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Discussion

Potential of Birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) for Forestry and Forest-Based Industry Sector within the Changing Climatic and Socio-Economic Context of Western Europe

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Abstract: Five commercial tree species comprise nearly 80% of the forest standing stock volume in Western Europe. Nowadays, there is a strong need to consider a wider diversity of tree species, as evidenced by the impact of climate change and the forest health crises over the past decades. In this context, this study focuses on the potential of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.), a neglected indigenous species, for forestry and the forest-based industry sector. We have therefore compiled, analyzed, and discussed literature regarding the strengths and weaknesses of the species and the opportunities and threats of its use for this purpose. Among the strengths, birch tolerates various climates and sites, and high genetic variability promotes its adaptability. Birch improves forest resilience by colonizing forest gaps and quickly increasing soil functioning and biodiversity. Birch is also remarkably resistant to game overpopulation-associated damage. Large-sized logs are produced within relatively short periods with proper silvicultural treatment, and the wood characteristics allow versatile and valuable uses, as shown in Northern Europe. However, its weaknesses include high sensitivity to crown competition and to wood rot as challenges for silviculture. Among the opportunities, birch is well-suited to the global changes with its adaptability to climate change and its possible integration in diverse productive mixed tree stands. In the context of societal evolutions and customer perceptions, birch wood could play an increasing role in the building and furniture sectors, and among non-wood forest products. In Western Europe, the main obstacle to birch development is the lack of information on the wood uses and, consequently, the lack of interest among forest managers and wood processing professionals, which have led to a poor quality of the resource and to insufficient demand for its wood. Moreover, its fast height growth can affect the vitality of other species in mixed stands. Our analysis highlighted the potential of birch in the Western European forestry considering societal, ecological, and economic purposes in a changing climatic and socio-economic context and the need to (i) develop opportunities for industrial uses of birch wood, (ii) inform forest owners, managers, and industrial professionals about the potential value of birch, and (iii) define silvicultural guidelines.

Keywords: birch; global change; forestry; valuation market

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1. Introduction

To date in Western Europe, forest management and wood processing industries are favoring a few commercial tree species such as Norway spruce (*Picea abies* (L.) Karst), pines (*Pinus* sp.), oaks (*Quercus* sp.), beech (*Fagus sylvatica* L.), and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), often grown in pure stands. These comprise approximately 80% of the forest standing stock volume [1]. However, this management approach is no longer adequate to the various risks associated with global changes [2–5]. During the past decades, multiple forest health crisis factors have emerged, e.g., oak dieback [6] and Douglas fir diseases, along with climatic stresses, pests, and storm damages on spruce and beech stands [7,8]. At the same time, people are becoming increasingly aware of the role of biodiversity in alleviating these risk factors, improving the resilience of the forest, and ensuring the sustainability of its ecosystem services supply [9–11]. As a result, in Western Europe, a tangible evolution in forest tree species proportion and abundances is expected over the coming decades [5,12].

In this context, there is a strong need to consider a wider diversity of tree species and new approaches to manage production forests. Largely neglected indigenous broadleaved taxa such as *Alnus*, *Tilia* and *Betula* appear to be interesting alternative species. Some of them may be more adaptable to the future climate and could generate valuable products for future markets [9,13,14].

Among these species, we focus on silver birch (*Betula pendula* Roth) and white birch (*Betula pubescens* Ehrh.), also called downy birch. We refer to them indiscriminately as "birch" unless otherwise specified.

Birch resource is important in Western European forests, reaching 0.5% to 15% of all hardwood standing volume, depending on the country, and its expansion is thriving in some regions [15]. Birch is scattered in mixed stands or grows in pure stands as a colonist during the early stages of succession, e.g., after clear-cutting or storm damage [15,16]. Nevertheless, it remains undervalued by forestry and wood industry sectors. Knowledge in birch management and wood uses is weak [17], and published studies are lacking, as it is also the case in Central Europe [18]. In contrast, in Northern Europe, the Baltic Sea region, and Northwestern Russia, where birch is the most abundant commercial hardwood, research is relatively active on its management, growth, and yield [19,20] along with physical and mechanical properties of its wood for various uses [21–27].

In this context, with a literature analysis, this paper aims to identify the potential role of birch for forest management and wood processing and trade in Western Europe, to understand the reasons limiting the use of this abundant resource in forestry and wood market, and to propose some main recommendations to develop a specific birch sector, from silviculture to wood products processing and market.

2. Method

We collected, analyzed in detail, and discussed in a practical perspective according to our expertise scientific and grey literature that considers strengths or weaknesses of or opportunities or threats for birch, in the context of forestry and wood industries and markets. We focused on Western Europe, were birch is little known and studied, but we interpreted Northern Europe and Baltic Sea Region information when other is lacking.

The results of this work are presented according to the four criteria of an analysis of the strengths, weaknesses, opportunities, and threats (SWOT analysis) [28]: strengths and weaknesses of birch were deducted from the species life traits, and opportunities and threats were identified in the socio-economic and environmental context of forestry and the wood market. Indeed, these criteria appear to be well suited in order to help decision-makers (e.g., forest owners and managers, policymakers, forest product industries) to evaluate the relevance of the use of birch according to their own need or affinity. This could permit them to find solutions based on the strengths of birch, to limit the impact of its weaknesses, to exploit the emerging opportunities, and to transform the threats into challenges. Nevertheless, we have not fully implemented the SWOT analysis methodology because of the complexity to give relative weight to the various information or to prioritize them while decision-makers have different affinities. Indeed, items cover economic, ecological, and societal considerations and sometimes all three at once.

3. Strengths

3.1. Adaptability

3.1.1. High Genetic Variability and Phenotypical Plasticity

Birch is wind-pollinated by cross-pollination; pollen grains are produced in large quantities [29] even by five-year-old or younger trees [30]. Abundant flowerings are synchronized over large geographic areas, and pollens are transported for hundreds of kilometers, promoting the gene flow and enriching the gene pool [31,32]. The nearly systematic presence of birch in the landscape facilitates gene exchanges, creating a high genetic variation within birch populations (e.g., [33–35]). Because of the inherent genetic variability and phenotypic plasticity, birch is able to adapt by natural selection to a wide range of sites and changing environmental conditions (e.g., [36–38]). For example, there are reports on genotype-dependent leaf area variations and root architecture adjustments in response to experimental warming or drought (e.g., [33–35]) and studies describing a proper acclimation of provenances when tested in warmer and drier regions [39].

3.1.2. Wide Range of Climate and Sites

Birch is distributed throughout Eurasia (Figure 1) and has the widest range of all European broadleaved tree species, which is boosted by its ability to develop at both the forest wet and dry limit [40]. White birch is more suitable than silver birch for colder climates and wetter soils, whereas the latter is more tolerant of warmer temperatures [9]. Birch performs well on a great diversity of soils, from rich and mesic soils to peatlands or poorly aerated and compact clay soils, where other species cannot develop well; it can even grow rapidly on infertile soils, including gleysols or podzols [19,20,30,41], and soils polluted with heavy metals, e.g., with zinc or nickel [42]. However, because birch is often found on very constraining soils where no other tree or agricultural species could survive or produce, this species is sometimes wrongly considered a non-productive species, which specifically applies to the white birch that survives on soils with excessive moisture content [19,20].

