. In turn, management scenarios focused on ecological functions decreased the volume of harvested timber due to the lower volume increments in older stands and the leaving of some trees for death and decomposition. Although the present study does not deal with the economic ramifications of the studied silvicultural patterns, it should be noted

that as compared to BA, the total harvest volume was higher by 14.6% in the PR scenario and lower by 16.2% in the LR scenario. For example, in Sweden a 22% increase in rotation period led to a 31% expansion in the mean habitat area of the tree creeper *Certhia familiaris* (Linnaeus, 1758) at a 5% cost to net present value and a 7% decrease in harvested volume [68].

Silvicultural systems geared towards intensive timber production based on short rotation periods and a low number of tree species, often poorly adapted to sites, have become much less popular in forest management planning. Assuming that the site requirements of black storks are constant, the production scenario has been found to exert an adverse effect on the size and quality of potential habitats, and in the long term it may completely eliminate nesting opportunities for that species on oligo- and mesotrophic sites. This is due to a deficient stand structure, an uneven distribution of stands across age classes, and a large harvested area in each cycle. The production scenario also negatively influences the possibility of long-term use of existing nesting sites as a result of harvesting stands inhabited by black storks, and by the same token, the removal of nesting trees [26]. Nest lifespan is a key factor for species protection and it has been reported that black storks may use the same nests for dozens of years [26,69]. Importantly, that parameter is distinct from nest location as under favorable site conditions a nest may be re-established in the same place in the event of destruction, e.g., by snow [19]. A possible solution would be to exclude the stands with black stork nests from harvesting, but that in itself cannot offset all the negative consequences of the productive scenario. In fact, the problem of conducting silvicultural activity in the vicinity of nests concerns all scenarios. As a result, zonal protection of the nests of the most endangered bird species has been implemented in Poland. According to that program, black stork nests should be protected by two concentric circular zones. One, with a radius of 200 m, functions as a strict nature reserve. The other one, with a radius of 500 m, is periodically excluded from human activity (from 15 March to 31 August) to ensure safety and undisturbed breeding [70]. Protective zones may be removed only if the birds permanently abandon the nesting site. Even if the nest is destroyed, protection should be maintained if only the birds remain within the forest division, until a new nest is located.

Under the LR regime, the resulting greater share of older stands, especially those with dominant oak, increases the area of habitats suitable for black stork nesting as the birds exhibit a preference for fertile sites with higher proportions of oak [24]. Diameter distribution analysis of old oaks in the Niepołomice Forest showed an average DBH of approximately 50 cm, with the 95th percentile reaching more than 70 cm DBH at a height of 33 m. The average pine dimensions were somewhat smaller. Furthermore, it should be noted that in the long term under LR some stands will become older than those measured in 2011, which should translate into larger trees available for nesting. Due to the considerable weight of the nest, trees with thicker limbs enhance its longevity, although the lifespan of a nest is also affected by its distance from the trunk. Each tree species is characterized by specific wood hardness and brittleness as well as a characteristic crown shape. In the case of Latvian black storks, nests built in oaks and pine trees exhibited a significantly greater longevity than those in aspens [19].

Although in the LR scenario the total habitat area was much larger than in BA, the potential population density (number of predicted territories) was the same under both management regimes since the maximum predicted number of nesting territories in the studied forest complex is eight. Thus, both in the BA scenario, which is similar to the management practices actually implemented in the Niepołomice Forest over the past decades, and in LR, which has been recently introduced there (except for swamp sites), it would be possible to attain that number of NTs in 20 years. It should be noted that the inter-nest distance adopted in this work is rather conservative (large), with some authors reporting distances as short as 600 or 300 m [62,71]. However, the mean values are typically much larger, which is probably attributable to local conditions. According to Zieliński et al. [71], in central Poland the mean distance between occupied nests amounts to 8.9 km. In turn, in the Kampinos National Park (also in central Poland) that distance has been found to range from 3.9 to 4.7 km, depending on the season [72]. Finally, Buczek [62] has reported 1.1–5.9 km for food-rich sites. These differences may be attributed not only to foraging opportunities, but also to individual territorial traits of birds, anthropogenic pressure,

and habitat fragmentation. Thus, in the case of continuous forest complexes, analysis of the effects of management scenarios on the black stork population should take into account not only the total nesting site area, but also the spatial distribution of such sites across the complex. In practice the spatial rules of forest management generally lead to the dispersion of stands characterized by similar parameters.

