forests

MDPI

Article

A Novel System for the Characterization of Bark Macroscopic Morphology for Central European Woody Species

László Zoltán [1] and Márton Korda [2,*]

[1] Department of Plant Systematics, Ecology and Theoretical Biology, ELTE Eötvös Loránd University, 1117 Budapest, Hungary; laszlo.zoltan@ttk.elte.hu
[2] Institute of Environmental Protection and Nature Conservation, University of Sopron, 9400 Sopron, Hungary
* Correspondence: korda.marton@uni-sopron.hu

Abstract

Accurate identification of deciduous woody species in winter is challenging, and the misidentification can lead to ecological and management damage. This study aims to substantiate a diagnostic system for woody species based on macromorphological bark characters. First, we reviewed the literature on bark-based species identification to assess existing approaches and their limitations. Building on this, we identified informative macromorphological features of bark through both literature analysis and our experiences. These characters cover all developmental phases, including twigs, young bark, and mature bark, and are supported by new diagnostic terminology. Using this framework, we compiled a character set for 115 Central European woody taxa, providing practical, primarily qualitative traits that can be applied directly in the field. Finally, we developed and tested "Single-access Keys" as an alternative to conventional dichotomous keys, demonstrating their effectiveness in enabling flexible and rapid species recognition, even under atypical conditions or when only partial observations are possible. Our results highlight the value of bark macromorphology as a diagnostic tool and emphasize its potential for advancing thematic identification keys, as well as digital applications in forestry, taxonomy, and ecological monitoring.

Keywords: bark identification; bark macromorphology; European tree species; periderm; twig; misidentification; bark trait

check for updates

Academic Editor: Angela Balzano

Received: 17 September 2025
Revised: 6 October 2025
Accepted: 14 October 2025
Published: 15 October 2025

Citation: Zoltán, L.; Korda, M. A Novel System for the Characterization of Bark Macroscopic Morphology for Central European Woody Species. *Forests* **2025**, *16*, 1586. https://doi.org/10.3390/f16101586

1. Introduction

A tree's bark appearance is shaped by various factors, and it can generally be stated that species-level adaptation emerges in response to climatic, habitat-related and biotic pressures. Site conditions [1–3], disturbance regimes [4–6], potential herbivores [7], and pathogens [8] all play a role. Evolutionary context is also important: bark morphology reflects which selective pressures dominated during the species' development [9]. Due to trade-offs in environmental adaptation, bark fulfills multiple functions [6,10,11]. Some flexibility is provided by phenotypic plasticity, allowing bark to vary depending on tolerable site conditions for the species [3]. However, under sudden environmental change (abiotic stress) or biotic damage, bark types may deviate from their normal appearance [12–14].

Macroscopic bark characterization is essential for deeper analysis. Bark–broadly defined as the outer covering and associated structures of woody plants–can have diagnostic value, though its characters are less frequently used in species identification. This may be due to the lack of standardized macromorphological definitions [15,16] and the high variability of bark features [17]. We believe that if bark-modifying factors are considered, the general bark pattern of a species can be described. A common strategy is to combine bark features with other morphological characters (e.g., buds, habit) for winter tree identification. Many field surveys focus on deciduous stands during winter (in forests, parks, gardens, etc.), where species recognition can be challenging. In many cases, individuals can only be distinguished based on bark characteristics, as the crowns remain positioned within the canopy layer, beyond close inspection. A study investigating misidentification rates demonstrated that error levels in woody species can be remarkably high [18]. The most significant economic implications of such errors arise during tree marking and subsequent timber harvesting operations. In close-to-nature managed forests trees may occasionally be misidentified by forest managers or conservationists, leading to unintended felling. Based on our field experience, this can result in the inadvertent removal of even protected species, constituting ecological damage. The same issue applies to shrub species: although often neglected due to their limited commercial value, they include both legally protected and conservation-priority taxa. Their preservation, however, is conditional upon correct recognition by forest managers, ecologists and technical staff alike. Reliable winter identification of woody species can also be highly valuable for scientists, since they sometimes collect field data that can only be gathered during the winter [19]. Tree species misidentification thus has consequences that extend beyond economic losses, potentially generating ecological and conservation risks [20], while also undermining the reliability of scientific research [21] and forest inventory data [22]. While a few works have addressed bark-only identification, to our knowledge, no comprehensive compilation of these publications exists.

Traditional field guides often rely on the authors' subjective selection of the most prominent characters for distinguishing taxa. These characters, however, may not offer complete diagnoses, might not be mutually exclusive, and are sometimes only seasonally observable (e.g., flowers and fruits). Instead of conventional dichotomous keys, it may be beneficial to use non-dichotomous alternatives. Fitter et al. proposed "Single-access Keys" as an alternative approach, where identification relies on a list of observable features rather than a single diagnostic character [23]. Even if some features are missing, reliable identification can still be achieved based on others. This approach may also be adapted in printed form for bark identification.

Based on our field experience, certain bark-related morphological characters are suitable for distinguishing woody plants. The goal of this study is to substantiate a diagnostic system for woody species based on a bark macromorphological character set. To achieve this, we distinguished three objectives. (1) We review the existing literature on approaches to species identification using bark characters, highlighting their potential and limitations. Building on this foundation, (2) we identify the most informative macromorphological bark features through a combination of literature analysis and our own field experience. Finally, (3) we develop and test a diagnostic framework for woody species found on these characters and provide Single-access Keys as an alternative to conventional dichotomous keys.

2. Materials and Methods

2.1. Bark Guide Collection

In our literature search, we mainly targeted English and German publications specifically focused on bark identification. We also included a smaller number of non-major language sources. Works that partially deal with bark (e.g., dendrological books or winter identification guides) were considered as well. Additionally, we found the image-rich publications relevant too, even when they lacked detailed descriptions. Searches were conducted using online search engines and library databases. To locate non-Hungarian, -English and -German sources, we translated terms such as "bark", "tree bark", "woody bark", "identifier", "guide", "twig" and "winter key" into various European languages. We then processed these materials–when available digitally or upon acquisition–using translation software, always interpreting results critically.

For books focused exclusively on bark characters, we provided detailed annotations: whether they include identification keys, distinguish between young and mature bark, show image scale bars, and the geographic range of the covered species. This characterization wasn't meant to critique, but rather to highlight the presence or absence of taxonomically relevant features.

2.2. Development of Identification Characters

After compiling the available literature, we reviewed the descriptions, methods, and characters used. These were synthesized, critically revised, and expanded to create a new set of bark diagnostic characters. As there is no universally accepted bark morphology nomenclature [24], we followed the terminology and definitions proposed by Junikka [17], noting whenever alternate concepts were applied. New macromorphological terms were introduced when needed for clarity and accuracy [15,16]. The final character set includes details for twigs, young and mature bark. Our approach enables the complete documentation of bark development throughout a tree's life.

2.3. Data Collection for Diagnostic Characters

We created a database using examples from 115 woody species native to or cultivated in Central Europe. This diverse species pool spans Pannonian, Carpathian, Atlantic, Illyrian, and Mediterranean zones, as well as alien species from North America and Asia–making it internationally relevant. We focused mainly on the most important woody taxa (trees, shrubs, and lianas) but included less significant species when necessary to demonstrate specific characters.

Data collection was supported by an extensive literature review, including rare and non-major language publications. In addition to primary sources [25–40], we used other works as supplementary references [41–57]. We paid special attention to intraspecific variation (subspecies, varieties, forms). The characters were compiled in a structured table and underwent multilevel validation, including (1) our own specimen collection of twigs, branches, young and mature bark; (2) a curated image archive with scale and diameter data; (3) systematic fieldwork in Hungary. Validation was conducted under dry, shaded conditions, free from epiphytes or pollutants, and on healthy individuals growing in ecologically suitable habitats–preferably with replicates. Based on these results, we revised and updated literature-based data, aligning them with our own observations.

2.4. Creating Identification Keys

We adopted the Single-access Keys model [23] for bark identification. In this method, each diagnostic question offers two alternatives, and only the relevant character is recorded–for instance, "ligule pointed (A)" or "ligule blunt (a)." If the ligule is pointed, we note "A"; if not, we skip it. This system produces a character string (e.g., "ACGH") that identifies a species or group.

The advantage is that unlike dichotomous keys, this method allows flexible, non-linear identification using any observable combination of characters. The number of possible combinations increases exponentially. For example, 10 characters yield $2^{10} = 1024$ combinations, which can handle intraspecific variability (e.g., twig hairiness differing by subspecies). Thus, multiple character strings may lead to the same species, even if some characters are missing. Including more characters enhances reliability and compensates for missing features. In many cases, mature bark alone can identify a species, but where this is too variable, characters from young bark or twigs improve accuracy.

We developed exemplary keys based on our 115-species character database. In this paper, we present keys only for woody species with fissured bark. We also outline the key development process and challenges faced. The keys were generated manually using stepwise selection from the database and tested for usability by university students.

3. Results

3.1. Bark Identification Bibliography

Some researchers have demonstrated that bark morphology can be classified using histological [58,59], allometric [60,61], or coefficient-based methods [62]. While these approaches can be precise, they are less practical for field-based species identification.

Relatively few authors have published field guides that are exclusively based on bark characteristics and include a broad species pool. Of these, only a small number offer structured identification keys (Table 1). Most of these works rely on external, macromorphological descriptions. The surveyed literature rarely includes a scale for its figures, leaving the presented size proportions unclear and resulting in the loss of much data. Similarly, distinctions between young and mature bark are rarely made (Table 1). Consequently, species descriptions are sometimes not informative and far from comprehensive. It is evident that such information is essential for producing a high-quality publication, including identification keys. Even those works that provide these data remain insufficiently detailed and do not consistently or systematically present all diagnostic characters for each species, which is a key feature of dichotomous key application. A more detailed overview of in Supplementary File S1.

In addition to books, some articles and field manuals have been published that focus either on larger geographical regions or broader species sets [63–66], or on local dendroflora with more limited species pool [67–69], and some of them also include identification keys.

After reviewing the relevant literature, we concluded that the development of a new system, incorporating a broader set of characters and species, is necessary in Central Europe for the proper characterization of barks and for reliable species identification.