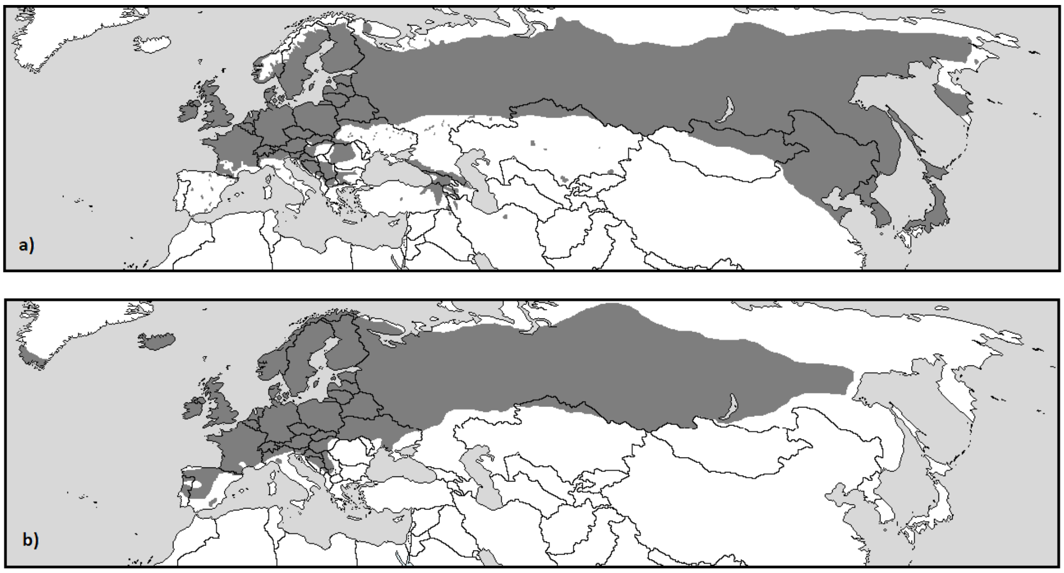

Figure 1. Distribution map of (**a**) silver and (**b**) white birch adapted from [15].

During severe drought in the growing season, birch avoids drought damages via reducing transpiration by leaf yellowing or abscission [43]. Nevertheless, Hemery et al. [9] reported on drought-related mortality that occurred after severe droughts in 1976 and 2003 (e.g., England

and Scotland). Birch also exhibits some resistance to wildfires, which may furthermore favor its establishment [44].

At the very early stage, in the absence of any constraints, birch develops a strong heart-shaped root system with a depth of 60–120 cm, which provides remarkable resistance to windthrows [17]. However, on pseudogleys, poor soils, and skeleton-rich soils, root development becomes superficial with large horizontal expansions [17,45].

3.2. Rapid Growth and High Productivity

Different authors from Scandinavia to Spain have determined birch height growth curves [20,46–49] (Figure 2). They all show an early rapid height growth, but they differ on its sustainability and maxima: for example, maximal height ranges from about 17 to 25 m at 30 years. Birch height growth is maximal during the first 20 years, decreases sharply at 30–40 years, and is very low from 50–60 years [49–51]. During the first years, birch is taller than almost all other tree species of the same age. The period with rapid height and diameter growth is longer in silver birch than in white birch [20]. At suitable sites, the mean annual volume increment would cover a range of 5–10 m^3 ha^{-1} a^{-1} until around 50–80 years [20,52] and sometimes more according to local observations (e.g., [53]). Maximum annual volume increment would reach 12–23 m^3 ha^{-1} a^{-1} at approximately 15 years of age [54]. Thus, birch is among the hardwood species of rapid growth and good productivity, such as sycamore (*Acer pseudoplatanus* L.) or ash (*Fraxinus excelsior* L.).

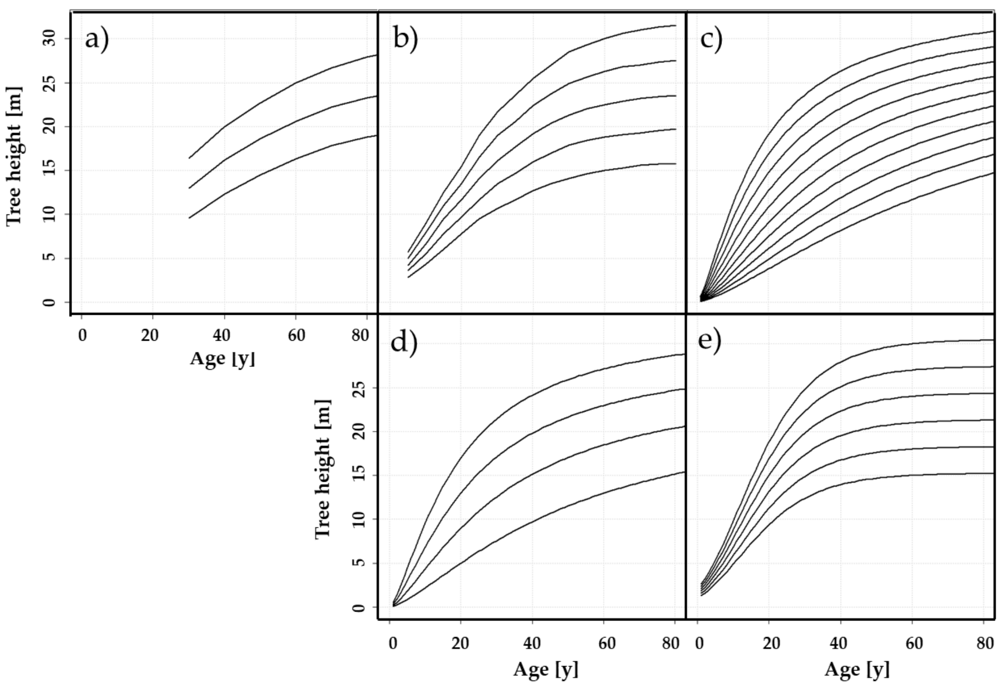

Figure 2. Height growth curves of birch drawn from the models of (**a**) Frauendorfer (1954, Austria) [46], (**b**) Lockow (1997, Germany) [20], (**c**) Eriksson (1997, Sweden) [47], (**d**) Diéguez-Aranda et al. (2006, Spain) [48], and (**e**) Hein et al. (2009, Germany) [49].

However, yield tables often describe the 20th-century silviculture results observed in old stands without considering the positive effect that early crown release could have on individual growth and productivity [55,56]. Interestingly, in Northern Europe, breeding, planting, and thinning programs have promoted the growth and shortened the commercial rotation of silver birch [19].