The area of nesting sites and potential nesting territories may also be limited by various disturbances. In the present study, it was assumed that the development of individual stands would proceed according to the adopted silvicultural scenarios. The simulation did not account for stochasticity, assuming that the probability of stand transition from one age class to the next one (until reaching the rotation age for the dominant species in the stand) equaled one, with the final felling (clearcutting or shelterwood cutting) conducted in accordance with the implemented management scenario. In practice, there is some probability that these stands may be affected by natural phenomena, such as windthrows, wildfires, insect outbreaks, etc., periodically causing a substantial decline in the potential habitat area. Still, it should be noted that the likelihood of disturbances is much higher for even-aged monospecific pine stands prevalent in the SR scenario (in which the number of stands available for black stork nesting sites is already very low) [73,74]. The use of the shelterwood system with a longer regeneration period and multi-species stand composition (LR scenario) makes stands more resilient to adverse events.

The modeling of black stork sites may help in the assessment of site availability for organisms which heavily rely on some of their constituent elements. Importantly, the LR scenario leads to an increased number of microsites crucial for biodiversity, which is associated with a greater area of old growth, a more varied species composition, no interventions in swamp sites, and the retention of stand fragments (absent from the other silvicultural regimes). The trees left on those fragments to die naturally and decay will form unique ecological niches, which is consistent with the management certification guidelines of the Forest Stewardship Council [75]. Over time, the retained fragments will reach a high growing stock volume; for instance, the mean volume of stands managed by the SFNFH that are 100 old or older exceeds 400 m³/ha [43]. This in turn will substantially increase the amount of various types of standing and downed deadwood at different stages of decay, depending on the onset of retention, the lifespan of the tree species growing in the set-aside areas, as well as the effects of abiotic and biotic factors. Currently, the mean deadwood volume in SFNFH forests is estimated at approximately 5–6 m³/ha [43], but the actual amount of deadwood in a given stand depends on a number of determinants, including site moisture and productivity [58,76]. In the productive and basic scenarios, one should expect deadwood volumes similar to the mean values given above. On the other hand, in the long rotation scenario deadwood volume is likely to be several times higher due to tree retention. The presence of various forms of deadwood is beneficial, or even indispensable, for numerous saproxylic organisms [77,78]. Among them, of special importance are woodpeckers. In some forests, they are responsible for more than 90% of available tree cavities, many of which are excavated in standing dead trees [79]. Tree cavities are valuable elements of forest biodiversity conservation as they greatly benefit secondary cavity nesters and other cavity-using organisms, including small mammals [80–82]. Sites rich in deadwood also tend to attract species such as owls and raptors for foraging purposes. Old growth not only contributes deadwood to the ecosystem, but also offers nest-building opportunities for large birds. In Sweden it has been found that large old trees and trunks constitute key resources for at least 26% of endangered vertebrate and invertebrate species, including birds. Changes in the species composition of stands that are beneficial for the black stork will also be favorable for other species requiring specific microsites. Examples include small woodpecker species (lesser spotted woodpecker *Dryobates minor* (Linnaeus, 1758), middle spotted woodpecker *Leipicus medius*) which mainly feed on trees with cracked and porous bark (such as oak).

5. Conclusions

Our findings show that the availability of habitats for wildlife in managed forests changes over time and space depending on the species composition and age structure of tree stands as well as the

adopted forest management model. A considerable decrease in rotation age and the elimination of oak from tree stands in the short rotation scenario adversely affects potential habitats for black storks. In turn, a more diverse species composition and a greater area of older stands is beneficial for the birds. Indeed, population density depends not only on the area of available forest habitats, but also on their suitable distribution within the landscape to account for the territorial behavior of birds. As the black stork has very complex and specific habitat requirements, efforts to meet them should also benefit a wide range of other species. The management scenarios analyzed in this work are used in silvicultural practice to a greater or lesser extent, although regimes focused solely on timber production, without catering to social and ecological functions, are being gradually phased out. Management scenarios with very long rotation periods are being introduced in some managed forests, and this trend should be maintained in the future.

