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REVIEW OF MACROSCOPIC FEATURES FOR HARDWOOD AND SOFTWOOD IDENTIFICATION AND A PROPOSAL FOR A NEW CHARACTER LIST

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ABSTRACT

With the adoption of a number of anti-illegal logging laws, treaties, memoranda, and international agreements around the world, there is broad and renewed interest in wood identification, especially in the field at the macroscopic level. In response to this interest, and to begin to fill an obvious gap in the corpus of wood anatomical reference material, we review several prominent English-language publications on macroscopic wood identification in order to form a list of characters. We compile characters and organize them in the spirit of the IAWA lists for hardwood and softwood microscopic identification, present the state of the art as it exists, attempt to reconcile the different sets of definitions, characters, and character states, then present our proposed working-list. It is our intent with this publication to open an international discussion regarding the standardization of macroscopic wood identification features, and it is our hope that such a discussion can include critical works from the non-English literature. We also call for an illustrated glossary to accompany the proposed list. A standard lexicon to describe wood at the macroscopic level will simplify the preparation of identification documents and permit the ready translation of keys and other references for easy use and deployment around the world.

Keywords: List, glossary, hand lens, wood identification, forensic wood anatomy, nomenclature, illegal logging.

INTRODUCTION

Microscopic identification is fundamentally a laboratory-based endeavor, typically restricted to people with access to and skill with light microscopes, reference collections, and operating from a place of significant expertise with wood anatomy. Such expertise is critical to maintain and to grow, especially in light of the increasing demand for forensic wood science *sensu lato*, to address concerns about illegal logging and supply chain verification of wood products. According to Johnson & Laestadius (2011)

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"Illegal logging has been increasingly acknowledged over the past decade as a major environmental, social and economic problem ..." and INTERPOL (2012 Nellemans) reports "Recent studies into the extent of illegal logging estimate that illegal logging accounts for 50–90 per cent of the volume of all forestry in key producer tropical countries and 15–30 per cent globally. Meanwhile, the economic value of global illegal logging, including processing, is estimated to be worth between US$ 30 and US$ 100 billion, or 10–30 per cent of global wood trade." In the last several years some regulations have come into effect in order to combat the circulation of illegally logged wood, namely the Lacey Act Amendment in the United States, and the European Regulation n. 995/2010, known as "European Timber Regulation" (EUTR).

Microscopic wood identification, while powerful and important (Wheeler & Baas 1998; Gasson 2011; Gasson *et al.* 2011), is not the only tool that can play a role in combating illegal logging and enforcing new laws and treaties. For every border agent, agriculture inspector, customs official, plant health inspector, environmental police officer, or other field agent that can be trained to make on-the-ground assessments of shipments of wood, we can expect better conservation of endangered species or protected lands – "... there will always be a need for methods and tools that customs border officials and inspectors can employ in the field" (Johnson and Laestadius, 2011). It is the role of wood anatomists to provide tools and technology useful to these professionals, and to be relevant in the field such tools and technology are most likely to be based on macroscopic rather than microscopic wood characters. Many such tools and technologies have been produced in the last few decades for general wood identification (FPRL 1952, Hoadley 1990, Ilic 1990, Richter & Oelker 2002), CITES identification (CITES 2002; USDA-APHIS-PPQ 2006; Garrett *et al.* 2010; Richter *et al.* 2014), regional commercial timber identification (Benoit & Dirol 2000; Safdari *et al.* 2008; Safdari & Devall 2009; Coradin *et al.* 2010; Wiedenhoeft 2011) and an even broader body of literature from earlier decades, much of which is restricted to individual countries, states, or provinces, already exists (additional references can be found in Gregory 1980 & 1994 and Wheeler & Baas 1998). These efforts have produced texts, scientific papers, laboratory identification manuals, field identification manuals, pamphlets, posters, and a range of electronic media, including electronic copies of paper publications and interactive software keys and atlases. Machine-vision systems of the type outlined in Hermanson & Wiedenhoeft (2011) also operate at a macroscopic scale. Future development of sophisticated anatomical feature detection by machine vision systems could be improved by standardized, robust character definitions.