3.3. Pioneer Species Improving Forest Resilience and Biodiversity

3.3.1. Restoration of Wood Production after Disturbance

Birch produces numerous light seeds that can travel hundreds of meters by the wind [42,55]. As a result, birch is a colonizer of open areas [19,20]. When a birch stand establishes, it creates favorable conditions for the natural immigration of other trees species [37] by the process of facilitation [57], thanks to the light conditions under its clear canopy, the soil improvement, and the protection it offers against herbaceous competition, game browsing, frost, or drying. In birch stands regenerated after hurricanes (1990 in Belgium and Germany and 1999 in France), various commercial species such as beech, oaks, wild cherry (*Prunus avium* (L.) L.), sycamore [58], and Norway spruce settled within 15–20 years in adequate quantities. Thus, birch contributes to forest resilience and rapid restoration of wood production after disturbance. The importance of early successions has also been demonstrated in North America [59,60].

3.3.2. Improvement in Soil Functioning

Birch is recognized as a soil improver [61,62]. The fast decomposition of abundant dead fine roots and fallen birch leaves improves soil porosity and water infiltration [42] along with biological properties, A-horizon depth, and nutrient cycling [20,61–65]. Birch has these effects even on degraded soils such as former *Calluna* heathland [66], moorland, podzolic soils [61], or *Sphagnum* peat soils [42]. The presence of birch improves soil fertility and growth within oak, beech, spruce, and pine forests (e.g., [62,67–70]). Transformation of pine or spruce stands into birch stands restores soil fertility by limiting the loss of base cations, decreasing the nitrate percolation [71], and reversing the podzolization process [72]. Less than one rotation period can be adequate to achieve measurable improvements in soil properties, which may even include the transformation of raw humus into mull [63]. Because of specific mycorrhizae [42], birch accumulates high amounts of zinc in its leaves on highly contaminated soils, which makes it usable in phytoremediation [73].

3.3.3. Direct and Indirect Contributions to Biodiversity

The number of specialized flora and fauna species associated with birch is higher than for other tree species in Europe [74], particularly for mycorrhiza [42] and insects [61,75]. The lighter conditions on the ground under a birch stand compared with the other tree species enable a greater development and flowering of the understory vegetation, which supports nectar feeders [20,61]. The soil improvement increases the abundance and richness of soil fauna, e.g., earthworms, oribatid, mesostigmatid and prostigmatid mites, and *Collembola* [60], which is also critical for shrews, moles and badgers [61]. Birch has a key role in maintaining invertebrate biodiversity in the landscape [76]. Different authors consider birch as a keystone species with a disproportionately large effect on its environment relative to its abundance [77–80], or, alternatively, as an ecosystem engineering species because its interactions with the environment modify and/or create habitats, with effects lasting for at least 20 years after its removal [66]. In multiple ecological restoration projects in North America, Scandinavia, Germany, Belgium, and Spain, birch is used as a target species to improve biodiversity, especially in coniferous forests [78,81–83].

In Western and Central Europe, early-successional forests, which are generally dominated by birch, have a great species diversity, including old-growth forest, ruderals, and habitat specialists. For some *Lepideptora*, reptile, or bird species, only this stage can provide suitable foraging or nesting habitats [60,84].

3.4. Interesting Wood Characteristics

Birch has an aesthetic white homogenous wood with diffuse pores and a glossy finish due to shimmering facets (termed the "white wild cherry" by some users). The physical and mechanical properties of birch wood, such as density, stiffness, strength, and hardness are almost at the level of beech wood (Table 1), its most important competitor in solid wood products in Europe [24]. Because of the diffuse pores, the quality of birch products is not affected by ring width [85]. Birch wood also has other suitable properties for specific uses, such as good machinability, ease of finishing [24,25], and lack of smell [85].

The two European birch species, the silver and the white birch, have very similar wood properties regarding their wood anatomy, chemical composition (e.g., in wood extractives), fiber properties, and physical and mechanical characteristics. On average, the performance of silver birch wood is slightly better than that of white birch wood because of its higher wood density, but their industrial uses are not differentiated [24,25,86–90].

Table 1. Physical and mechanical mean wood properties of beech, oak, birch, and Norway spruce determined on small clear wood specimens, according to Wagenführ and Scheiber 1985 [91], *Heräjärvi 2002 (Finnish conditions) [25], and **Boedts 2016 (Belgian conditions) [92].

	Beech	Pedunculate (Sessile) Oak	Birch	Norway Spruce	
Wood density at 12%–15% MC	720 (540–910)	690 (430–960)	650 (510–830); **654 (± 40)	470 (330–680)	kg m^{-3}
Porosity	55	57	59	71	%
Volumetric shrinkage	17.9 (14.0–21.0)	12.2–15.0	13.7–14.2; **18.0	11.6–12.0	%
Volumetric shrinkage per 1% moisture content	0.46–0.60	0.45	0.23	0.39-0.40	% $\%^{-1}$
Flexural strength (MOR)	123 (74–210)	88 (74–105) (110 (78–117))	147 (76–155); *114; **100 (± 13)	78 (49–136)	MPa
Resilience	10.0 (3.0–19.0)	6.0 (1.0–16.0)	10.0 (4.5–13.0); **4.4	4.6 (1.0–11.0)	J cm^{-2}
Stiffness (MOE)	16.0 (10.0–18.0)	11.7 (10.0–13.2) (13.0 (9.2–13.5))	14.5–16.5; *14.5; **15.0 (± 2.2)	11.0 (7.3–21.4)	GPa

Table 1 compares birch wood to other species for which it may be a substitute in some case: beech and oak wood, which are two widely used species for noble hardwood processing, and Norway spruce, which is widely used in construction.

3.5. Recreational Value

Birch has an aesthetic appearance because of its unique white bark, light crown and silhouette, and autumn color. Thus, its close integration into forests increases their recreational value [19,93] by bringing extra light and extra color, diversifying landscapes, etc., while that function is increasingly demanded by the public [94].

4. Weaknesses

4.1. Short Lifespan

Birch vitality declines before the age of 100 years, and heart discoloration and rot that goes along with senescence start at 60–70 years [20,49]. After approximately 80 years, the vertical root system starts to rot, which increases the danger of windthrows [17]. These natural processes start later in the silver birch than in the white birch [20].

4.2. Low Durability of Wood

Wood from living birch trees has poor resistance against microorganisms [24,95]. Broken or dead branches that remain on the stem induce detrimental discoloration or decay that spreads into the trunk [24,96–98]. In Northern Europe, snow helps to remove thin dead branches naturally, but that does not typically happen in Western Europe. Wounds, caused for example by skidding or pruning of large branches or separation of a double trunk, induce very serious decay in birch wood [19].

Birch logs do not tolerate long storage in the forest or on sawmill log yards because fungal discolorations, stains, and insect damage develop rapidly for this species [24]. Noticeable radial holes of *Scolytus ratzeburgi* or *Trypodendron signatum* with associated coloration occur, and excessive drying, checking, and decay start from log ends [95]. Birch wood products have low durability class rankings, as low as class 5, i.e., not durable (EN 350:2016). Therefore, without specific treatment, they can be used indoors only [25].