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References

1. Sarkar, A.U. Sustainability, sustainable development and forest resources. *Int. J. Sustain. Dev. World Ecol.* **1998**, *5*, 164–171. [\[CrossRef\]](#)
2. Vierikko, K.; Vehkamäki, S.; Niemelä, J.; Pellikka, J.; Lindén, H. Meeting the ecological, social and economic needs of sustainable forest management at a regional scale. *Scand. J. For. Res.* **2008**, *23*, 431–444. [\[CrossRef\]](#)
3. Heinonen, T.; Pukkala, T.; Mehtätalo, L.; Asikainen, A.; Kangas, J.; Peltola, H. Scenario analyses for the effects of harvesting intensity on development of forest resources, timber supply, carbon balance and biodiversity of Finnish forestry. *For. Policy Econ.* **2017**, *80*, 80–98. [\[CrossRef\]](#)
4. Eggers, J.; Lindhagen, A.; Lind, T.; Lämås, T.; Öhman, K. Balancing landscape-level forest management between recreation and wood production. *Urban For. Urban Green.* **2018**, *33*, 1–11. [\[CrossRef\]](#)
5. Angelstam, P.; Roberge, J.-M.; Lohmus, A.; Bergmanis, M.; Brazaitis, G.; Dönn-Breuss, M.; Edenius, L.; Kosinski, Z.; Kurlavicius, P.; Lärmanis, V.; et al. Habitat modelling as a tool for landscape-scale conservation—A review of parameters for focal forest birds. *Ecol. Bull.* **2004**, *51*, 427–453. [\[CrossRef\]](#)
6. Gao, T.; Nielsen, A.B.; Hedblom, M. Reviewing the strength of evidence of biodiversity indicators for forest ecosystems in Europe. *Ecol. Indic.* **2015**, *57*, 420–434. [\[CrossRef\]](#)
7. Cramp, S. *Handbook of the Birds of Europe, the Middle East, and North Africa. The Birds of the Western Palearctic: Ostrich to Ducks*; Oxford University Press: Oxford, UK, 1980; Volume I.
8. Roberge, J.M.; Angelstam, P.; Villard, M.A. Specialised woodpeckers and naturalness in hemiboreal forests—Deriving quantitative targets for conservation planning. *Biol. Conserv.* **2008**, *141*, 997–1012. [\[CrossRef\]](#)
9. Pirovano, A.R.; Zecca, G. Black Woodpecker *Dryocopus martius* habitat selection in the Italian Alps: Implications for conservation in Natura 2000 network. *Bird Conserv. Int.* **2014**, *24*, 299–315. [\[CrossRef\]](#)
10. Michalczyk, J.; Michalczyk, M. Nesting preferences of Syrian Woodpeckers *Dendroccopus syriacus* in the agricultural landscape of SE Poland. *Acta Ornithol.* **2016**, *51*, 71–81. [\[CrossRef\]](#)
11. Mikusiński, G.; Gromadzki, M.; Chylarecki, P. Woodpeckers as indicators of forest bird diversity. *Conserv. Biol.* **2001**, *15*, 208–217. [\[CrossRef\]](#)
12. Sergio, F.; Newton, I.; Marchesi, L. Top predators and biodiversity. *Nature* **2005**, *436*, 192. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Sergio, F.; Newton, I.; Marchesi, L. Top predators and biodiversity: much debate, few data. *J. Appl. Ecol.* **2008**, *45*, 992–999. [\[CrossRef\]](#)