Table 1. Books focused exclusively on bark identification and their attributes. In cases where multiple editions exist, only the most recent or most widely accessible (in major languages) version is included here; all editions are listed in Supplementary File S1. We consider a bark-focused field guide to be sufficiently detailed if it (1) includes identification keys; (2) differentiates between young and mature bark; (3) indicates scale on photographs in some manner. ×: Not applied; ✓: Applied; * DBH: Diameter at Breast Height.

Book	Identification Keys	Mature/Juvenile Bark Distinction	Scale Indication	Geographic Range	Note
Baraton A. Le monde des écorces. Editions du Rouergue: Parc Saint-Joseph, France, 2003 [41].	×	×	×	Central Europe	Native and exotic woody species of horticultural importance
Godet, J.-D. Baumrinden. Eugen Ulmer KG: Stuttgart, Germany, 2011 [36].	×	Somewhere	×	Europe	Infraspecific diversity of bark morphology
Mikolas, M. A Beginner's Guide to Recognizing Trees of the Northeast. The Countryman Press: New York, USA, 2017 [40].	×	×	×	Northeastern United States	

Table 1. *Cont.*

Book	Identification Keys	Mature/Juvenile Bark Distinction	Scale Indication	Geographic Range	Note
Spohn, M.; Spohn, R. Die Rinden unserer Bäume. Quelle & Meyer Verlag: Wiebelsheim, Germany, 2020 [32].	✓	✓	✓	Central Europe	The most comprehensive book from Europe
Schwankl, A. Guide to Bark. Thames and Hudson: London, UK, 1956 [70].	×	Somewhere	Indirect (DBH *)	Central Europe	Unique bark formations
Vaucher, H. Bäume. Prisma Verlag: Gütersloh, Germany, 1987 [71].	×	×	×	Europe	
Vaucher, H. Baumrinden. Naturbuch-Verlag: Augsburg, Germany, 1997 [37].	×	×	×	Europe and North America	
Vaucher, H. Tree Bark. Timber Press: Portland, Oregon, 2010 [72].	×	somewhere	×	Worldwide	
Wojtech, M. Bark. Brandeis University Press: Waltham, Massachusetts, 2020 [73].	✓	✓	✓	Northeastern United States	The most comprehensive book from North America

3.2. Identification Characters

3.2.1. Bark Types

First, we present the bark types and subtypes we distinguished in our classification system. A total of six main bark types were identified, along with several subtypes (Figure 1). These categories were developed specifically to describe the bark of trees, shrubs, and lianas in Central Europe.

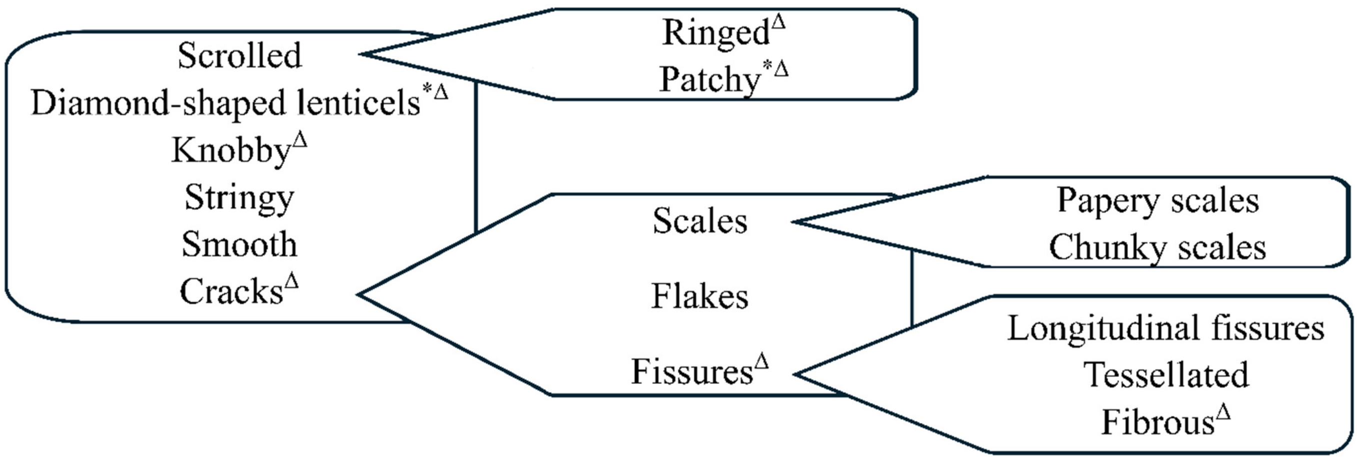

Figure 1. Bark types and subtypes used in this classification. *: Newly defined types; Δ: Definitions that deviate from Junikka's [17]. The term "diamond-shaped lenticels" was suggested by Bartha in Hungarian literature [25] but has not been published in English.

Whether a distinct bark pattern is considered a bark type or simply a character depends on whether it requires further individual description or combination in later analyses. Each type is described below in detail and illustrated visually (Figure 2). Additional type-specific characters are provided in the corresponding diagnostic character tables.

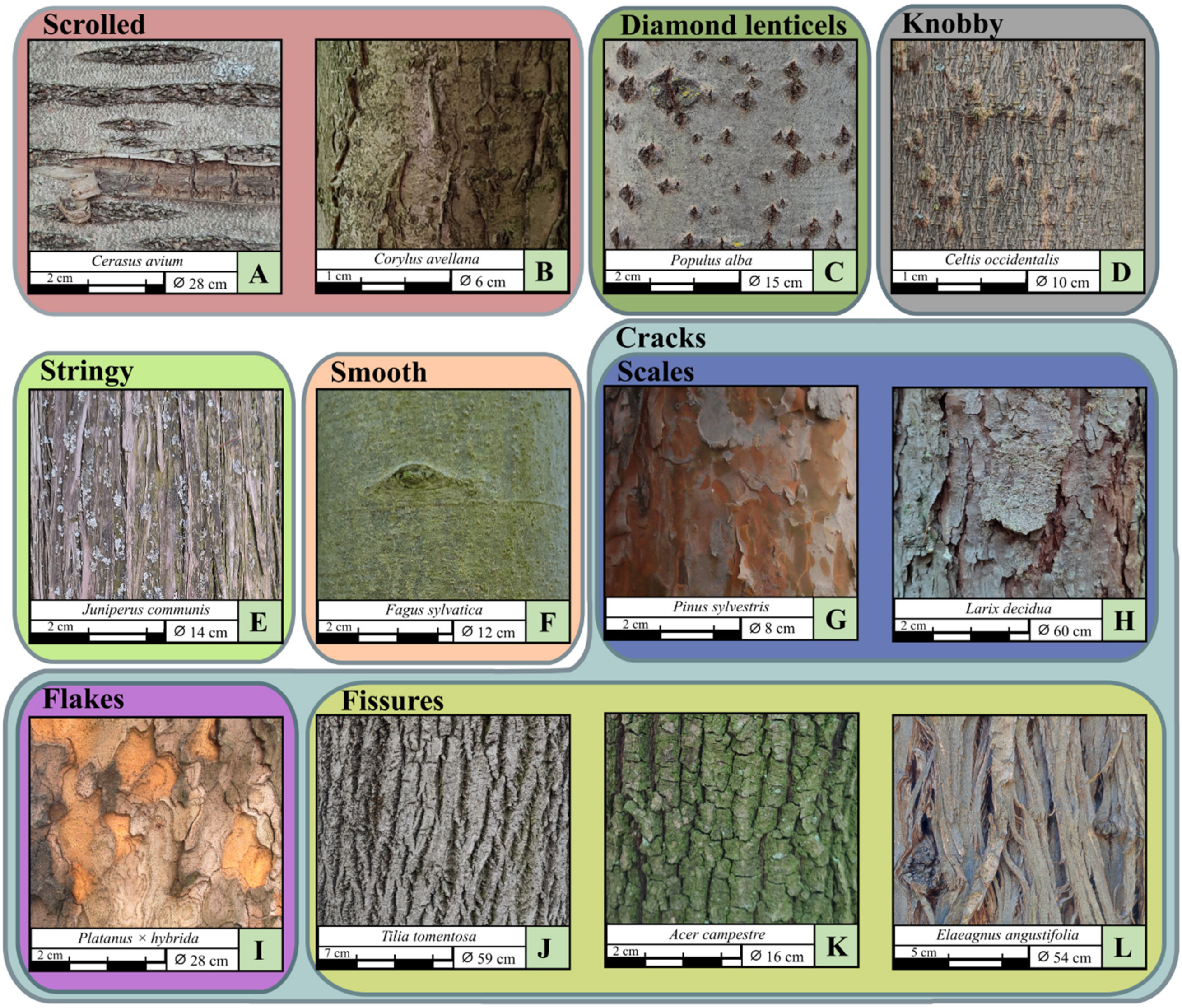

Figure 2. Illustrations of bark types used in the classification: Scrolled (**A**,**B**)–stringy (**A**), patchy (**B**); Diamond-shaped lenticels (**C**); Knobby (**D**); Stringy (**E**); Smooth (**F**); Cracks (**G**–**L**); Scaly (**G**,**H**): thin papery (**G**) and thick chunky scales (**H**); Flakes/plates (**I**); Fissured/furrowed (**J**–**L**): longitudinal fissures (**J**), tessellated with square-like patterns (**K**), and fibrous (**L**).

One bark type is scrolled bark, where the outer bark layer peels away and often curls outward. This type has two subtypes: (1) bark peeling off in horizontal or vertical strips (Figure 2A), and (2) bark detaching in irregular patches, referred to as patchy bark (Figure 2B).

In the case of diamond-shaped lenticels, the lenticels become larger, deeper, and more pronounced with age. They typically develop a species-specific diamond shape, split vertically, and expose brightly colored inner bark (Figure 2C). To be classified within this category, lenticels must reach at least 1 cm in diameter; smaller, round, or elongated lenticels are instead categorized under smooth bark.