4.3. Growth Affected by Intraspecific Competition

Birch tree crown expansion and individual stem diameter growth potential are irreversibly impacted by intraspecific competition [20,56,99] already from an early age, i.e., during the first 10 years. Strong intraspecific competition generally occurs early in naturally regenerated pure birch stands.

4.4. Pest Damages

Birch is particularly sensitive to the European hornet (*Vespa crabro germana*) which strips birch bark from thin branches, probably for nest construction and sap collection [100,101]. The twig part above the injured area can be broken by wind or snow, which creates a fork that is a hindrance in log production if it occurs when the stem is less than six meters tall. Sometimes, all birches in a dense natural regeneration are affected. Other insects, such as moths [102] and aphids, or insect larvae, e.g., caterpillars, cause leaf damage without significant impact on the tree health or growth.

Phytobia betulae, a small fly, causes black irregular-shaped configurations in core birch wood, which may be problematic for some aesthetic wood valorization. However, the damage is restricted to a limited area of the transverse section [103], and it appears to be more common in plantations with wide spacing and on former agricultural lands [19].

4.5. Aero-allergenic Tree

Birch is the most important aero-allergenic tree in Europe, its pollen causing allergies in more than 100 million people and being the most frequent triggers of respiratory diseases: seasonal hay fever, asthma, and cross-reactive food allergy [104–107]. During certain meteorological conditions, birch pollen is transported over long distances, e.g., from Poland and Germany to Denmark [108]. Climate change is increasing pollen concentrations and expanding the pollen season, which has an impact on human health by causing more severe symptoms and at an earlier time of the year. Some scientists suggest avoiding planting birch in urban areas [104,105,109–111]. In forest areas, birch is well present and is naturally expanding [15]. Its impact for allergy will neither be worsened nor lowered whether or not there is a silvicultural treatment to allow the production of valuable timber from birch.

5. Opportunities

5.1. An Increasing Place for Birch in Global Change

5.1.1. Climate Change and Forest Resilience

- Uncertainties of Climate change

Against the uncertainties of climate change and the associated biotic risks, birch has a great advantage over many other species due to its (i) high tolerance to a large variety of climates and soils; (ii) adaptation capacity; (iii) ability to recolonize damaged areas after windthrow, disease outbreak, or dieback impacting other tree species [102] or wildfire, e.g., in Spain [112], Italy [44], and Poland [113]; and (iiii) rapid growth should support rapid large-sized log production which is a means of reducing the risks of a production system.

- Development of Mixed Stands

Developing mixed stands improves forest resistance and resilience and diversifies the valuable timber production [4]. Birch is well suited to be included in different types of mixed stands, especially if it ensures complementary use of light, nutrients, and rooting zones [4]. For example, Curt and Prévosto [114] observed in France that the beech fine root biomass was higher under birch stands than under pine stands. In the alpine regions of Germany and Austria, birch has been considered for mixed species stands to increase biodiversity in spruce-dominated forests [115] and replace Scots pine in areas sensitive to tree breakage because of snow load and beech in areas exposed to acid rain [116,117].

On forest soils or abandoned agricultural lands, a temporary mixture of birch as a nurse stand functions as a light shelter that protects more sensitive, naturally regenerated or planted target species against too much sunlight, evapotranspiration, precipitation, late frost, wind or ground vegetation (e.g., [118,119]). This method, which mimics the facilitation process governing the successional sequence, may have been used in Germany and Switzerland for almost 200 years [118]. Sheltering of silver fir (*Abies alba* Mill.), spruce, beech, and oak by a birch overstory is successful under hemiboreal conditions (e.g., [20,120–122]), as well as in Western Europe [118,119,123], if the shelter density is well regulated. These two-storied stands lead to an increase in total wood production, a short-term wood supply, and an improved stem form of the understory species. However, natural regeneration can sometimes take time to arrive if there is too much vegetation on the ground due to abundant light under old or sparse birch stands. On damp sites, the nurse stand works as a pump by transpiration and lowers the water table [118,124], which facilities other tree species regeneration.

Cluster planting of the target species in naturally regenerating birch stand is gaining interest in Europe and has been studied with oaks in Germany, Switzerland, and Austria [125,126]. This type of planting represents an economic and ecological alternative to the traditional row planting of oaks, beech, and maple [120,126], which benefit from a protective shelter formed by surrounding birches.

Birch represents an opportunity to develop mixed stands with some species of interest, e.g., with Norway spruce, Douglas fir, larch, cedar (*Cedrus atlantica* (Endl.) Carr.), indigenous or American oaks, beech, and sycamore. Mixed stands may be more resistant to insect damages due to the difficulty for insects to locate and reach host trees surrounded by non-host trees [127]. Birch appears to have two additional specific effects to protect other species, e.g., pine, against processionary moth (*Thaumetopoea pityocampa*) or oaks against oak miners [128,129]. The first effect is a physical hiding of target trees by taller birches; the second one is the emission of repellent chemical volatile compounds, which simultaneously dilute host attractants [127,129,130].

- Game Damage

In Western Europe, game overpopulation associated damage is an important concern for forest regeneration [131]. Even with expensive protections, plantations or natural regenerations can be either partially or entirely destroyed. Birch is seriously affected in Northern Europe by moose [19,20,132], but is relatively unaffected in Western Europe, where moose is not present. Under game overpopulation, birch can be browsed, especially white birch, and frayed by deer, but i) almost all other tree species are more palatable [133], ii) naturally regenerated birches are generally abundant and destruction is rarely total, and iii) the vulnerability period is shortened by strong juvenile growth. Thus, birch is often the only tree species to resist. Forest managers sometimes decide to favor naturally regenerated birches in areas where the previous target tree species is destroyed [15]. Young birches also act as a shield against fraying damages, and white birch against browsing, in plantations of other species.

5.1.2. Societal Changes

- Land Use Evolution

Spontaneous natural birch reforestation has recently occurred on a large scale in European countries where agricultural activity has decreased, e.g., in some regions of France [57], Northern Europe [20,122], and Eastern Europe [134–136], which will reinforce the presence of birch trees.

For example, in Belgium, the land sometimes remains unplanted after clear-cutting of spruce stands due to the owner's lack of interest in forestry activities [15,137]. In the context of climate change, forest health crises, game overpopulation, and instability of the timber market, planting appears to some forest managers an uncertain investment. Most of those areas will be naturally converted into birch-dominated stands [15]. Soil scarification, which often occurs prior to planting stands, facilitates abundant natural regeneration of birches [138,139]. To avoid planting-associated costs, some forest owners show a willingness to learn how to manage freely settled birch regeneration.

Nevertheless, birch stand makes the light conditions unsuitable for its own seedlings and, therefore, almost always hosts other tree species in its understory, leading to a new stand composition [140]. Birch is therefore not intended to replace other species in the long term, where they are healthy.