14. Roberge, J.M.; Angelstam, P.E.R. Usefulness of the umbrella species concept as a conservation tool. *Conserv. Biol.* **2004**, *18*, 76–85. [[CrossRef](#)]
15. Branton, M.; Richardson, J.S. Assessing the value of the umbrella-species concept for conservation planning with meta-analysis. *Conserv. Biol.* **2011**, *25*, 9–20. [[CrossRef](#)] [[PubMed](#)]
16. Maslo, B.; Leu, K.; Faillace, C.; Weston, M.A.; Pover, T.; Schlacher, T.A. Selecting umbrella species for conservation: A test of habitat models and niche overlap for beach-nesting birds. *Biol. Conserv.* **2016**, *203*, 233–242. [[CrossRef](#)]
17. Moreno-Opo, R.; Fernández-Olalla, M.; Guil, F.; Arredondo, Á.; Higuero, R.; Martín, M.; Soria, C.; Guzmán, J. The role of ponds as feeding habitat for an umbrella species: best management practices for the black stork *Ciconia nigra* in Spain. *Oryx* **2011**, *45*, 448–455. [[CrossRef](#)]
18. Council of the European Communities. Council Directive 79/409/EEC on the Conservation of Wild Birds. 1979. Available online: http://europa.eu/legislation_summaries/environment/nature_and_biodiversity/ (accessed on 25 March 2019).
19. Strazds, M. Conservation Ecology of the Black Stork in Latvia. Ph.D. Thesis, University of Latvia, Riga, Latvia, 2011.
20. Zawadzka, D.; Olech, B.; Zawadzki, J. Population density, reproduction and food of the Black stork in the Kampinoski National Park in years 1979–1987. *Notatki Ornitologiczne* **1990**, *31*, 5–20.
21. Lõhmus, A.; Sellis, U. Foraging habitats of the Black Stork in Estonia. *Hirundo* **2001**, *14*, 109–112.
22. Tucker, G.M.; Heath, M.F. *Birds in Europe: Their Conservation Status*; BirdLife International: Cambridge, UK, 1994; Conservation, 3.
23. Treinys, R.; Lõhmus, A.; Stončius, D.; Skuja, S.; Drobėlis, E.; Šablevičius, B.; Rumbutis, S.; Dementavičius, D.; Narusevičius, V.; Petraska, A.; et al. At the border of ecological change: Status and nest sites of the Lithuanian Black Stork *Ciconia nigra* population 2000–2006 versus 1976–1992. *J. Ornithol.* **2008**, *149*, 75–81. [[CrossRef](#)]
24. Rosenvald, R.; Lõhmus, A. Nesting of the black stork (*Ciconia nigra*) and white-tailed eagle (*Haliaeetus albicilla*) in relation to forest management. *For. Ecol. Manag.* **2003**, *185*, 217–223. [[CrossRef](#)]
25. Lõhmus, A.; Sellis, U.; Rosenvald, R. Have recent changes in forest structure reduced the Estonian black stork *Ciconia nigra* population? *Biodivers. Conserv.* **2005**, *14*, 1421–1432. [[CrossRef](#)]