Knobby bark develops when the bark surface becomes irregular and bumpy due to woody protrusions (Figure 2D). Surface irregularities caused by lenticels or resin ducts are not included here but belong to the smooth bark category.

In stringy bark, the bark can be removed in long, vertical strips that generally do not curl and remain attached to the trunk (Figure 2E). Contrary to the definition of Junikka [17], this characteristic is not restricted to coniferous species.

Smooth bark typically does not crack under optimal site conditions and healthy growth (Figure 2F). The presence of basic lenticels, resin ducts, or shallow growth striations does not alter this classification.

The cracks category includes bark that splits longitudinally, transversely, or irregularly into fissures of varying depth (Figure 2G–L). Within this category, several subtypes can be distinguished. (1) Scales form when shallow cracks divide the bark into segments of diverse shapes, each not exceeding 7.5 cm in length [17]. This subtype can be further divided into (1/i) papery scales, consisting of thin, flaky bark layers (Figure 2G), and (1/ii) chunky scales, characterized by multilayered, thick bark fragments (Figure 2H). (2) Flakes or plates occur when bark detaches in irregular patches larger than 7.5 cm [17], either building up or continuously detaching (Figure 2I). Finally, (3) fissured or furrowed bark is defined by pronounced ridges and cracks, which may be longitudinal or cross-directional. This subtype includes (3/i) longitudinal fissured bark, dominated by vertical cracks along the trunk (Figure 2J); (3/ii) tessellated bark, where both vertical and horizontal cracks produce a block-like pattern, with cross-fissures that may be shallow or equally deep as vertical ones (Figure 2K); and (3/iii) fibrous bark, where layers appear as longitudinally oriented, overlapping, and sometimes branching bundles that cannot be removed in long strips (Figure 2L).

3.2.2. Bark Characters and Attributes

The following tables summarize the characters and their states for twigs (Table 2), young bark (Table 3) and mature bark (Table 4). We have collected detailed explanations of the characters in a glossary (Supplementary File S2), but we need to present some important clarifications here as well. We have grouped the diverse characters to make them easier to manage: main color category (black, gray, brown, reddish-brown were classified as dark; yellow, silver, light brown as light; and green and sun-exposed red shades as green-red–Tables 2–4) and leaf scar main category (non-distorted: round, oval, triangular; slightly distorted: heart, semicircle, crescent; highly distorted: horseshoe, ring–Table 2, Figure 3).

Table 2. Characters and possible values applied to twigs. Where the prerequisite column is left blank, the variable must always be assessed.

Prerequisite	Character	Character States
	Color main category	Dark, light, green-red, white (partially)
	Color	Free description
	Phyllotaxis	Opposite, alternate, spiral, whorled
	Branching	Monopodial, sympodial, twisted
	Cross-section	Round, oval, ribbed, angular
	Shiny bark	Yes/no
	Winged cork	Yes/no
	Trichomes	Glabrous, sparse pilose, dense pilose, tomentose, woolly, pulverulent, glandular, felted
Trichomes	Trichome color	Free description
	Visible lenticels	Yes/no
Visible lenticels	Lenticel shape	Rounded, transversely elongated, longitudinally elongated
	Lenticel color	Free description

Table 2. *Cont.*

Prerequisite	Character	Character States
	Visible leaf scar	Yes/No
	Leaf scar size	Small, large
	Leaf scar main category	Non-distorted, slightly distorted, highly distorted
	Leaf scar shape	Circle, semicircle, oval, crescent ("C"), horseshoe ("U"), triangular, heart, annular
	Raised leaf cushion	Yes/no
	Bundle scars	Free description, but common forms include 1, 3, 1–3, 3–5, irregular, many along the margin
Opposite phyllotaxis	Touching leaf scars	Yes/no
	Other characters	Free description

By twig, we refer exclusively to first-year shoots during their first winter. All color and trichome characters should be evaluated with this definition in mind. For trichomes we based our terminology on Payne's classification [74], selecting only easily distinguishable types in practice (Figure 4). In opposite phyllotaxis, some species have leaf scars that (almost) touch, which is a useful diagnostic character (Figure 5A). Although English botanical terminology does not differentiate between various forms of alternate phyllotaxis, in our framework we distinguish between general alternate and spiral arrangements. To ensure clarity and maintain diagnostic precision, we apply the term spiral specifically to describe leaves arranged in a helical pattern along the twig.

Table 3. Characters and possible values used to describe young bark. If the prerequisite column is blank, the variable must be assessed in all cases.

Prerequisite	Character	Character States
	Color main category	Dark, light, green-red, white (partially)
	Color	Free description
	Bark development direction	Bark main and subtypes (indicating transitions)
Non-persistent smooth bark	Transitional bark	Yes/no
	Bark development time (years)	Free description (accuracy within 5 years)–only literature data
	Bark development time (diameter)	Free description
	Winged cork	Yes/no
	Shiny bark	Yes/no
	Persistent epidermis	Yes/no
	Slow periderm formation	Yes/no
	Knobby short shoots	Yes/no
	Visible lenticels	Yes/no /No
Visible lenticels	Lenticel shape	Rounded, transversely elongated, longitudinally elongated, diamond
	Lenticel color	Free description
	Thorns/spines	Yes/no
Thorns/spines presence	Thorn/spine type	Prickles, branched thorns, simple thorns, stipular spines, multiple types
Scaly/needle-leaved species	Leaf fall time	Free description (years)

Table 3. *Cont.*

Prerequisite		Character	Character States
Transitional bark		Color main category	Dark, light, green-red, white (partially)
		Color	Free description
		Further transition stages	Yes/no
		Bark development direction	Bark main and subtypes (indicating transitions)
		Bark development time (diameter)	Free description
		Shiny bark	Yes/no
		Visible lenticels	Yes/no /No
	Visible lenticels	Lenticel shape	Rounded, transversely elongated, longitudinally elongated, diamond
		Lenticel color	Free description
		Thorns/spines	Yes/no
	Thorns/spines presence	Thorn/spine type	Prickles, branched thorns, simple thorns, stipular spines, multiple types
Further transitional bark		Bark development direction	Bark main and subtypes (indicating transitions)
		Bark development time (diameter)	Free description
		Other characters	Free description

Table 4. Characters and states for mature bark. If the prerequisite column is blank, the character must always be assessed.

Prerequisite	Character	Character States
	Color main category	Dark, light, green-red, white (partially)
	Color	Free description
	Eye-marks	Yes/no
	Texture	Soft/Hard
	Lenticels	Yes/no
	Shiny bark (ridge)	Yes/no
	Combined bark	Yes/no
	Bark main type	Knobby, cracks, diamond-shape lenticels, smooth, stringy, scrolled
Cracked bark	Cracked subtypes	Scales, flakes, fissures
Fissured bark	Fissured subtypes	Longitudinal fissures, tessellated, fibrous
	Fissure depth and density	Shallow and sparse; shallow and dense; deep and sparse; deep and dense
	Fissure network	Longitudinal ridges dominate, reticulate ridges
	Fissure color	No difference, free description
	Ridgeside color	No difference, free description
Tessellated bark	Tile shape	Square, rectangular
	Removable tiles	Yes/no
Scales, tessellated bark	Separated edges	Yes/no
Scales, flakes, tessellated, stringy, scrolled bark	Lower layer color	Free description
Scaly bark	Scaly subtype	Papery, chunky
	Scale shape	Rectangular, rounded, irregular
Scrolled bark	Scrolled subtype	Patchy, ringed

Table 4. *Cont.*

Prerequisite	Character	Character States
Smooth bark	Pattern	None, reticulate, patchy, mixed
	Veteran bark	Yes/no
Veteran bark	Fissured veteran bark Veteran bark at trunk base	Yes/no Yes/no
	Other characters	Free description

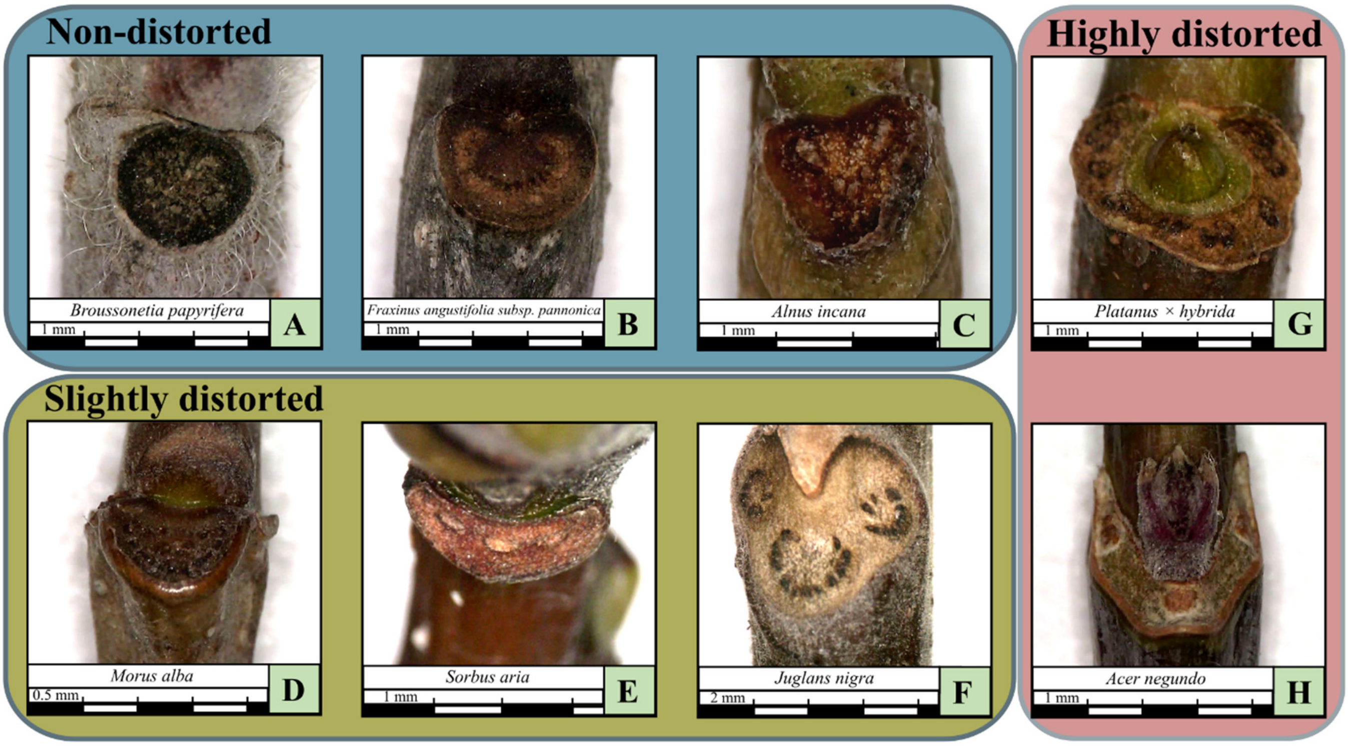

Figure 3. Main types and forms of leaf scars used in twig characterization: Not distorted by bud: round (**A**), oval (**B**), triangular (**C**); Slightly distorted: semicircle (**D**), crescent (**E**), heart (**F**); Highly distorted: ring (**G**), horseshoe (**H**).