- New Trends in Forest Policies

As a general trend in Western Europe [57,141] and Central and Northern Europe [93], forestry policies aim to move from monocultural plantations to more close-to-nature forests that include native species, e.g., by using certification systems such as the world organizations Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification Schemes (PEFC) or directives such as NATURA 2000 in European Union, promoting natural habitats and species conservation. The Second Ministerial Conference on the Protection of Forests in Europe (Helsinki, June 1993) incited to plant tree species, preferably native species, that are well suited to locally forecasted ecological conditions, and to improve the integration of species that are currently of minor importance but with a high potential in timber production [142]. Promoted by policymakers, e.g., in Northern Belgium [82,141] and in Britain [143], large areas of pine and Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) are marked for forest transformation by birch for a variety of reasons, e.g., site constraints, biodiversity, landscape, ecosystem services, and facilitating oak understory arrival [70].

5.2. Production of Valuable Birch Timber

In Western Europe, due to the lack of interest in birch, specific silvicultural methods do not exist for producing birch quality logs (i.e., straight and free from knots, scars, cracks, and decay [20,23]). In Germany, the "QD method" [144], consisting of starting silvicultural operations such as thinning between 12 to 15 years for birch, is proposed. This appears successful in specific cases to produce high-quality birch timber, but it must be adapted to obtain sufficient results in many other contexts. Nevertheless, strong and early thinning, i.e., already during the first 10 years, permits to harvest large-sized logs, i.e., with a diameter between 50–60 cm, within 40–50 years [20,49].

In contrast, in Finland, silvicultural guidelines provide growing-for-quality recommendations for silver birch and white birch stands, separately [19]: evaluation and selection of soil, site and climatic region; choosing between planting, natural regeneration, or mixed-species management; timing, intensity, and tree selection during cleaning, tending, and pre-commercial and commercial thinning operations; rotation period and harvesting season of final cutting; storage, seasoning, and delivery of timber to the processing plants or other users. In Finland, birch silviculture occurs at the stand level [20]. The management of birch stands in Northern Europe highlights the potentialities of birch for valuable wood production in Western Europe.

Since the 1960s in Finland [20], and today at least occurring in Sweden, Estonia, Latvia, and Britain [145], birch silviculture is associated to intensive tree breeding programs (plus tree selection, crossing, and progeny testing). Birch is an ideal model for tree genetics because it generates substantial gains by simple selection [29]. In Western Europe, where one of the reasons for birch silviculture is to reduce stand establishment costs thanks to natural regeneration, birch breeding is currently not a major focus. Some Western European countries have selected birch stands for seed collection (e.g., five in Belgium), but, to our knowledge, there is no current birch breeding program. However, planting should be an alternative if there is a strong competition of ground vegetation, e.g., on former agricultural lands, or in the absence of seed trees in the area.

5.3. Birch Products Valuation

In Western European countries, e.g., in Great Britain and Ireland [55,146], Belgium and France [15], and Germany and Austria [25,116,147,148] but also in Central Europe (e.g., [18]), birch has a bad reputation because of (i) its capacity to strongly colonize open landscapes and young plantations, not unlike a weed and (ii) the poor quality of the birch resource (i.e., bad stem form, poor dimension, rot, and knots) as a result of a lack of adequate management. Data about trade statistics of birch roundwood are therefore missing, at least for Belgium, France, and Germany. Birch is there sought-after for the production of paper and paperboard, medium-density or high-density fiberboards (MDF, HDF), or oriented strand boards (OSB). People in Western Europe generally prefer firewood from other broadleaved species such as oak, beech, or ash, but birch appears to be particularly suitable for bakeries and pizzerias [50,148]. Therefore, even if some large birch logs free of knots and rot may occasionally reach high price levels, e.g., in South-Western Germany, the references about birch valuation opportunities are largely based on the long experience and competence in research, development, and use of birch in Northern Europe and Baltic countries where the species is of great industrial importance [24,25,27,89]. However, several decades ago, birch was considered a weed in those countries [19,22,37,55], prompting forest managers to eliminate it from the forests, as it is the case now in Western Europe. Since the 1950s, forest product industries realized its value as a versatile wood material [24,25,37]. In Finland, for example, pulp industries consume more than 80% of all commercial birch wood (excluding firewood), i.e., 10 million m^3 (including the small-diameter birch logs). More than 90% of the birch logs are used in plywood industries, which consume approximately 800,000–1,200,000 m^3 annually (2014-2016); sawmills consume 100,000–150,000 m^3 of birch logs per year [97].

5.3.1. Opportunities to Use more Birch

- Wood Products

Birch wood properties permit multiple uses. Sawn wood and veneers are produced for furniture, cabinetry, parquetry, and floorings, as well as tool handles, sports equipment, and musical instruments [24,26,27]. Birch wood is also used to manufacture baby cradles and toys because, in addition to its aesthetic appearance, it is non-toxic, and its use does not cause any splinters.

Cross-laminated timber (CLT) and glued laminated timber (GLT) are being increasingly used in wood construction due to their multifunctionality, economic competitiveness, and suitability according to fire regulations. CLT and GLT made from birch have a far better rolling shear modulus than those made from spruce or pine [149,150], permitting a longer span with a similar size or a reduced size for a similar span. Birch CLT has a white color, which is a contributing aesthetic factor to its use as wall and floor elements [97]; brown birch heartwood that is not soft decay can be used for non-visible elements. In Austria, a CLT house and a GLT industrial hall made from birch have been built, in which 10%–15% and 20%–25% less wood was needed, respectively, than if spruce wood had been used [150].

Birch plywood is used for construction elements, casting molds, furniture, interior panels, in land vehicles (trucks, buses, railway wagons), and in liquefied natural gas tanker ships [97]. Interestingly, plywood and sawn wood made from birch are ideal for interiors of concert halls due to the acoustic and visual properties (e.g., world-class concert halls in Katowice in Poland and Lahti in Finland).

Chemical and semi-chemical pulping (Neutral Sulfite Semi Chemical, Chemi-thermomechanical, kraft, dissolving) and selected paper types and paperboards that are manufactured from birch have excellent properties because birch wood has relatively short but stiff fibers and an evenly light color (e.g., [19,97]). Birch extractives are used in high value-added end-uses, e.g., in textiles, tires, coatings, paints, and tobacco products, as well as in food and pharmaceutical products [19,89,97,151–153].

Thermal treatment of birch wood, an environmentally friendly method of wood modification, improves its dimensional stability and resistance to weather and decay, while it darkens its color. This may be a desirable improvement. It either positively or negatively affects some mechanical properties [25,97,154,155], depending of the temperature, but birch wood is, for example, less impacted than beech wood [18,156]. Temporarily increasing the elasticity by compression also adds another use of birch wood for designed and shaped furniture [25,97]. Finishing oils and phenol or melamine films increase birch plywood wear, UV-light, and weather resistance, durability, and hardness. Thus, even if birch wood already has a moderate surface hardness, this property can be improved to the level of oak wood [26,97].