Driven by the need for tools and technologies to combat illegal logging, researchers have been developing non-anatomical methods in order to reach levels of identification accuracy capable of fulfilling legislative requirements. Chemometric methods such as near infrared spectroscopy (Pastore *et al.* 2011; Braga *et al.* 2011) and extractive analysis (Kite *et al.* 2010), or DNA analysis (Tnah *et al.* 2009; Eurlings *et al.* 2010; Tnah *et al.* 2010; Hanssen *et al.* 2011; Holtken *et al.* 2012; Jolivet & Degen 2012; Degen *et al.* 2013; Lichao *et al.* in press) make possible specificity that wood anatomy alone cannot achieve. Although the results of these non-anatomical methods are encouraging, the anatomical method still represents a highly efficient and effective way to identify wood, and even as non-anatomical techniques mature and become more powerful, we expect anatomy in conjunction with them to remain relevant to a streamlined process for analyzing specimens in a forensic context.

IAWA has always been the world's leader in standardizing and summarizing the characters used in microscopic wood identification (Record 1933; IAWA Committee 1964, 1989, 2004), and it is clear that the Association should continue its leadership role in establishing the same type of consensus framework for macroscopic identification.

Despite the large number of publications noted above, a standardization of macroscopic features terminology is still lacking. The potential "customer base" for macroscopic wood identification extends far beyond the traditional boundaries of wood anatomy, and macroscopic identification tools can support both compliance activities for commercial interests (legal compliance, product claim verification) as well as enforcement activities (working with the legal authorities). The utility of standardized nomenclature for macroscopic wood anatomy and identification within the traditional wood anatomy research community is also clear. A standardized set of features could support the constitution of a searchable interactive online key such as InsideWood (Wheeler 2011).

APPROACH

To initiate this process and establish a provisional set of characters for macroscopic wood identification, we surveyed the literature, with special emphasis on English-language sources, for characters and character definitions used by authors in six macroscopic identification publications: FPRL 1952, Hoadley 1990, Ilic 1990, CITES 2002, Richter & Oelker 2002, and Wiedenhoeft 2011, although this selection represents only a small portion of the vast literature on the subject. Despite the breadth of prior references on macroscopic wood identification, there is relatively small variability in the number and nature of characters used by different authors, but a much larger variability in their interpretation and definition. We focused therefore on English literature sources to avoid language misinterpretation, selecting works that put special attention on character definitions, that themselves represent a review and elaboration of previous literature, that are widely known and applied, and that represent both temperate and tropical hardwood and softwood macroscopic characters.

We compiled these characters and definitions in the framework of the IAWA lists for hardwoods (IAWA 1989) and softwoods (IAWA 2004), and present those results for each publication, including the author (Table 1). Table 1 is thus the basis of our proposed characters list and their definitions, wherein we seek to reconcile different terminologies and propose a set of definitions (Table 2).

Definitions of proposed characters are presented in the following annotated list of macroscopic characters, with reference to the sources employed. In order to have a robust system of character coding and the ability to code all combinations of states, a distinction between character and character state is adopted in Table 2, allowing for negative space or multiple coding in each character or character set when appropriate. This is a critical aspect of the list, and brings the coding of character states better into line with character and character state definitions as would be employed in comparative phylogenetic or evolutionary work. Almost every character also incoporates a "variable" character state so that polymorphic taxa can be represented accurately.

Annotated list of macroscopic characters

Each character listed in Table 2 is presented in the text with applicable character states in square brackets and a short definition, as well as planes of observation. For each part of the definition bibliographic sources are indicated.

The adoption of character states is finalized to obtain descriptions compatible with an XML-based data entry sheet. A correctly designed data entry page would facilitate data entry and output a cleanly formatted text file that can be easily imported to a database, and would include important metadata to subtend the specified anatomical data (*e.g.*, radio buttons for each character would carry a "tag" that adds metadata for whether or not a value for the character was specifically selected, or if it was left not coded). Such information is central to employing the eventual database in a way that takes full advantage of the negative character space built into the structure of the list. Such a data input tool would also automatically exclude irrelevant character questions based on earlier inputs (*e.g.* if vessels are absent, none of the vessel queries would appear, and would be automatically coded N/A for not applicable. The metadata would thus indicate the source [automatic] for coding those character states, whereas the metadata would indicate direct coding of "vessels absent"). Another principle underlying the proposed list is to gather quantitative values for features when possible. With the ubiquity of computers, it is no longer necessary or desirable only to reduce quantitative features to a coded range value. As quantitation becomes significantly easier (*e.g.* as a result of machine-vision systems), explicit character definitions for quantitative characters will become necessary, as will explicit definitions for machine-determined identification of qualitative characters. Despite the inherent desirability of large quantitative data sets, the majority of characters in this list are qualitative.