Young bark refers to the period from the second year of growth until the onset of mature bark formation (Table 3). This duration varies among species. The proposed characters below primarily describe long shoots; where short shoots are relevant, this is noted specifically. In some cases, mature bark does not develop directly from smooth young bark but via intermediate forms, which we call transitional bark. For instance, *Pinus* spp., smooth twigs first develop papery scales (transitional bark), which only later becomes cracked (mature bark). While anatomical and ecological data on transitional bark are limited [16], collecting thematic characters allows us to document species with such intermediate phases. Some species may require more than one transitional bark type to be described (Table 3). In most species, the epidermis tears apart and peeling off during the first year, while in others the epidermis remains (at least partially) on the twig (persistent epidermis–Figure 5B). In some species, periderm develops slowly and appears patchy (e.g., *Acer negundo* L.–[75]; Figure 5C).

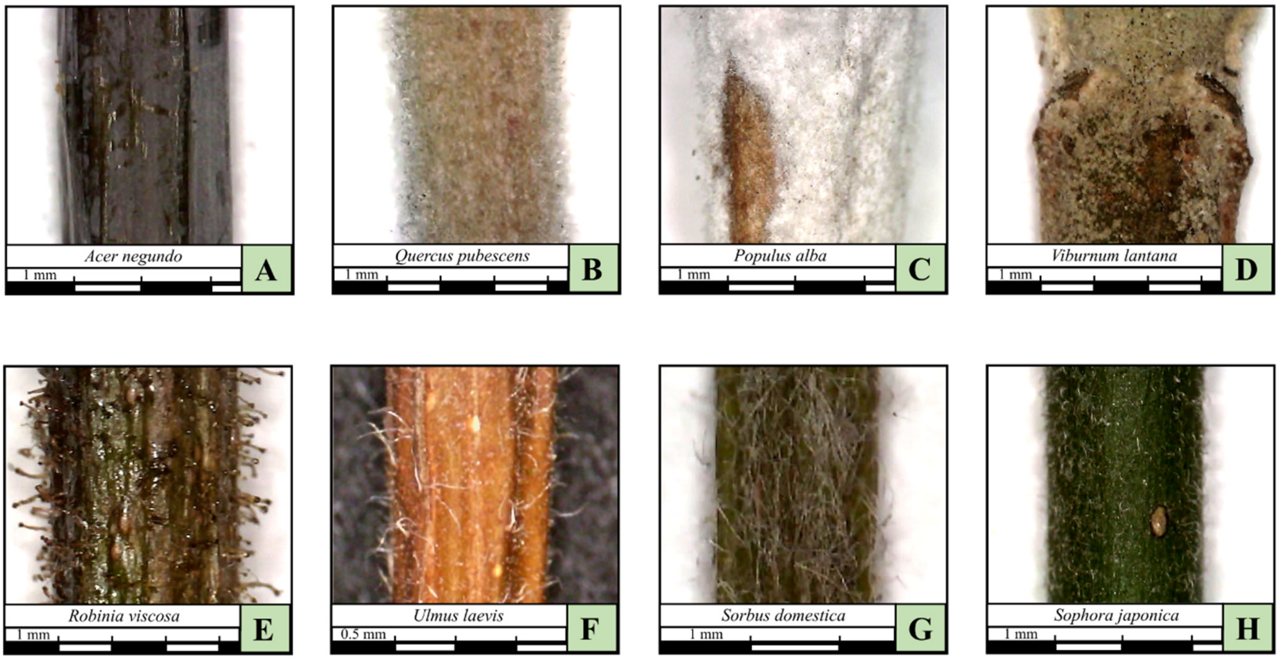

Figure 4. Trichome types used for twig characterization: Glabrous (**A**); Tomentose (**B**); Woolly (**C**); Pulverulent (**D**); Glandular (**E**); Sparse pilose (**F**); Dense pilose (**G**); Felted (**H**).

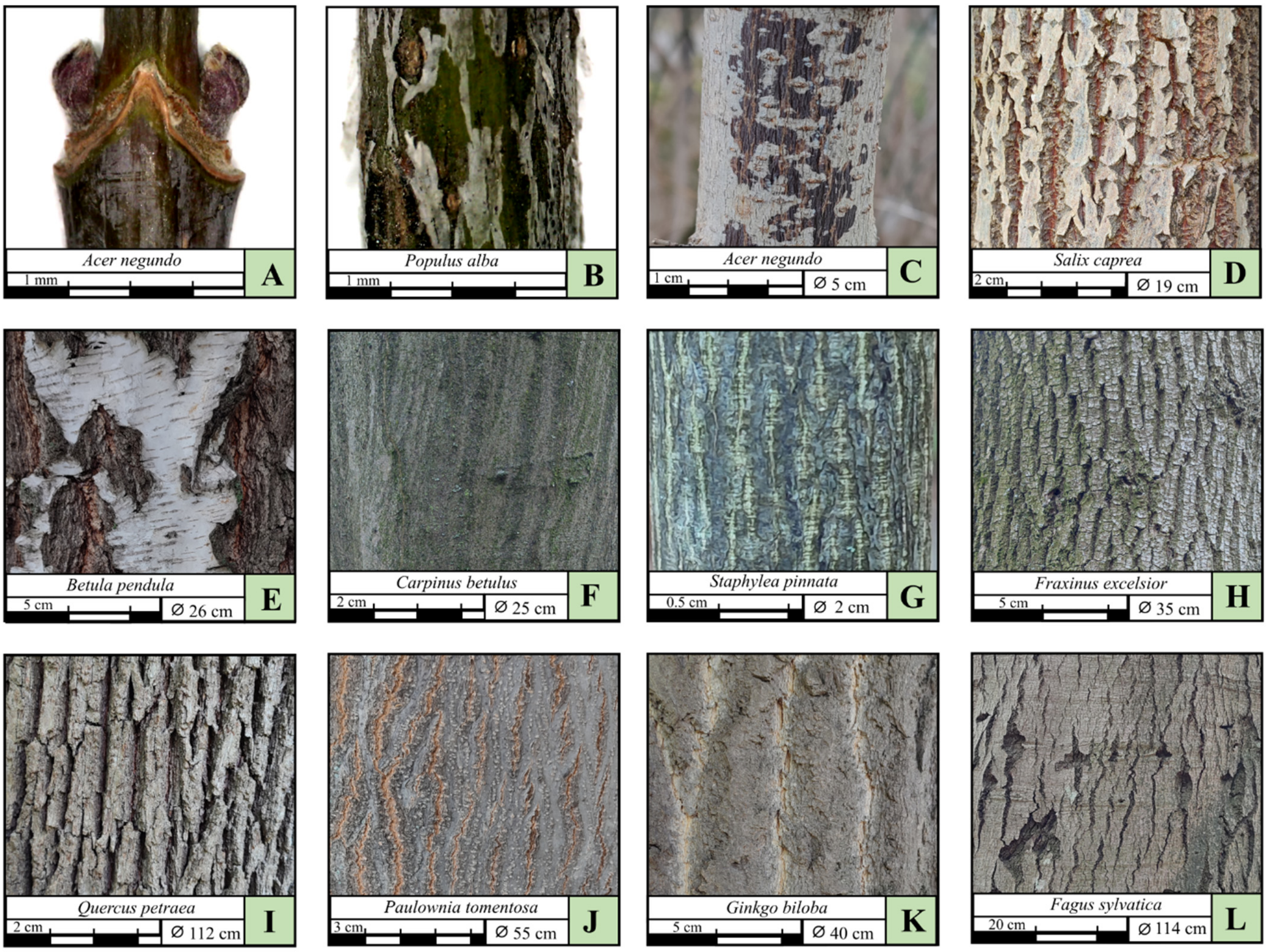

Figure 5. Illustration of selected characters from twigs, young and mature bark. Twig characters: Touching leaf scars (**A**). Young bark characters: Persistent epidermis (**B**); Delayed periderm formation (**C**).

Mature bark characters: Combined bark (**D**,**E**) fissured with diamond-shaped lenticels and reddish-brown fissures (**D**); Ringed and fissured with orange fissures and black ridegesides (**E**); Smooth bark with patchy (**F**) and reticulate (**G**) patterns; Fissured (**H**–**K**) densely, shallowly fissured with shiny ridges (**H**); Dense, deep fissures (**I**); Sparse, shallow reddish-brown fissures (**J**); Sparse, deep orange fissures (**K**); Basal cracking of veteran trees with primarily smooth bark (**L**).

Mature bark refers to bark found on fully developed, adult trees (Table 4).

In the case of combined bark, a primary surface pattern (e.g., diamond-shaped lenticels, knobby, scaly) forms first, and later, cracks develop. Remnants of the original bark type remain visible on the surface for a long time (Figure 5D,E). Subtypes may also combine (e.g., *Picea abies* (L.) H.Karst. has both thick and thin papery scales). Smooth or fissured bark subtypes are not considered combined. All other combinations are classified as combined. Trees with dual bark (basal section of the bark differing from the rest of the trunk) are also considered to have combined bark.