26. Strazds, M. Conservation status of the Black stork in Europe and in the World. *Aves* **2003**, *40*, 12–13.
27. Chevallier, D.; Le Maho, Y.; Brossault, P.; Baillon, F.; Massemin, S. The use of stopover sites by Black Storks (*Ciconia nigra*) migrating between West Europe and West Africa as revealed by satellite telemetry. *J. Ornithol.* **2011**, *152*, 1–13. [[CrossRef](#)]
28. Pugacewicz, E. Stan populacji bociana czarnego (*Ciconia nigra*) na Nizinie Północnopodlaskiej w latach 1985–1994. *Notatki Ornitologiczne* **1994**, *35*, 297–308.
29. Sikora, A.; Rohde, Z.; Gromadzki, M.; Neubauer, G.; Chylarecki, P. Bocian czarny *Ciconia nigra*. In *Atlas Rozmieszczenia Ptaków Lęgowych Polski 1985–2004*; Bogucki Wydawnictwo Naukowe: Poznań, Poland, 2007.
30. Zieliński, P.; Stopczyński, M.; Janic, B.; Gapys, A.; Bańbura, J. Czy ochrona strefowa miejsc gniazdowych bociana czarnego *Ciconia nigra* jest wystarczająca? *Studia i Materiały CEPL w Rogowie* **2011**, *27*, 49–56.
31. Newton, I. *Population Limitation in Birds*; Academic Press Inc.: Londyn, UK, 1998.
32. Bettinger, P.; Boston, K.; Kim, Y.H.; Zhu, J. Landscape-level optimization using tabu search and stand density-related forest management prescriptions. *Eur. J. Oper. Res.* **2007**, *176*, 1265–1282. [[CrossRef](#)]
33. McComb, W.C.; McGrath, M.T.; Spies, T.A.; Vesely, D. Models for mapping potential habitat at landscape scales: An example using northern spotted owls. *For. Sci.* **2002**, *48*, 203–216. [[CrossRef](#)]
34. Aberg, J.; Swenson, J.; Per, A. The habitat requirements of hazel grouse (*Bonasa bonasia*) in managed boreal forest and applicability of forest stand descriptions as a tool to identify suitable patches. *For. Ecol. Manag.* **2003**, *175*, 437–444. [[CrossRef](#)]
35. Suorsa, P.; Huhta, E.; Jäntti, A.; Nikula, A.; Helle, H.I.; Kuitunen, M.; Koivunen, V.; Hakkarainen, H. Thresholds in selection of breeding habitat by the Eurasian treecreeper (*Certhia familiaris*). *Biol. Conserv.* **2005**, *121*, 443–452. [[CrossRef](#)]
36. Loehle, C.; Wigley, T.B.; Rutzmoser, S.; Gerwin, J.A.; Keyser, P.D.; Lancia, R.A.; Reynolds, C.J.; Thill, R.E.; Weih, R.; White, D.; et al. Managed forest landscape structure and avian species richness in the southeastern US. *For. Ecol. Manag.* **2005**, *214*, 279–293. [[CrossRef](#)]