Because nomenclature frequently varies among different authors, the nomenclature and definitions here proposed are largely based upon the IAWA lists of microscopic features for hardwoods and softwoods identification, with adaptations and integrations from other sources. This was done to facilitate the adoption of definitions that are, when appropriate, substantially similar to those already in use in the wood identification community at large.

The implied plane of observation is the transverse, except when explicitly indicated in the character description.

This list does not seek to serve as the final set of definitions, but rather as the start of an international discussion to codify and clarify terminology and concepts useful in macroscopic wood identification. It is our hope that IAWA will form an international committee to arrive at useful, robust consensus definitions, and that such a committee will bring together international specialists dealing with the macroscopic identification of wood.

Table 1. Characters and character definitions used by authors in six macroscopic identification publications (F = FPRL 1952, H = Hoadley 1990, I = Ilic 1990, C = CITES 2002, R = Richter & Oelker 2002, W = Wiedenhoeft 2011) presented in the framework of the IAWA standard lists of microscopic features for hardwood and softwood identification (IAWA 1989, 2004). Implied plane of observation is transverse, if different or multiple planes are present, they are indicated in the “Definitions/Notes” column in square brackets as TR = transverse, TLS = tangential, RLS = radial.

		Structure	**Property**	**Feature** (IAWA # if applicable)	**Character**	**Source**	**Definitions / Notes**
Anatomical features	Hardwood	Growth rings	Growth ring boundaries	1–2		F	sufficiently distinct to be counted
						H	distinct / indistinct
						I	distinct / indistinct
						R	distinct / indistinct
			Growth rings per cm	–		W	many / few
			Growth rings width	–		H	narrow
			Growth ring shape	–		H	fluted / irregular contour
		Vessels	Number of rows of earlywood vessels	–		R	uniseriate / multiseriate
						H	single row / multiple layer (with numerical quantification)
			Porosity	3–5		C	wood ring-porous / wood diffuse porous
						R	ring-porous / semi-ring-porous / diffuse porous
						H	ring-porous / semi-ring-porous / diffuse porous (TR, TLS)
						I	ring-porous and semi-ring-porous / diffuse porous
						W	ring-porous / semi-ring-porous / diffuse porous
						F	ring-porous
			Arrangement	6	in tangential bands	C	other
						R	
						H	wavy bands (TR, jagged pattern on TLS)
						I	
						F	tangential arrangement
				7	in diagonal and/or radial pattern	C	in files
						R	diagonal and radial pattern distinct
						H	
						I	comprises dendritic pattern
						W	distinguishes amongst radial and diagonal (echelon)
						F	radial or oblique arrangement
				8	in dendritic pattern	C	other
						R	
						H	dendritic or flamelike patches
						W	
						F	radial or oblique arrangement

Table 1 contd		**Structure**	**Property**	**Feature** (IAWA # if applicable)	**Character**	**Source**	**Definitions / Notes**
Anatomical features	Hardwood	Vessels *contd*	Groupings	9	solitary	C R H I W F	vessel single 98% solitary pore multiples rarer than about 1 in 50
				–	in multiples	R	
				10	radial multiples	C R H I W F	several vessels adjacent to one another form a file short (2–3 vessels) / 4 or more pore multiples (few vessels) / pore chains (many vessels) 2 classes (up to 4 / more than 4) pore pattern dominated by radial multiples of 3 or more
				11	clusters common	F H I W R	 nested pores 3 or more vessels having both radial and tangential [common walls
			Frequency	46–50	per square mm	C R H I F	no classes, just adjectives without numerical reference 5 classes (1–3 / 9–14 / 34–44 / 40–60 / 15–155) different adjectives (few, numerous …) without numerical [reference 3 classes (less than 4 / 4–12 / more than 12) 6 classes
			Perforation plates	13–14	perforation plates	I	simple / multiple [TR, RLS]
			Size	40–43	tangential diameter	F C R H I W F	 large–small small (not visible to the naked eye, less than 80 µm) / medium (just visible to the naked eye, 80–130 µm) / large (commonly visible to the naked eye, larger than 130 µm) different adjectives without numerical reference 4 classes (large / intermediate, visible to the naked eye / small, indistinct to the naked eye / very small, barely visible with lens) 3 classes (small / medium / large) 5 classes
				–	earlywood pore diameter	H	