The terms ridge, fissure, ridgeside, and tile-side are associated with deeply fissured or tessellated barks. Ridges are raised sections, often retaining younger bark characters. The base of deep fissures may reveal the lighter-colored inner bark, a useful diagnostic character. Surfaces between fissures and ridges or tiles are referred to as ridgesides and tile-sides (newly introduced terms). These form the sides of the ridge or tile cross-sections, which may be square, trapezoidal, or triangular (Figure 6) and may differ in color (Figure 2J,K).

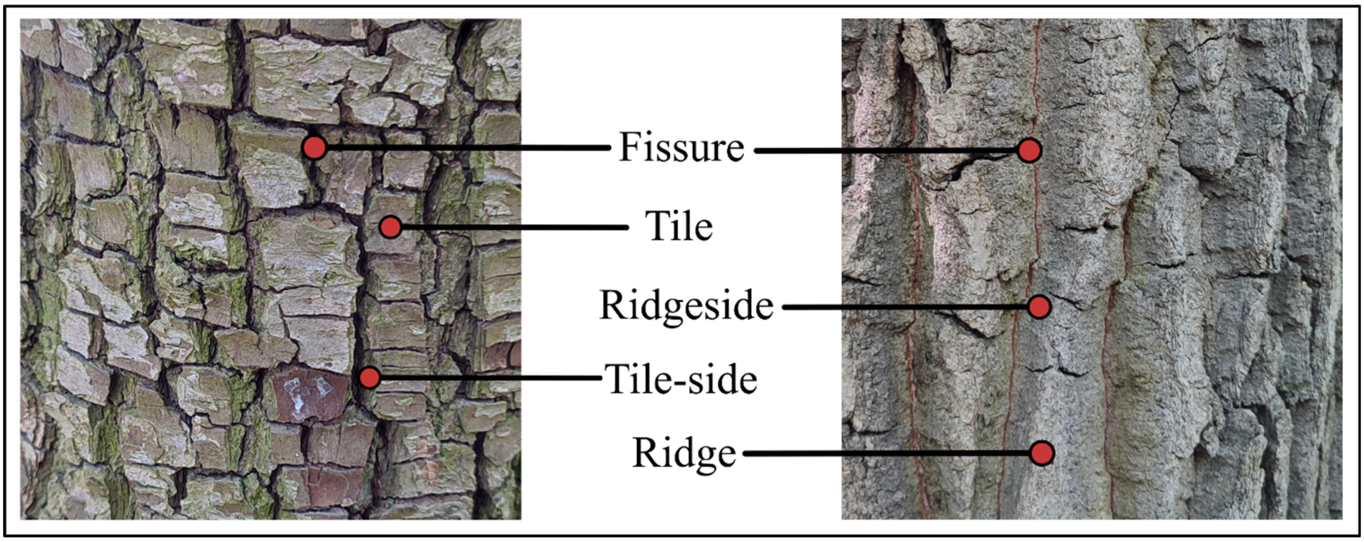

Figure 6. Terminology of tessellated (*Crataegus* spp.) (**left**) and deeply longitudinally fissured (*Quercus cerris* L.) (**right**) bark. Tessellated bark is characterized by horizontal cracks, unlike purely vertical fissured bark.

Fissured bark subtypes are classified into four categories based on crack spacing and depth: Shallow and dense (Figure 5H); Deep and dense (Figure 5I); Shallow and sparse (Figure 5J); Deep and sparse (Figure 5K). Defining fissure spacing and depth precisely is difficult. Junikka suggested relating fissure depth to bark thickness [17], but this is impractical in fieldwork. Instead, we used simple semi-quantitative rules: If the average spacing between fissures is more than 2 cm, bark is sparsely fissured; If the ridge height appears easily measurable (>2 cm), bark is deeply fissured.

Based on crack orientation (fissure network), fissures can be either longitudinally dominant or reticulate (with no dominant direction). Reticulate fissuring may appear even within fissured types if cross-fissures do not run fully horizontal (unlike true tessellation).

These may form rhomboid, diamond, or "X"-shaped patterns. If transverse cracks are very shallow and sparse, bark is still considered fissured (Figure 6).

Smooth bark with different patterns is not a bark subtype but helpful in distinguishing characters. Smooth bark may exhibit patchy patterns (Figure 5F) or reticulate striation (Figure 5G), caused by growth-related tissue expansion. Some species (e.g., *Broussonetia papyrifera* (L.) L'Hér. ex Vent.) show both simultaneously.

Veteran bark occurs most often in smooth-barked species, where basal fissuring might appear with age (Figure 5L). Threshold values are difficult to define due to inconsistent expression. Such features may reflect senescence, spontaneous periderm rupture, or external factors (e.g., mechanical damage). In some cases, extremely old trees exhibit a final developmental bark phase (e.g., deeply fissured veteran bark in *Picea abies*). This requires high age and large trunk diameter (DBH > 70–80 cm). In such cases, not only the base but the lower trunk also shows this bark type. Due to limited occurrence and practicality, we do not classify this as a separate bark phase but note it here. This may occur in several species, but data is lacking for many. The two veteran bark types are distinguished using the variable "Veteran bark at trunk base". Although rare, veteran bark should still be considered during identification.

3.3. Characterization of Example Species

The characterization of 115 Central European woody taxa based on the characters outlined in Tables 2–4 is provided in Supplementary File S3. During our investigations, we observed that–even with extensive literature research–information was lacking for several characters. For example, the winter identification of coniferous species is generally straightforward using other features, so the literature often provides little data on their young bark and twigs. Similarly, data on shrubs are limited due to their lower forestry relevance.

In describing the species pool examined, we identified some recurring patterns. Among deciduous trees, new twigs during the vegetation period are often green (reddish on the sunny side) and hairy, but these features typically change by winter–the colors fade, and the hairs may shed. If this transformation does not occur, the species can often be distinguished more clearly. Lenticels may appear already on one-year-old twigs (or later), usually initially round, but their shape may distort as the twig grows. In most species, longitudinal cracking begins along the lenticels (where the periderm starts to split), eventually forming the fissured mature bark. In some species, such fissuring occurs only late in life (veteran bark) or not at all.

For gymnosperms, multiple developmental stages can be distinguished. One-year-old shoots are usually covered in needle- or scale-like leaves (sometimes completely sheathing the twig). These die off and fall gradually. In some species, the leaf bases remain for several years, giving the twig a rough texture. As branches thicken, these remnants also fall off, and a thin, papery, scaly bark begins to form. With further thickening, these scales become larger and thicker, eventually forming overlapping, multilayered bark plates. As the plates accumulate, the spaces between them deepen into fissures. In very old individuals, horizontal cracks may appear between layers, resulting in tessellated bark. Some species develop only flaking bark even in maturity, while others may develop longitudinal fissures or tessellation. In our opinion, some authors have mistakenly classified these as distinct bark types [35].

Among the characters we studied, the coloration, twig trichomes, the shape of leaf scars and lenticels proved to be the most plastic. Some species exhibit variants where even their most defining features are missing. In such cases, we included all found variants in our summary tables.

3.4. Construction of Identification Keys

The identification keys were constructed on bark types (Figure 2). In the first step, age classification is not essential–only the bark type of the woody plant needs to be identified. This can be problematic in the case of fissured and smooth bark, as both frequently appear as transitional developmental phases. The key for smooth bark covers the full species list; for fissured bark, all its subtypes (developmental stages) are included.

For fissured bark types, it is useful to create separate keys for each subtype (Supplementary File S4). For example, when identifying a tree with tessellated bark, it's easier to begin with the shorter Tessellated bark key. However, if a younger individual of the same species does not yet exhibit tessellation but shows longitudinal fissures, the Longitudinal fissured bark key should be used. The resulting diagnostic character strings should be matched in a fuzzy way with the species-specific descriptions, because the bark of a given tree may deviate from typical characters due to growing under unusual environmental conditions. In the character series some values whose appearance is contingent due to the variability of the species are included in parentheses.

4. Discussion

The description, characterization, and identification of external bark is a highly neglected area within botanical and dendrological sciences. In species descriptions, bark is often reduced to a few words or merely a color reference, even though it can be defined by many more distinct and measurable characters. To our knowledge, a detailed macromorphological bark identification system like ours has not been published to date. A few classical dichotomous identification books for barks have already been developed (Supplementary File S1). In contrast, we propose a system that partly differs from the characters applied in those works. Furthermore, we provide all background data for every species examined within the framework of the present research (Supplementary File S3). Thematic compilations exist for other fields, such as wood anatomy [76], but not yet for bark in this form. Such character lists can be used to construct identification keys or develop searchable databases, depending on the species pool.

4.1. Bark Traits

The aim of our work with the developed character list was to provide practical criteria that can be easily used by anyone in the field to distinguish woody species. For this reason, quantitative traits were given less emphasis on the list. Nevertheless, such trait development and quantitative data collection are essential for plant trait databases, as they have received less attention in the past [77,78]. The TRY database compiles global plant traits, scientific publications, datasets, and unpublished sources [79]. The strictly macroscopic bark morphological traits are represented here with bark persistence (deciduous or persistent) [80] and bark surface structure [81]. A closer inspection of the sources further reveals that the data were collected primarily to address a variety of research questions involving many other variables, rather than specifically for the purpose of studying bark morphology. Some additional traits that may aid in species identification are also available, but only sporadically. When filtering for the species included in our study, further available characters are twig diameter [82], stem color [80,83], and outer bark thickness [84]. The latter provides indirect insight into bark type (with thicker bark being more likely to develop cracks). The data reveals that in many cases values were derived from a single measurement, and only rarely from multiple repetitions. Based on these, it becomes evident that (1) macromorphological bark traits are highly underrepresented and insufficiently developed, (2) the existing traits are predominantly qualitative, and (3) data concerning the bark of the species presented in this study were extremely limited.