37. Loehle, C.; van Deusen, P.; Wigley, T.B.; Mitchell, M.S.; Rutzmoser, S.H.; Aggett, J.; Beebe, J.A.; Smith, M.L. A method for landscape analysis of forestry guidelines using bird habitat models and the Happlan harvest scheduler. *For. Ecol. Manag.* **2006**, *232*, 56–67. [\[CrossRef\]](#)
38. Mitchell, M.S.; Reynolds-Hogland, M.J.; Smith, M.L.; Wood, P.B.; Beebe, J.A.; Keyser, P.D.; Loehle, C.; Reynolds, C.J.; van Deusen, P.; White, D., Jr. Projected long-term response of Southeastern birds to forest management. *For. Ecol. Manag.* **2008**, *256*, 1884–1896. [\[CrossRef\]](#)
39. Marušák, R.; Kašpar, J. Spatially-constrained harvest scheduling with respect to environmental requirements and silvicultural system. *For. J.* **2015**, *61*, 71–77. [\[CrossRef\]](#)
40. Vopěnka, P.; Kašpar, J.; Marušák, R. GIS tool for optimization of forest harvest-scheduling. *Comput. Electron. Agric.* **2015**, *113*, 254–259. [\[CrossRef\]](#)
41. Kašpar, J.; Hlavatý, R.; Kuželka, K.; Marušák, R. The impact of assumed uncertainty on long-term decisions in forest spatial harvest scheduling as a part of sustainable development. *Forests* **2017**, *8*, 335. [\[CrossRef\]](#)
42. Central Statistical Office (CSO). *Forestry*; Central Statistical Office: Warsaw, Poland, 2014.
43. Wielkoobszarowa inwentaryzacja stanu lasu. *Wyniki za okres 2009–2013*; Biuro Urządzania Lasu i Geodezji Leśnej: Sękocin Stary, Poland, 2014.
44. Krzyżanowski, A.; Zajaczkowski, S.; Zielony, R. Struktura siedlisk leśnych w Polsce oraz kierunki zmian. *Inżynieria Ekologiczna* **2002**, *6*, 38–46.
45. Zarządzenie nr 36 Dyrektora Generalnego Lasów Państwowych z dnia 19 maja 2004 r. w sprawie zmian w Instrukcji Urządzania lasu; Załącznik nr 1: Warsaw, Poland, 2004.
46. Wilk, T. Niepołomice Forest. In *Important Bird Areas of International Importance in Poland*; OTOP: Marki, Poland, 2010; pp. 409–411.
47. Górniak, J. *Prognoza Oddziaływania na Środowisko Projektu Planu Urządzenia lasu Nadleśnictwa Niepołomice na Okres Gospodarczy od 1 Stycznia 2012 r. do 31 Grudnia 2021 r.*; Biuro Urządzania Lasu i Geodezji Leśnej Oddział w Krakowie: Kraków, Poland, 2011.
48. Plan Urządzania Lasu (PUL). *Nadleśnictwa Niepołomice na lata 2012–2021*; Biuro Urządzania Lasu i Geodezji Leśnej: Kraków, Poland, 2012.
49. Państwowe Gospodarstwo Leśne Lasy Państwowe. *Zasady Hodowli Lasu (ZHL)*; ZILP: Warsaw, Poland, 2012.
50. Państwowe Gospodarstwo Leśne Lasy Państwowe. *Manual of Forest Management (IUL)*; ZILP: Warsaw, Poland, 2012.
51. Jones, J. Habitat Selection Studies in Avian Ecology: A Critical Review. *auk* **2001**, *118*, 557–562. [\[CrossRef\]](#)
52. Janssen, G.; Hormann, M.; Rohde, C. *Der Schwarzstorch*; Westarp Wissenschaften: Hohenwarsleben, Germany, 2004.
53. Kononov, A.; Kaldma, K.; Bokotey, A.; Brossault, P.; Chapalain, F.; Dmitrenok, M.; Dzyubenko, N.; Sellis, U.; Strazds, M.; Strenna, L.; et al. Spatio-temporal variation in nestling sex ratio among the Black Stork *Ciconia nigra* populations across Europe. *J. Ornithol.* **2015**, *156*, 381–387. [\[CrossRef\]](#)
54. Murray, A.T.; Weintraub, A. Scale and unit specification influences in harvest scheduling with maximum area restrictions. *For. Sci.* **2002**, *48*, 779–789. [\[CrossRef\]](#)
55. Yoshimoto, A.; Brodie, J.D. Comparative analysis of algorithms to generate adjacency constraints. *Can. J. For. Res.* **1994**, *24*, 1277–1288. [\[CrossRef\]](#)
56. Magurran, A.E. *Measuring Biological Diversity*; Blackwell Publishing: Malden/Oxford, UK, 2004.
57. Lõhmus, A. Nest-tree and nest-stand characteristics of forest-dwelling raptors in east-central Estonia: implications for forest management and conservation. *Proc. Estonian Acad. Biol. Ecol.* **2006**, *56*, 31–50.
58. Banaś, J.; Bujoczek, L.; Zięba, S.; Drozd, M. The effects of different types of management, functions, and characteristics of stands in Polish forests on the amount of coarse woody debris. *European journal of forest research. Euro. J. For. Res.* **2014**, *133*, 1095–1107. [\[CrossRef\]](#)
59. Hagemeyer, W.J.M.; Blair, M.J. *The EBCC Atlas of European Breeding Birds: Their Distribution and Abundance*; Poyser: London, UK, 1997.
60. Bobek, M.; Hampl, R.; Peške, L.; Pojer, F.; Šimek, J.; Bureš, S. African Odyssey project—satellite tracking of black storks *Ciconia nigra* breeding at a migratory divide. *J. Avian Biol.* **2008**, *39*, 500–506. [\[CrossRef\]](#)
61. European Environment Agency. *European Forest Ecosystems. State and Trends*; EEA Report no 5; Publications Office of the European Union: Copenhagen, Denmark, 2016.