Table 1 contd		Structure	Property	Feature (IAWA # if applicable)	Character	Source	Definitions / Notes
Anatomical features	Hardwood	Vessels *contd*	Contents	56	tyloses	C	
						R	
						H	
						I	tyloses abundant
						W	
						F	tyloses are often best seen on a split longitudinal surface [TR, TLS, RLS]
				58	deposits	C	
						R	
						H	
						I	white and yellow [TR, TLS, RLS]
						W	powders / gums or resins
						F	
			Shape	–		H	oval / round
			Wall thickness	–		H	thick-walled
			Arrangement uniformity	–		H	regular, even / irregular
			Latewood pore visibility	–		R	
		Tracheids	Vasicentric / vascular tracheids	60	lighter tissue	H	term used to avoid the problem of using 'axial parenchyma' when the lighter visible on tr section is actually made of trach.
		Axial parenchyma	Absence	–		R	
						I	
			Distribution	76–77	diffuse / diffuse-in-aggregates	C	apotracheal
						R	only "diffuse-in-aggregates"
						H	diffuse-in-aggregates only - apotracheal diffuse not visible with hand lens
						I	distinguishes between diff and diff-in-agg (2 distinct features)
						W	distinguishes between diff and diff-in-agg (2 distinct features)
						F	
				78–79	vasicentric	C	paratracheal
						R	
						H	paratracheal - scanty paratracheal not visible with hand lens
						I	surrounding the pores
						W	narrow / wide
						F	
				80	aliform	R	lozenge+winged
						I	lozenge+winged
						H	lozenge+winged+confluent

Table 1 contd		Structure	Property	Feature (IAWA # if applicable)	Character	Source	Definitions / Notes
Anatomical features	Hardwood	Axial parenchyma *contd*	Distribution *contd*	81	lozenge-aliform	C	lozenge-aliform paratracheal
						R	lozenge type
						W	
						F	wing-like and / or confluent
				82	winged-aliform	C	aliform paratracheal
						R	winged
						W	
						F	wing-like and / or confluent
				83	confluent	C	confluent paratracheal
						R	
						H	paratracheal confluent
						W	connecting few vessels / connecting many vessels (= wide [bands])
						F	wing-like and / or confluent
				85–86	banded (presence or absence)	C	banded apotracheal
						R	banded / not banded
						H	banded / wavy bands
						I	banded
						W	banded (banded parenchyma restricted to apotracheal; bands surrounding vessels treated as confluent)
						F	banded
				89	marginal or seemingly marginal	C	marginal
						R	exclusively marginal / not only marginal
						H	marginal
						W	marginal
						F	terminal
				85–86	width	C	prominent / distinct / thin
						R	narrow / wide
						H	faintly visible / fine
						I	larger or narrower than vessels radial diameter
						W	wide / narrow (1 single row of cells)
						F	broad and conspicuous / fine lines
				87–88	aliform	C	regularly / irregularly spaced
						R	reticulate / scalariform / much wider than rays
						H	reticulate / irregular / closely spaced
						I	regularly / irregularly spaced (in the latter it comprises marginal parenchyma)
						F	reticulate / scalariform