Any of the qualitative elements of our list and bark typology can readily be incorporated into trait databases, and we also developed some quantitative descriptors, such as the bark development time (cm) or the number of bundle scars. Our work may also serve as a basis for defining further quantitative traits. Examples include the depth (cm) and spacing (cm) of fissures, where we applied a threshold of 2 cm; or an index of fissure density (X-index) for tessellated, fibrous, and reticulate fissured bark types. In this latter case, the number of intersections within a given diameter class and surface area (e.g., 100 cm^2) could provide valuable information about fissure density. Similarly, the frequency of any other structure can be quantified, such as the density of lenticels, knobs or scales, either per unit surface area or standardized by branch or stem length (e.g., on a 10 cm long branch section with a 10 cm diameter). Collecting quantified data on these traits is currently beyond the scope of this paper, but it may provide a valuable direction for future research.

4.2. Implementation

Our work can serve as a foundation for developing identification keys in printed, analogue, or digital formats. For printed keys, we provided examples in this paper (Supplementary File S4). As an example for an analogue approach, Kucharzyk designed perforated cards for a small species pool [85], which could be sorted by inserting sticks into the holes. A corresponding digital interpretation of this work is also available [86]. In digital format, this modern, database-driven approach could be even more powerful. A background database would contain all recorded character states for each species. Based on the characters selected in the user interface, a progressively narrowing species list would assist with identification. While this may resemble existing plant trait databases, the explicit purpose here is to compile characters that specifically support identification. Successful implementation requires precise, broad data collection and processing, which may necessitate international collaboration. A similar initiative is the Lucidcentral software suite, where users can build their own identification key matrices and select observed character states from structured lists [87].

4.3. Limitations

When establishing diagnostic characters of taxa, descriptions should be based on individuals occurring in their typical habitats and most representative sites. Due to anthropogenic influences and habitat modifications, species with broader ecological tolerance may also appear in environments where they would not naturally occur. Many such occurrences represent atypical, even extreme conditions, in which the species is unlikely to be in an optimal state.

Bark morphology offers an example of how environmental conditions influence intraspecific variation. Abiotic factors such as climate and site conditions strongly affect bark development: individuals growing in colder or drier (micro)climates typically develop thicker bark compared to those in warmer, more humid environments [88]. On steep slopes with shallow soils, or under conditions of strong winds and intense solar radiation, even smooth-barked species may develop cracks [89]. In urbanized areas, where environmental extremes such as air pollution, water limitation, and anthropogenic nutrient inputs are more pronounced, these mechanisms may become accentuated [90]. Under such conditions, the development of thicker bark may also enhance bark water storage capacity [91], potentially conferring an adaptive advantage. The color of bark can also change due to significant air pollution: a well-known example of this is the industrial melanism [92]. Biotic influences further modify bark characters: pathogens can induce structural changes, such as the development of cracks of usually smooth-barked species [13].

Since these abiotic and biotic modifiers alter bark appearance, they must be carefully considered in bark-based identification. Therefore, reliable taxonomic determination using this method is possible only on healthy individuals growing under non-extreme conditions, with minimal colonization by epiphytes.

5. Conclusions

The definitions and values presented for the characterization of bark macroscopic morphology can be adjusted or expanded as needed, depending on the species involved. For Central European taxa, the current list appears sufficient for discrimination. However, other geographic regions may require additional characters. Junikka provides a solid foundation for identifying potential variables and character states [17]. Incorporating easily observable features (e.g., leaves, flowers, fruits) could yield complete species profiles and comprehensive identification tools. Still, bark-based (especially winter) guides are of particular importance in forestry applications [67,93], especially in temperate regions. In these areas, tree species must be identified even during leafless seasons, justifying the practical value and necessity of bark-specific identification systems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f16101586/s1, Supplementary File S1 [94–129]: Bibliography and characteristics of important books on bark; Supplementary File S2 [130–135]: Glossary of new and other terms which needs explanation; Supplementary File S3: Data of the 115 woody taxa from Central Europe; Supplementary File S4: Fissured bark identification keys.

Author Contributions: Conceptualization, L.Z.; methodology, L.Z., M.K.; software, L.Z.; validation, L.Z., M.K.; formal analysis, L.Z.; investigation, L.Z., M.K.; resources, M.K.; data curation, L.Z., M.K.; writing—original draft preparation, L.Z.; writing—review and editing, M.K.; visualization, L.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This article was supported by the RRF-2.1.2-21-2022-00011 project, financed by the Government of Hungary within the framework of the Recovery and Resilience Facility.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Acknowledgments: We gratefully acknowledge Tibor Standovár and Tibor Kalapos for their helpful suggestions that improved this manuscript. During the preparation of this study, the authors used Google Lens and Google Translate service for the purposes of translation. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Payette, S.; Delwaide, A.; Simard, M. Frost-ring chronologies as dendroclimatic proxies of boreal environments. *Geophys. Res. Lett.* **2010**, *37*, 1–6. [CrossRef]
2. Rosner, S.; Morris, H. Breathing life into trees: The physiological and biomechanical functions of lenticels. *IAWA J.* **2022**, *34*, 234–262. [CrossRef]
3. Roth, I. *Structural Patterns of Tropical Barks*; Borntraeger: Berlin, Germany, 1981.
4. Nicolai, V.V. The ecological significances of trees' bark during ecosystem dynamics. *Spixiana* **1995**, *18*, 187–199.
5. Pausas, J.G. Bark thickness and fire regime. *Funct. Ecol.* **2015**, *29*, 315–327. [CrossRef]
6. Rosell, J.A. Bark in Woody Plants: Understanding the Diversity of a Multifunctional Structure. *Integr. Comp. Biol.* **2019**, *59*, 535–547. [CrossRef] [PubMed]
7. Franceschi, V.R.; Krokene, P.; Christiansen, E.; Krekling, T. Anatomical and chemical defenses of conifer bark against bark beetles and other pests. *New Phytol.* **2005**, *167*, 353–376. [CrossRef] [PubMed]
8. Morris, H.; Jansen, S. Bark: Its anatomy, function and diversity. In *International Dendrology Society Yearbook*; Anon, Ed.; International Dendrology Society: Kington, UK, 2016; pp. 51–61.

9. Lev-Yadun, S. Why is the bark of common temperate Betula and Populus species white? *Int. J. Plant Sci.* **2019**, *180*, 632–642. [CrossRef]
10. Paine, C.E.T.; Stahl, C.; Courtois, E.A.; Patiño, S.; Sarmiento, C.; Baraloto, C. Functional explanations for variation in bark thickness in tropical rain forest trees. *Funct. Ecol.* **2010**, *24*, 1202–1210. [CrossRef]
11. Rosell, J.A.; Gleason, S.; Méndez-Alonzo, R.; Chang, Y.; Westoby, M. Bark functional ecology: Evidence for tradeoffs, functional coordination, and environment producing bark diversity. *New Phytol.* **2014**, *201*, 486–497. [CrossRef]
12. Kaufert, F. Factors Influencing the Formation of Periderm in Aspen. *Am. J. Bot.* **1937**, *24*, 24–30. [CrossRef]
13. Langenfeld-Heyser, R.; Fiebelkorn, G.; Polle, A. Können Stichverletzungen oder Frühfrostereignisse bei Fagus sylvatica L. Rauborkigkeit und Holzstrahlproliferationen hervorrufen. In *Strategien zur Sicherung von Buchenwäldern*, 1st ed.; Petercord, R., Block, J., Eds.; Forschungsanstalt für Waldökologie und Forstwirtschaft Rheinland-Pfalz: Trippstadt, Germany, 2006; pp. 95–110.
14. Ross, W.D.; Krahmer, R.L. Some sources of variation in structural characteristics of Douglas-fir bark. *Wood Fiber* **1971**, *3*, 35–46.
15. Angyalossy, V.; Pace, M.R.; Evert, R.F.; Marcati, C.R.; Oskolski, A.A.; Terrazas, T.; Kotina, E.; Lens, F.; Mazzoni-Viveiros, S.C.; Angeles, G.; et al. IAWA List of Microscopic Bark Features. *IAWA J.* **2016**, *37*, 517–615. [CrossRef]
16. Shtein, I.; Gričar, J.; Lev-Yadun, S.; Oskolski, A.; Pace, M.R.; Rosell, J.A.; Crivellaro, A. Priorities for Bark Anatomical Research: Study Venues and Open Questions. *Plants* **2023**, *12*, 1985. [CrossRef] [PubMed]
17. Junikka, L. Survey of English macroscopic bark terminology. *IAWA J.* **1994**, *15*, 3–45. [CrossRef]
18. Scott, A.W.; Hallam, C.J. Assessing Species Misidentification Rates through Quality Assurance of Vegetation Monitoring. *Plant Ecol.* **2002**, *165*, 101–115.
19. Juhász, E.; Katona, K.; Molnár, Z.; Hahn, I.; Biró, M. A Reintroduced Ecosystem Engineer Species May Exacerbate Ongoing Biological Invasion: Selective Foraging of the Eurasian Beaver in Floodplains. *Glob. Ecol. Conserv.* **2020**, *24*, e01383. [CrossRef]
20. Dexter, K.G.; Pennington, T.D.; Cunningham, C.W. Using DNA to Assess Errors in Tropical Tree Identifications: How Often Are Ecologists Wrong and When Does It Matter? *Ecol. Monogr.* **2010**, *80*, 267–286. [CrossRef]
21. de Almeida, R.F.; Pellegrini, M.O.O.; de Morais, I.L.; Simão-Bianchini, R.; Rattanakrajang, P.; Cheek, M.; Simões, A.R.G. Barking up the Wrong Tree: The Dangers of Taxonomic Misidentification in Molecular Phylogenetic Studies. *Plant Ecol. Evol.* **2023**, *156*, 146–159. [CrossRef]
22. Knott, J.; Wang, J.; Walker, D.; Domke, G.; Fei, S. Robustness of Ecological Indicators to Species Misidentification in the National Forest Inventory of the United States. *Ecosphere* **2025**, *16*, e70340. [CrossRef]
23. Fitter, R.S.R.; Fitter, A.H.; Farrer, A. *Collins Guide to the Grasses, Sedges, Rushes and Ferns of Britain and Northern Europe*; HarperCollins: London, UK, 1984.
24. Trockenbrodt, M. Survey and discussion of the terminology used in bark anatomy. *IAWA Bull.* **1990**, *11*, 141–166. [CrossRef]
25. Bartha, D. *Fa- és Cserjehatározó*; Mezőgazda Kiadó: Budapest, Hungary, 1997.
26. Bartha, D. *Magyarország fa- és Cserjefajai*; Mezőgazda Kiadó: Budapest, Hungary, 2018.
27. Nagy, C. *Erdészeti Növénytan*; FVM Képzési és Szaktanácsadási Intézet: Budapest, Hungary, 2009.
28. Schweingruber, F.H.; Steiger, P.; Börner, A. *Bark Anatomy of Trees and Shrubs in the Temperate Northern Hemisphere*; Springer: Berlin, Germany, 2019.
29. Soó, R. *A Magyar Flóra és Vegetáció Rendszertani-Növényföldrajzi Kézikönyve I*; Akadémiai Kiadó: Budapest, Hungary, 1964.
30. Soó, R. *A Magyar Flóra és Vegetáció Rendszertani-Növényföldrajzi Kézikönyve II*; Akadémiai Kiadó: Budapest, Hungary, 1966.
31. Soó, R. *A Magyar Flóra és Vegetáció Rendszertani-Növényföldrajzi Kézikönyve IV*; Akadémiai Kiadó: Budapest, Hungary, 1970.
32. Spohn, M.; Spohn, R. *Die Rinden Unserer Bäume: Die 70 häufigsten Arten entdecken, Bestimmen und Verstehen*; Quelle + Meyer Verlag: Wiebelsheim, Germany, 2020.
33. Blakeslee, A.F.; Jarvis, C.D. *Trees in Winter: Their Study, Planting, Care and Identification*; The Macmillan Company: New York, NY, USA, 1913.
34. Fekete, L.; Mágocsy-Dietz, S. *Erdészeti Növénytan II*; Erdészeti Egyesület: Budapest, Hungary, 1896.
35. Gencsi, L.; Vancsura, R. *Dendrológia. Erdészeti Növénytan II*; Mezőgazda Kiadó: Budapest, Hungary, 1992.
36. Godet, J.-D. *Baumrinden—Vergleichen und Bestimmen*; Eugen Ulmer: Stuttgart, Germany, 2011.
37. Vaucher, H. *Baumrinden. Aussehen, Struktur, Funktion, Eigenschaften*; Naturbuch Verlag: Augsburg, Germany, 2000.
38. Idžojtić, M. *Listopadno Drvece i Grmlje u Zimskom Razdoblju*; Šumarski Fakultet: Zagreb, Croatia, 2005.
39. Johnson, O. *Európa Fái*; HarperCollins Publishers Ltd.: London, UK, 2007.
40. Mikolas, M. *A Beginner's Guide to Recognizing Trees of the Northeast*; Countryman Press: Woodstock, VT, USA, 2017.
41. Baraton, A. *Le Monde des Écorces*; Editions du Rouergue: Rodez, France, 2003.
42. Bartha, D. *Magyarország Ritka fa- és Cserjefajainak Atlasza*; Kossuth Kiadó: Budapest, Hungary, 2012.
43. Kiss, L. *Fenyők. Fák és Cserjék 1.*; Mezőgazda Kiadó: Budapest, Hungary, 1965.
44. Krüssmann, G. *Handbuch der Nadelgehölze*; Paul Parey: Berlin, Germany, 1972.
45. Majer, A. *A Bakony Tiszafása*; Akadémiai Kiadó: Budapest, Hungary, 1980.