62. Buczek, T. *Ciconia nigra* (L., 1758)—Bocian Czarny. In *Ptaki (część 1). Poradniki Ochrony Siedlisk i Gatunków—Podręcznik Metodyczny*; Gromadzki, M., Ed.; Ministerstwo Środowiska: Warszawa, Poland, 2004; pp. 81–85.
63. Treinys, R.; Mozgeris, G.; Skuja, S. Can intensified forestry be responsible for changes in habitat usage by the forest-dwelling Black Stork? *Eur. J. For. Res.* **2016**, *135*, 1175–1186. [[CrossRef](#)]
64. Larrieu, L.; Paillet, Y.; Winter, S.; Büttler, R.; Kraus, D.; Krumm, F.; Lacht, T.; Michel, A.K.; Regnery, B.; Vandekerckhove, K. Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. *Ecol. Indic.* **2018**, *84*, 194–207. [[CrossRef](#)]
65. Paillet, Y.; Archaux, F.; Du Puy, S.; Bouget, C.; Boulanger, V.; Debaive, N.; Gilg, O.; Gosselin, F.; Guilbert, E. The indicator side of tree microhabitats: A multi-taxon approach based on bats, birds and saproxylic beetles. *J. Appl. Ecol.* **2018**, *55*, 2147–2159. [[CrossRef](#)]
66. Noss, R.F. Local priorities can be too parochial for biodiversity. *Nature* **2010**, *463*, 424. [[CrossRef](#)] [[PubMed](#)]
67. Kangas, J.; Kangas, A. Multiple criteria decision support in forest management—The approach, methods applied, and experiences gained. *For. Ecol. Manag.* **2005**, *207*, 133–143. [[CrossRef](#)]
68. Roberge, J.M.; Öhman, K.; Lämås, T.; Felton, A.; Ranius, T.; Lundmark, T.; Nordin, A. Modified forest rotation lengths: Long-term effects on landscape-scale habitat availability for specialized species. *J. Environ. Manag.* **2018**, *210*, 1–9. [[CrossRef](#)]
69. Strazds, M. Micro-Reserves for the Black Stork in Latvia—An Important Measure for Habitat Conservation. In *Schutzstrategien für Schwarzstorch und Rauchfußhühner*; Naturschutzzentrum Vasserschloß Mitwitz: Mitwitz, Germany, 1993; pp. 39–45.
70. Rozporządzenie Ministra Środowiska w Sprawie Ochrony Gatunkowej Zwierząt, Dz.U. 2016 poz. 2183, 16 Grudnia 2016; DZIENNIK USTAW: Warsaw, Poland, 2016.
71. Zieliński, P.; Janic, B.; Kamiński, M.; Stopczyński, M.; Marszał, L.; Szpetmańska, H.; Bańbura, J. Wzrost liczebności i zagęszczenie bociana czarnego *Ciconia nigra* w Polsce środkowej. *Chrońmy Przyrodę Ojczyzn* **2017**, *72*, 101–109.
72. Olszewski, A.; Różycki, A.; Matusiak, J. Wybiórczość środowiskowa miejsc lęgowych oraz typy umiejscowienia gniazd bociana czarnego *Ciconia nigra* w Kampinoskim Parku Narodowym. *Studia i Materiały CEPL w Rogowie* **2017**, *51*, 169–185.
73. Jactel, H.; Nicoll, B.C.; Branco, M.; Gonzalez-Olabarria, J.R.; Grodzki, W.; Långström, B.; Santos, H. The influences of forest stand management on biotic and abiotic risks of damage. *Ann. For. Sci.* **2009**, *66*, 701. [[CrossRef](#)]
74. Mitchell, S.J. Wind as a natural disturbance agent in forests: a synthesis. *Forestry* **2013**, *86*, 147–157. [[CrossRef](#)]
75. Forest Stewardship Council (FSC). *Zasady, Kryteria i Wskaźniki Dobrej Gospodarki Leśnej w Polsce*; Dokument Standardów w Obowiązujących w Certyfikacji Obszarów Leśnych w Systemie Forest Stewardship Council w Polsce; Forest Stewardship Council (FSC): Warsaw, Poland, 2012.
76. Bujoczek, L.; Zięba, S.; Banaś, J. Ocena zasobów martwego drewna w lasach gospodarczych z uwzględnieniem typów siedliskowych lasu oraz bonitacji gatunku panującego. *Sylvan* **2016**, *160*, 320–327.
77. Gutowski, J.M.; Bobiec, A.; Pawlaczyk, P.; Zub, K. *Drugie Życie Drzewa*; WWF: Warszawa-Hajnówka, Poland, 2004; ISBN 83-916021-6-8.
78. Stokland, J.N.; Siitonen, J.; Jonsson, B.G. *Biodiversity in Dead Wood*; Cambridge University Press: Cambridge, UK, 2012.
79. Andersson, J.; Domingo Gomez, E.; Michon, S.; Roberge, J.M. Tree cavity densities and characteristics in managed and unmanaged Swedish boreal forest. *Scand. J. For. Res.* **2018**, *33*, 233–244. [[CrossRef](#)]
80. Radu, S. The Ecological Role of Deadwood in Natural Forests. *Nat. Conserv.* **2006**, 137–141. [[CrossRef](#)]
81. Gábor, A.; Horváth, G.; Ortmann-né Ajkai, A.; Csicssek, G. Quantitative classification of macrohabitats for small mammals' habitat segregation surveys in a forest reserve. *Natura Somogyiensis* **2015**, *15*, 123–134.
82. Jancewicz, E.; Kielan, E. Importance of coarse woody debris in the functioning of small mammals populations. *Sylvan* **2017**, *161*, 519–528.