The various uses of birch make it possible to enhance the value of logs, for example, in veneer slicing or sawing to high-value products from the best-quality logs, i.e., large-sized straight logs free from knots and discoloration [25,96,97], in rotary cutting to produce plywood that can include lower-quality logs (i.e., moderate deviations from straightness, larger knots, and limited heart rot), and in diverse uses from the lowest-quality logs, such as for paper, paperboard, or bioenergy products. Moreover, some niche markets are specific to birch: small-sized birch logs for nesting boxes or for cleaning materials of steel mill chimneys; logs with specific wood figurations such as flamed wood and burls or wood with early stages of decay [157]; house decorations or even decorative firewood logs. Birch veneer with discoloration may be marketed as "natural color" and worm tracks as "character" [158].

- Non-Wood Forest Products

Birch also offers business opportunities for non-wood forest products (NWFP) [97], which include the well-known birch sap. Birch sap has been introduced many years ago to the market in Finland and there is still a growing demand. Revenues from renting birch trees to a sap tapping company sometimes exceed those from veneer log and pulpwood sales. This business is also starting in Western European countries. New technology permits the development of non-perishable birch sap concentrate-based beverages with preserved healthy properties and improved organoleptic characteristics [159].

Finland has developed new value chains, along with research and development actions, for the cultivation of high-value mushrooms, e.g., chaga (*Inonotus obliquus*), which grows on birch stems, reishi (*Ganoderma lucidium*), and sheathed woodtuft (*Kuehneromyces mutabilis*). These are in growing demand in the nutraceutical and food supplement market [160].

Birch bark contains commercially interesting extractives with unique properties that are beneficial for many health issues, e.g., prevention or reduction of cardiovascular diseases, diabetes, obesity and cancer; bactericidal, antiviral (e.g., HIV), anti-inflammatory, antiarthritic, antioxidant, and antitumor activities (especially toward human melanoma); cosmetics, wood adhesives, wood-protective agents, paints, plant-protective products, and detergents [89,97,161–163]. Industrially used birch extractives include betulinol, suberin, and xylitol (e.g., [89,152]), which have been used since the 1980s in dental care.

5.3.2. A Place for Birch Development in the Hardwood Sector in Western Europe

The forest product industries in Western Europe have concentrated investments on softwoods, whereas hardwood resources are underutilized [14,164] and a great part goes to the bioenergy sector [165]. Softwood timber properties are generally superior because of their naturally straighter shape and smaller knots. For hardwoods, sawing, drying, and other processes require more knowledge and sometimes special equipment, and the varying properties among the species make the implementation of the economy of scale difficult [165]. Birch shares some properties with softwoods, e.g., short rotation, dimension, harvesting, and transportation performed using the same machines [19,97,166]. Wood veneers, particle boards, OSB, MDF, and HDF can be manufactured at the same mills with a similar technology for birch and softwoods [167,168].

Broadleaved species will be significantly increased during the ongoing century [14,169,170], specifically under the influence of the European silvicultural strategies, which encourages forest owners and public authorities to enhance the share of broadleaved species in the forests. The expansion of the wood processing production capacity for softwood and the shift from softwoods to hardwoods in many forests is inevitably leading to a future shortage of supply and rising prices of softwood timber. Therefore, the competitiveness of hardwoods may grow in the wood product markets, and partial substitution of softwoods with hardwoods appears realistic in the industrial context (e.g., [14,165]). For example, hardwood veneer products, wood panel products, and engineered wood products have been re-developed during the current decade [168,169].

Timber construction is by far the dominant driver and growing market for wood products in Europe [166,169]. Carbon taxes may also favor the use of wood raw materials for carbon sequestration and substitution of non-renewable raw materials [166,171]. Recent legislation in France aims to introduce mandatory wood percentages in new constructions and enhance the requirements for thermal efficiency [166]. A German policy wishes to stimulate the use of hardwood resources as a raw material in the building sector [170]. In the context of building and living with wood, the availability of birch, its good mechanical properties, and the technically possible uses in GLT products, CLT panels, and elements and bent parts of furniture have been reported to make birch wood one of the most interesting raw materials in the future in Western Europe [97,172].

Recent fashion trends favor light colors for furniture. The world's largest furniture manufacturer and trader, IKEA, uses 18% birch wood, which is the second species after pine [173]. According to some sawmill owners in Belgium and France, until now, limited quality resources did not permit them to offer birch products to their customers. However, some of them are now seriously considering the utilization of local birch, for example, for furniture or external cladding using thermally modified birch wood. These possibilities are examined not only in Western Europe (e.g., [92]) but also in Central Europe [156].

5.3.3. Availability and Demand of Birch Wood

In Northern Europe and the Baltic countries, birch log resources are nearly in full use, and industries have imported large quantities of birch logs and pulpwood since the 1990s, mostly from Russia [97,167]. In Finland, Estonia, and Latvia, plywood and veneer industries are the dominant users of log-sized birch. Surprisingly, Finnish and Swedish industries lack large birch sawmills, but birch sawing is a rather important industry in the Baltic countries and Eastern Europe, which aim to increase the manufacture of value-added ready-to-assemble furniture product segments [26,121,174].

However, in Finland and Sweden, the log quality from naturally regenerated birch forests has continuously decreased since the 1960s [27,167]. In Finland, the main future supply of veneer and sawlogs is expected to come from silver birch plantations, complemented by sourcing from naturally occurring spruce-birch and pine-birch mixed forests [26,167]. However, the establishment of plantations has steadily decreased after the 1990s, mainly because of moose damage [19,32,88,132]. As a result, some decrease in the availability of high-quality large-sized logs, which have always been in demand, is expected [19,25].

Regional and global market changes also affect birch availability. During the past ten years, the rising costs of log import and the increased production of plywood and sawn timber in Russia have reduced imports from Russia to Finland, Estonia, and Latvia [26,97,175]. Despite the strong competitive position of the birch product import from Northern Europe, the Baltic countries, and Russia to Western Europe, there is an interest in Western Europe to develop and exploit local resources to avoid extra sourcing and transportation of raw materials and products, associated with rising prices. This trend would be supported by introducing a carbon tax in European countries [171]. Moreover, local production is becoming trendier and improves the image of a company.

6. Threats

6.1. Strong Early Height Growth as a Risk for Silviculture

Birch colonizes forest plantations or natural regenerations of commercial tree species. It quickly becomes taller than the other trees, disturbs their growth, and, as reported by some authors, causes whipping injuries in beech [120], oak [176], Norway spruce [121], and larch (*Larix* sp.) [177]. Even if the forest manager eliminates birch, vigorous coppice sprouts will quickly restore the competition. Thus, only managed and well-organized mixed stands can avoid such problems.

Furthermore, current practices do not take into account the early growth of birch and generally miss pre-commercial thinning at an early age, when strong intraspecific competition is in progress. In these conditions, even with later intensive thinning, trees never recover their strong diameter growth to produce large-sized logs before tree senescence onset. Moreover, birch trees that develop low diameter/height ratios and asymmetric crowns, which often occurs in stands that are too dense, have a high risk of snow damage [49,56].