46. Mihály, B.; Botta-Dukát, Z. *Biológiai Inváziók Magyarországon. Özönnövények I*; TermészetBÚVÁR Alapítvány Kiadó: Budapest, Hungary, 2004.
47. Price, D.; Bersweden, L. *Winter Trees—A Photographic Guide to Common Trees and Shrubs*; Field Studies Council Publications: Shrewsbury, UK, 2013.
48. Schmidt, G. *Rügyhatározó*; Mezőgazda Kiadó: Budapest, Hungary, 2003.
49. Vancsura, R. *Lombos Fák és Cserjék. Fák és Cserjék 2*; Mezőgazda Kiadó: Budapest, Hungary, 1960.
50. Bokor, R. *A Magyar Erdőkben (és Nyilvános Parkokban) Honos és Fontosabb Honosított Fás Növények Téli Állapotban való Határozója (Rügyhatározó)*; Röttig-Romwalter Nyomda Részvénytársaság: Budapest, Hungary, 1932.
51. Caudullo, G.; De Rigo, D.; Mauri, A.; Houston Durrant, T.; San-Miguel-Ayanz, J. *European Atlas of Forest Tree Species*; European Commission: Luxembourg, 2011.
52. Csapody, I.; Csapody, V.; Rott, F. *Erdei Fák és Cserjék*; Országos Erdészeti Főigazgatóság–Mezőgazdasági Könyv- és Folyóiratkiadó Vállalat: Budapest, Hungary, 1966.
53. Csiszár, Á. *Inváziós Növényfajok Magyarországon*; Nyugat-Magyarországi Egyetem: Sopron, Hungary, 2012.
54. Debreczy, I.; Rácz, Z. *Conifers Around the World: Conifers of the Temperate Zones and Adjacent Regions I–II*; DendroPress: Budapest, Hungary, 2012.
55. Farjon, A.; Baas, P. *A Handbook of the World's Conifers*; Brill Academic Publishers: Leiden, The Netherlands, 2010.
56. Jagel, A.; Dörken, V.M. Weihnachtsgrün und Friedhofskoniferen—Bestimmung immergrüner Nadelbäume ohne Zapfen. *Jahrb. Bochumer Bot. Vereins* **2013**, *4*, 280–307.
57. Keresztesi, B. *A Tölgyek*; Akadémiai Kiadó: Budapest, Hungary, 1967.
58. Caccianiga, M.; Compostella, C.; Caccia, G.; Cattaneo, C. Contribution of plant anatomy to forensic investigation: Tree bark morphology. *Forensic Sci. Int.* **2021**, *318*, 110598. [CrossRef]
59. Yunus, M.; Yunus, D.; Iqbal, M. Systematic bark morphology of some tropical trees. *Bot. J. Linn. Soc.* **1990**, *103*, 367–377. [CrossRef]
60. Adams, D.C.; Jackson, J.F. Estimating the Allometry of Tree Bark. *Am. Midl. Nat.* **1995**, *134*, 99–106. [CrossRef]
61. MacFarlane, D.W.; Luo, A. Quantifying tree and forest bark structure with a bark-fissure index. *Can. J. For. Res.* **2009**, *39*, 1859–1870. [CrossRef]
62. Anna, I.; Jarosław, K. Hydrological properties of bark of selected forest tree species. Part I: The coefficient of development of the interception surface of bark. *Trees Struct. Funct.* **2014**, *28*, 831–839. [CrossRef]
63. Jiménes Saa, J.H. *La Identificación de los Arboles Tropicales por Medio de Caracteristicas del Tronco y la Corteza*; Instituto Interamericano de Cooperación para la Agricultura (IICA): San José, Costa Rica, 1967.
64. Rollet, B. Interet de l'etude des ecorces dans la determination des arbres tropicaux sur pied. *Bois For. Trop.* **1980**, *194*, 3–28.
65. Rollet, B. Interet de l'etude des ecorces dans la determination des arbres tropicaux sur pied. *Bois For. Trop.* **1982**, *195*, 31–50. [CrossRef]
66. Thorenaar, A. *Naar Bruikbare Kenmerken Ter Identificatie Van Boomen Naar Hun Bast*; Cambridge University: Cambridge, UK, 1926.
67. Beard, F.S. Key for the identification of the more important trees of Tobago on characters of bark and blaze. *Emp. For. J.* **1944**, *23*, 34–36.
68. De Vall, W.B. A bark character for the identification of certain Florida pines. *Proc. Florida Acad. Sci.* **1944**, *7*, 101–103.
69. Kumari, A.K.R.; Kavitha, S.; Sheena, E.V. Bark morphology as a tool to identify the trees. *Svādhyāya Int. J. Transdiscipl. Res. Dev.* **2024**, *4*, 33–48.
70. Schwankl, A. *Guide to Bark*; Thames and Hudson: London, UK, 1956.
71. Vaucher, H. *Bäume an den Rinden Erkennen und Bestimmen*; Prisma Verlag: Güters-loh, Germany, 1987.
72. Vaucher, H. *Tree Bark: A Colour Guide*; Timber Press: Portland, OR, USA, 2010.
73. Wojtech, M. *Bark: A Field Guide to Trees of the Northeast*; Brandeis University Press: Waltham, MA, USA, 2020.
74. Payne, W.W. A Glossary of Plant Hair Terminology. *Brittonia* **1978**, *30*, 239–255. [CrossRef]
75. Wacowska, M. Ontogenesis and structure of periderm in *Acer negundo* L. and × *Fatshedera lizei* Guillaum. *Acta Soc. Bot. Pol.* **1985**, *54*, 17–27. [CrossRef]
76. Ruffinatto, F.; Crivellaro, A.; Wiedenhoeft, A.C. Review of macroscopic features for hardwood and softwood identification and a proposal for a new character list. *IAWA J.* **2015**, *36*, 208–241. [CrossRef]
77. Cornelissen, J.H.C.; Lavorel, S.; Garnier, E.; Díaz, S.; Buchmann, N.; Gurvich, D.E.; Reich, P.B.; ter Steege, H.; Morgan, H.D.; van der Heijden, M.G.A.; et al. A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. *Aust. J. Bot.* **2003**, *51*, 335–380. [CrossRef]
78. Pérez-Harguindeguy, N.; Díaz, S.; Garnier, E.; Lavorel, S.; Poorter, H.; Jaureguiberry, P.; Bret-Harte, M.S.; Cornwell, W.K.; Craine, J.M.; Gurvich, D.E.; et al. New handbook for standardised measurement of plant functional traits worldwide. *Aust. J. Bot.* **2013**, *61*, 167–234. [CrossRef]
79. Kattge, J.; Bönisch, G.; Díaz, S.; Lavorel, S.; Prentice, I.C.; Leadley, P.; Tautenhahn, S.; Werner, G.D.A.; Aakala, T.; Abedi, M.; et al. TRY plant trait database—Enhanced coverage and open access. *Glob. Change Biol.* **2020**, *26*, 119–188. [CrossRef] [PubMed]