6.2. Dramatic Pest Outbreaks

Birch species are among the most resistant tree species to pests and diseases, but climate change and globalization could cause this type of problems in birch forests as well. Some examples have been reported during recent years. Dieback of birch saplings 5–10 years after planting on field sites has been observed in Scotland, which was probably due to two fungal pathogens [178,179]. Damage caused by leaf-chewing and leaf-mining insects is estimated to at least double in northern birch forests, but it may be marginal in more southern regions [180]. There could be a risk to strongly lower birch stem quality if the Asian hornet (*Vespa velutina*) increases the pressure already exerted by the European hornet. From the early 1930s to the late 1950s, American birches went through a dieback for which the cause was never confirmed [181]. In 2015 and 2016, crown degeneration and early dieback of roadside birches due to the "Birch leaf roll-associated virus" [182] was observed within the Berlin area in Germany [183]. It was first observed in Northern Europe, more frequently since the summer of 2002, and it affected birches of various sizes and ages in urban parks as well as forests [184]. The most severe danger comes from the *Coleoptera* called Bronze birch borer (*Agrilus anxius*), endemic to North America, which has led there to mortalities among the evolutionarily naive Eurasian birch species throughout the 20th century. There is a high risk of widespread birch mortality if the borer is accidentally introduced in Eurasia, where it has not yet been detected to date [185].

6.3. Demand for Birch Wood for Industrial Uses

In Northern Europe, large quantities and adequate availability of birch wood has facilitated the development of a specific roundwood market combined with the establishment of large-scale industries, whereas in Western Europe, forest management and industrial use of hardwood rely on two main species, oak and beech, and some minor precious broadleaves (ash, sycamore, and wild cherry). Birch is generally included in a group called "other hardwoods", together with species such as lime, alder, willow, and hornbeam, which rarely enter valuable roundwood markets. If knowing the birch wood potentials, close to those of beech, will the industry and the consumers of Western Europe change their production and consumption habits, respectively?

Birch is not known well enough among construction industries, building developers, and designers as a wood material with potential for building, although the wood properties (Table 1) indicate its suitability [24,97]. Industrial wood product standards (specifically, CE-marking) as well as generally accepted sorting methods, grading rules, and valuation practices are needed for birch to be used at mills, log yards, and timber terminals [97]. Environmental product declarations (EPD) are also needed to regulate the domestic and export markets.

6.4. Information for Landowners and Forest Managers

Outside Finland and the Baltic countries, there is no adequate education of professionals and training of forest owners on birch management and utilization. The bad historical reputation of birch does not encourage forest managers to invest in its silviculture or to let it colonize forest areas. Moreover, when forest owners get engaged in birch management, they often make mistakes during silvicultural operations, for example, during thinning or pruning operation. Therefore, they fail in producing large-sized, high-quality logs for the most valuable uses despite their serious efforts, reinforcing the bad reputation of birch in forestry.

7. Discussion

In this paper, we analyzed the potential of birch for forestry and the forest-based industry sector within Western European changing climatic and socio-economic conditions. We therefore identified the main strengths and weaknesses of birch and opportunities and threats concerning birch in the changing context of Western European forest clusters (Table 2).

Table 2. SWOT matrix used to analyze and derive the position and perspectives of birch within the changing context of the Western European forest cluster.

STRENGTHS	**WEAKNESSES**
• Adaptable species: - with high genetic variability and phenotypic plasticity and a short generation time; - performing in a wide range of climates and soils; - resistant to climatic stresses and damages. • Productive species: - mean stand volume increment: 5–10 $m^3 ha^{-1} a^{-1}$ at 50 years. • Improving forest resilience and biodiversity: - regenerating naturally and abundantly in forest gaps, restoring wood production potential of the forest; - improving soil functioning (porosity, water infiltration, fertility, soil fauna, and microorganism activities, etc.); - creating favorable conditions for the natural arrival and development of other tree species; - supporting a high diversity of flora and fauna species by its set of associated specific species, by the light conditions of its understory, and through the early-succession stage it forms. • Interesting visual and technical wood properties for a large variety of uses and NWFP. • Aesthetic and scenic aspect in landscapes.	• Short lifespan and poor resistance against micro-organisms, therefore: - silvicultural operations have to avoid wounds; - rotation must be max. 60–70 years because of stem discoloration and root rot risks; - birch wood products cannot be used outdoors without specific treatment (durability class 5); - birch logs do not tolerate long storage in the forest or in sawmill log yards because of fungal discoloration, checks, and insect damage. • Stem diameter growth is strongly and durably affected by intraspecific competition since an early age. • Some pests affect birch: - European hornet may cause forks; - *Phytobia betulae* causes black irregular-shaped configurations within the core wood. • Major aero-allergenic tree.
OPPORTUNITIES	**THREATS**
• Increasing position in the context of global change: - invading areas where agricultural activity has ceased or after windfall, in plantations of other tree species, non-replanted clear-cut, areas where dieback of other species occurs; - being one of the most resistant species to game overpopulation-associated damage; - very suitable species for interesting tree mixtures, to shelter other tree species as a nurse crop and with specific properties to protect certain tree species against some pests; - favored by Western European forestry policies to move from monocultural plantations to more close-to-nature forests including native species. • High-value birch logs can be produced within 40-50 years. • Timber and NWFP have numerous uses as shown by long experience in Northern Europe and Baltic countries. • Novel product opportunities and growing demand of wood-based products in the European building sector. • Upcoming softwood shortage may encourage industry to use the hardwood resource, and birch especially thanks to its straight stem, short rotation, harvest, transport, and partly processing similar to softwoods, etc.	• Due to its rapid and early growth, birch may cause negative impacts on growth and quality of other tree species in tree mixtures; • Accidental introduction of *Agrilus anxius* or other pests or diseases might be catastrophic for birch. • Birch processing, products, and market are unfamiliar aspects outside Finland, the Baltic countries, and Russia. It may be difficult to convince - forest owners about profitable management and markets for birch; - forest industries and construction business about the potential, availability, and competitiveness of the products; • Too little education of professionals and forest owners on birch management. • Absence of CE-standards, EPDs, sorting, grading, and valuation methods and rules for birch wood products to be used in mills and at timber terminals.

Among its strengths, birch is usually profusely available through natural regeneration, is suitable for a large variety of climatic conditions, efficient in a great diversity of soils, being the only suitable tree species on the most constraining sites. It has a great capacity to adapt physically and genetically to climate change, is to date not severely affected by pests and diseases, and is one of the most resistant tree species to game overpopulation-associated damage. In addition, this native species also promotes biodiversity by the set of associated species, by the light conditions it supports in the understory, and throughout the early-succession stage to which it belongs. Many animals, fungi, and plant species feed on or find their habitat in birch stands. Birch contributes to improving site growth conditions by promoting soil functioning (e.g., porosity, water infiltration, fertility, microbial and soil fauna activities) and light and microclimate regulation. Thus, birch functions as an engineering and a keystone species. These ecosystem services support the resistance and the resilience of the forest to perturbations such as pests and diseases and extreme climatic events. Birch also protects other tree species against some pests because of its early rapid growth and the emission of chemical compounds. These characteristics make birch an interesting species in the context of climate change and forest health management. Birch, acting as a nurse crop, provides shelter for other tree species, planted or naturally regenerated by the facilitation process, and has a strong potential for the management of a diversity of mixed stands.