80. Prentice, I.C.; Meng, T.; Wang, H.; Harrison, S.P.; Ni, J.; Wang, G. Evidence of a universal scaling relationship for leaf CO2 drawdown along an aridity gradient. *New Phytol.* **2011**, *190*, 169–180. [CrossRef]
81. Wirth, C.; Lichstein, J.W. The Imprint of Species Turnover on Old-Growth Forest Carbon Balances—Insights from a Trait-Based Model of Forest Dynamics. In *Old-Growth Forests: Function, Fate and Value*; Wirth, C., Gleixner, G., Heimann, M., Eds.; Springer: New York, NY, USA, 2009; pp. 81–113.
82. Milla, R.; Reich, P.B. Multi-trait interactions, not phylogeny, fine-tune leaf size reduction with increasing altitude. *Ann. Bot.* **2011**, *107*, 455–465. [CrossRef]
83. Wang, H.; Harrison, S.P.; Prentice, I.C.; Yang, Y.; Bai, F.; Togashi, H.F.; Wang, M.; Zhou, S.; Ni, J. The China Plant Trait Database: Toward a comprehensive regional compilation of functional traits for land plants. *Ecology* **2018**, *99*, 500. [CrossRef]
84. Rosell, J.A. Bark thickness across the angiosperms: More than just fire. *New Phytol.* **2016**, *211*, 90–102. [CrossRef] [PubMed]
85. Kucharzyk, S. *Flora Wiosenna Lasów—Kluczyk Botaniczny do Oznaczania*; Bieszczadzki Park Narodowy: Lutowiska, Poland, 2017.
86. Kucharzyk, S. Flora Wiosenna Lasów—Kluczyk Botaniczny do Oznaczania Gatunków. Available online: https://archiwum.bdpn.pl/moje_php/kluczyk (accessed on 30 August 2025).
87. Lucidcentral. Lucid Key: Identification and Diagnostic Tools for Biodiversity and Biosecurity. Available online: https://www.lucidcentral.org (accessed on 20 January 2025).
88. Richardson, S.J.; Laughlin, D.C.; Lawes, M.J.; Holdaway, R.J.; Wilmshurst, J.M.; Wright, M.; Curran, T.J.; Bellingham, P.J.; McGlone, M.S. Functional and environmental determinants of bark thickness in fire-free temperate rain forest communities. *Am. J. Bot.* **2015**, *102*, 1590–1598. [CrossRef] [PubMed]
89. Bartha, D. A közönséges bükk morfológiája. In *A Bükk és a Bükkösök Magyarországon*; Bartha, D., Csóka, G., Mátyás, C., Eds.; Soproni Egyetem Kiadó: Sopron, Hungary, 2024; pp. 28–45.
90. Lima, M.T.; Guandique, M.E.G.; Tonello, K.C. Bark Morphology and Nutrient Flux in Urban Trees: Investigating Water Absorption and Ion Concentration Dynamics. *Hydrology* **2024**, *11*, 56. [CrossRef]
91. Dowtin, A.L.; Cregg, B.C.; Nowak, D.J.; Levia, D.F. Towards optimized runoff reduction by urban tree cover: A review of key physical tree traits, site conditions, and management strategies. *Landsc. Urban Plan.* **2023**, *239*, 104849. [CrossRef]
92. Kettlewell, H.B.D. Selection experiments on industrial melanism in the Lepidoptera. *Heredity* **1955**, *9*, 323–342. [CrossRef]
93. Ontario Ministry of Natural Resources (OMNR). *Ontario Tree Marking Guide, Version 1.1*; OMNR: Toronto, ON, Canada, 2004.
94. Godet, J.-D. *Baumrinden*; Arboris Verlag: Wohlen bei Bern, Switzerland, 2011.
95. Godet, J.-D. *Guide des Écorces des Arbres d'Europe*; Delachaux et Niestlé: Paris, France, 2012.
96. Godet, J.-D. *Guide des Écorces des Arbres d'Europe: Reconnaître et Comparer les Espèces*; Delachaux et Niestlé: Paris, France, 2022.
97. Propat, P. *Barks and Trunks: Rainforest Trees of South-Eastern Australia—Vol 1*; Dragonwick: Goonellabah, Australia, 2009.
98. Propat, P. *Barks and Trunks: Rainforest Trees of South-Eastern Australia—Vol 2*; Dragonwick: Goonellabah, Australia, 2013.
99. Propat, P. *Barks and Trunks: Rainforest Trees of South-Eastern Australia—Vol 1*; Dragonwick: Goonellabah, Australia, 2020.
100. Schwankl, A. *Die Rinde, das Gesicht des Baumes. Ein Buch zum Bestimmen der Bäume und Hölzer nach ihren Rinden von 75 Arten des In- und Auslandes*; Kosmos: Stuttgart, Germany, 1953.
101. Vaucher, H. *Les Arbres leurs Ecorces*; Hatier: Paris, France, 1980.
102. Vaucher, H. *Bomen—Herkennen aan de Schors*; Moussault: Bussum, The Netherlands, 1982.
103. Vaucher, H. *Les Arbres leurs Écorces*; Hatier: Paris, France, 1985.
104. Vaucher, H. *Baumrinden*; Verlag von Ferdinand Enke: Stuttgart, Germany, 1990.
105. Vaucher, H. *Guide des Écorces*; Delachaux et Niestlé: Paris, France, 1993.
106. Vaucher, H. *Tree Bark: A Colour Guide*; Timber Press: Portland, OR, USA, 2003.
107. Wojtech, M. *Bark: A Field Guide to Trees of the Northeast*; Brandeis University Press: Waltham, MA, USA, 2011.
108. Core, E.L.; Ammons, N.P. *Woody Plants in Winter*; The Boxwood Press: Pacific Grove, CA, USA, 1958.
109. Johnson, O.; More, D. *Collins Tree Guide*; HarperCollins Publishers Ltd.: London, UK, 2006.
110. Pikula, J. *Stromové a Keřové Dřeviny lesů a Volné Krajiny České Republiky*; Akademické nakladatelství CERM: Brno, Czech Republic, 2013.
111. Sterry, P. *Collins Complete Guide to British Trees: A Photographic Guide to Every Common Species*; HarperCollins Publishers Ltd.: London, UK, 2008.
112. Trelease, W. *Winter Botany: A Companion Volume to the Author's Plant Materials of Decorative Gardening*; Trelease, W., Ed.; Wentworth Press: Wilmington, DE, USA, 1918.
113. Watts, M.T.; Watts, T. *Winter Tree Finder: A Manual for Identifying Deciduous Trees in Winter*; Nature Study Guild: Berkeley, CA, USA, 1970.
114. Forel, O. *Synchromies*; Temps: Paris, France, 1961.
115. Forel, O. *Synchromies*; Le Manoir: Suisse, Switzerland, 1967.
116. Forel, O. *Secrets des Ecorces. Synchromies*; Edita: Edita, Finland, 1972.
117. Forel, O. *Geheimnisvolle Rinden Synchromien*; Edita: Edita, Finland, 1972.
118. Forel, O. *Hidden Art in Nature. Synchromies*; Harper & Row: New York, NY, USA, 1972.

119. Forel, O. *Secrets des Ecorces. Synchromies*; Éditions Denoël: Paris, France, 1980.
120. Johnson, D. *Bark*; Dojopico Books: Hudson, NY, USA, 2022.
121. Pollet, C. *Écorces: Voyage dans l'intimité des Arbres du Monde*; Eugen Ulmer KG: Stuttgart, Germany, 2008.
122. Pollet, C. *Bark: An Intimate Look at the World's Trees*; Frances Lincoln Publishers: London, UK, 2010.
123. Pollet, C. *Rinde: Die Wunderwelt der Bäume Entdecken*; Eugen Ulmer KG: Stuttgart, Germany, 2012.
124. Pollet, C. *Rinde: Die Wunderwelt der Bäume Entdecken*; Eugen Ulmer KG: Stuttgart, Germany, 2016.
125. Pollet, C. *Cortecce: Viaggio Nell'intimità Degli Alberi del Mondo*; L'Ippocampo: Milano, Italy, 2017.
126. Pollet, C. *Écorces: Voyage dans L'intimité des Arbres du Monde*; Eugen Ulmer KG: Stuttgart, Germany, 2022.
127. Pollet, C. *Écorces: Galerie d'art à ciel Ouvert*; Eugen Ulmer KG: Stuttgart, Germany, 2011.
128. Pollet, C. *Beautiful Trees: Close-Ups of Amazing Tree Bark from Around the World*; Frances Lincoln Publishers: London, UK, 2012.
129. Sandved, K.B.; Prance, A.E.; Prance, G.T. *Bark: The Formation, Characteristics, and Uses of Bark Around the World*; Timber Press: Portland, OR, USA, 1993.
130. Evert, R.F. Periderm. In *Esau's Plant Anatomy*, 3rd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2006; pp. 427–445.
131. Smithson, E. Development of winged cork in *Acer campestre* L. *Proc. Leeds Philos. Lit. Soc. Sci. Sect.* **1952**, *6*, 97–103.
132. Smithson, E. Development of winged cork in Ulmus × hollandica Mill. *Proc. Leeds Philos. Lit. Soc. Sci. Sect.* **1952**, *6*, 211–220.
133. Majer, A. *Magyarország Erdőtársulásai (az Erdőműveléstan Alapjai)*; Akadémiai Kiadó: Budapest, Hungary, 1968.
134. Serra, O.; Mähönen, A.P.; Hetherington, A.J.; Ragni, L. The Making of Plant Armor: The Periderm. *Annu. Rev. Plant Biol.* **2022**, *73*, 405–432. [CrossRef]
135. Gill, A.M. Stems and fires. In *Plant Stems*; Academic Press Inc.: San Diego, CA, USA, 1995; pp. 323–342.