Moreover, the current socio-economic and climatic context is favorable to an increased presence of birch in forests. It benefits from trends such as forest diversification, game overpopulation, extreme climate events (e.g., storms), or health problems in many other tree species or even from a favorable perception of people for birch as an aesthetic species and its ecological roles in the ecosystem.

There is then an opportunity for producing valuable birch wood. Indeed, (i) visual and mechanical characteristics of birch wood are suitable for many uses, including valuable furniture, and (ii) rapid early growth of birch ensures that large-sized and straight logs free from knots or discoloration can be obtained at least as early as from softwood species. However, producing this kind of log requires silvicultural operations performed with appropriate timing, tree selection, and intensity according to the short lifespan of birch, its sensitivity to rot, and crown competition. Otherwise, the timber may fall into the class of firewood or pulpwood. The lack of knowledge on the silvicultural needs of birch or the absence of birch silviculture has largely contributed to its bad reputation among forestry and wood industries. Indeed, the current birch resource in Western Europe is mainly composed of trees characterized by poor dimension, bad stem form, or timber with rot and large knots. However, with better information, forest managers can easily adapt silviculture to avoid these defects. In this way, single-tree silviculture for birch in pure stands or in tree species mixtures is an appropriate approach based on (i) the selection of a few promising birches for growing-for-quality; (ii) their early thinning allowing optimal crown development from a very young age, before the age of 10 years; and (iii) the control of their knottiness and decay by careful complementary artificial pruning. This method should permit to produce cheaply and relatively shortly high-quality birch logs for sawmills and for slicing or rotary cutting mills. These provide a notably higher value for forest owners than conventional veneers or sawlogs [20,99]. However, there is not yet any prospect for industries in Western Europe of becoming competitive in rotary cutting of lower-quality logs to plywood or veneers like in Finland, Latvia, Estonia, or Russia.

Given the need to act early in the birch's life, this program can only apply to new and future naturally regenerating resources. Birches which have not benefitted from thinning operations provide raw material opportunities for wood panels, paper and paperboard, and bioenergy products, but they also contribute to biodiversity development and availability of NWFP, for which the market potential is growing. Canopy openings can be made to under-plant clusters of other tree species, which will benefit from the birch nurse crop.

Nevertheless, in most Western European countries, there is not any specific industrial valorization of birch, except for paper, paperboard, and some particle- and fiberboards. In Northern Europe and the Baltic countries, industrial use is versatile and largely developed even for lower-quality logs. Birch wood has many known uses based on its interesting technical and visual properties. Finland, the Baltic countries, and Russia export large volumes of birch plywood and sawn timber to Western Europe, including high-quality birch logs in moderate amounts for manufacturing of veneers, mainly in Germany and the United Kingdom [24,25,167]. Interestingly, in Western European forests, the birch resource is gradually increasing, while Northern Europe, where birch is regularly harvested and used, may face a decrease in the availability of high-quality birch logs, exacerbated by different mammal damage. Carbon taxes and environmental awareness may also encourage more local production. The resource characteristics, as well as the organization of wood mobilization, have been major constraints for the establishment of valuation chains. Nevertheless, in the future, appropriate silvicultural operations may considerably improve the resource. Wood mobilization may be supported by focused product development, product and environmental standards, raw material sorting and allocation, and investments in production technology in small and medium-scale enterprises of wood processing and also on NWFP (mushrooms, extractives, fine chemicals, etc.). The EHIA European research program launched in 2016 has pre-defined 16 Innovation and Research themes for hardwood species, including birch, which will emphasize the value-added use of hardwoods within Europe [14]. This can be used as a guideline during the early-stage raw material evaluation, product segment choices, product development initiatives, and set-up of value networks and production-supply-processing-distribution chains.

Nevertheless, it will be a serious challenge to convince forest managers and owners to invest in birch when its processing, products, and markets are still unknown in Western Europe. Further, because of its vigor and colonizing temperament, birch has wrongly been considered as an "invasive" weed. Indeed, in mixed stands, forest managers have to control its abundance in order to prevent constraining the development of other tree species. However, following the climate change and forest health crisis of the last decades, more and more forest owners are looking for alternative silviculture and tree species options in forestry, and some of them count on the future market potential for valuable birch wood assortments in Western Europe. Some forest industries also show interest to introduce this species at least as sawn timber. In any event, the industries undeniably should adapt to the fact that certain commercial species are running a risk of decrease in supply, whereas the demand for wood products is growing. For the Western European hardwood markets, birch offers promising properties: its abundance; its prospectively high-quality logs and short rotation periods under proper silvicultural treatments; and harvesting, transportation, and primary processing technology close to that of softwoods. The most specific constraint in the supply chain is the fact that the logs do not tolerate long storage in the forest, on terminals, or in mills.

8. Conclusions and Perspectives

Our analysis has highlighted (i) the positive role of birch for biodiversity and ecosystem functioning; (ii) a large knowledge on wood processing to produce sawnwood, veneer, plywood, glued and cross-laminated timber, extractives, and NWFP, especially in Northern Europe; and (iii) promising opportunities of birch silviculture, for timber production and ecosystem services, in pure stands or in mixed stands and forest restoration. Birch has a great potential of development in the Western European forest cluster while considering ecological and socio-economic purposes, and taking into account the changing context of climate, forestry, and forest product industries.

However, in Western Europe, this is in contradiction with the lack of interest of forest owners and managers in birch, which is reflected in the field, in the lack of silvicultural operations favoring birch and in the tendency to eliminate birch from forests stands. This situation has prevented the development of a quality wood resource, such that the wood industry has not developed specific wood processing tools for log valorization. Consequently, without a specific market for high-value birch logs, forest owners and managers are rarely interested in investing in their production, thus maintaining the poor state of the resource.

To break the spiral, the priority needs for research, development, and dissemination appear to consist of three points:

1. To define silvicultural guidelines for birch that are adapted to Western Europe, taking account the life traits of the species (light-demanding species, abundant natural regeneration, rapid early

growth, short lifespan, high risk of decay) to supply valuable wood raw materials, NWFP, and biodiversity benefits to the market.

2. To develop birch wood processing and corresponding markets for all log dimensions and qualities and provide product and environmental standards for sorting, grading, and valuation methods that better define the potential uses of birch wood for construction industries and building developers and designers.
3. To inform, on the one hand, forest owners and managers about the existing potential to produce and sell high-quality logs when adequate forest management is applied, and on the other hand, sawmills, wood panel industries, and other involved processing enterprises (in building products, furniture, and interior products), as well as construction industries, building developers, designers, architects, and the customers (BtoB, BtoC) about the opportunities of birch-based raw materials, along with the potential products and end-uses.

This analysis should also inspire Central or Eastern European countries for which there are some similarities.

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