Table 1 contd		**Structure**	**Property**	**Feature** (IAWA # if applicable)	**Character**	**Source**	**Definitions / Notes**
Anatomical features	Hardwood	Axial parenchyma *contd*	Distribution *contd*	—	presence / absence in earlywood or latewood zone	H	
				—	extension	C W H	long / short bands long / short bands (the latter interrupt at rays) regular-irregular lines / short-long lines / short-long wings
		Rays	Width	96–99		C R H W F	small / large [TLS] narrow / wide from invisible to clearly distinct; various adjectives [TR, TLS] 2 classes (wide / narrow) 3 classes - visibility of rays depends on their colour, lustre and degree of contrast with adjacent tissues [TR, TLS]
			Ray-vessel width ratio	—		F I H	more than half the width of pores / wider than pores 2 dimensions related to vessels dimension; smaller and wider narrower / same width / larger than largest pores
			Aggregate rays	101		F H	 relatively few in number and may be sporadic in distribution [TLS]
			Rays of two distinct sizes	103		I R	aggregate rays are excluded by this definition aggregate rays are included in this definition [TR, TLS]
			Cellular composition	104–109		I F	markedly heterogeneous (opposed to homogeneous) - on split radial surface [RLS] heterogeneous / heterogeneous with several rows of marginal cells [RLS]
			Rays per mm	114–116	ray number ray spacing	F W H	5 classes 3 classes (few / normal / numerous) adjectives [TR, TLS]
			Distribution	—		H	uniform / irregular
			Storied	118		C R H I W F	[TLS] present / absent [TLS] ripple marks [TLS] ripple marks (also due to other cells, like fibres) [TLS] 3 classes (coarse / medium / fine) [TLS] rays producing ripple marks [TLS]
			Arrangement of tiers	122		R	regular / irregular [TLS]

Table 1 contd		Structure	Property	Feature (IAWA # if applicable)	Character	Source	Definitions / Notes
Anatomical features	Hardwood	Rays *contd*	Number of tiers per mm	—		C	2 rows or less per mm / 3 to 6 rows per mm / more than 6 rows per mm [TLS]
				—	coarse / medium / fine	W	[TLS]
						R	possibility to insert a number of tiers]TLS]
			Noded rays	—		H	appear to flare or become swollen as they cross the growth-ring boundary
			Height	102		C	less than 5 mm / more than 5 mm [RLS]
						H	from imperceptibly small to several inches high, various adjectives or numerical values (more than, less than) [TLS]
						R	less than 1 mm / between 1 and 5 / over 5 up to several cm [TLS]
						I	more than 3 mm [RLS]
						F	exceeding 2 cm in height [TLS]
			Size variability	—		H	variable / uniform [TLS]
			Ray flecks	—		H	presence / absence of evident flecks [RLS]
		Fibres	Radial arrangement	—		C	
						F	
		Oil / mucilage cells	Presence	124–126		I	[TR, RLS]
						F	[RLS]
		Intercellular canals	Presence	—		F	axial and radial canals presence
			Radial canals	130		I	presence [TLS]
			Axial canals arrangement	127–132		R	long tg lines / short tg lines / diffuse
						I	presence
						H	long tg lines / arcs
		Prismatic crystals	Presence	136		I	
		Phloem	Included	133–134		C	
						I	
						F	
	Softwood	Growth rings	Earlywood / latewood transition	42–43		C	abrupt / gradual
						H	abrupt / gradual
						W	abrupt / gradual / absent
						R	abrupt / gradual
			Latewood prominence	—		C	narrow / prominent
						H	narrow

Table 1 contd		**Structure**	**Property**	**Feature** (IAWA # if applicable)	**Character**	**Source**	**Definitions / Notes**
Anatomical features	Softwood	Resin canals	Presence	58		C H W R	
			Dimension	112–114		R H	large / small large / medium / small
			Frequency	—		H	numerous
			Distribution	—		H	even irregular
			Grouping	—		H	solitary / tangential groups
		Axial parenchyma	Visibility	—		H	[TR, TLS, RLS]
			Arrangement	73–75		H	zonate
			Colour of contents	—		H	
Non-anatomical features	Hardwood + Softwood	Heartwood	Distinct	196		R H	
			Colour	197–202		C F H I W R	5 categories luster is considered too weak to code as a character distinct character for “presence of streaks”
			Weight	193–195		C R H I W F	heavy / light average air-dry density value average specific gravity 4 classes (very heavy >1000 / heavy to moderately heavy 830–1000 / light to moderately light 430–830 / very light <430) light / medium / heavy
			Odour	203		C R H I W F	
			Natural durability	—		R	classes according to DIN EN 350-2

Table 1 contd		Structure	Property	Feature (IAWA # if applicable)	Character	Source	Definitions / Notes
Non-anatomical features	Hardwood + Softwood	Sapwood	Width	—		R H	4 classes adjectives or number of rings
			Geographical distribution	164–188		F I R	
			Hardness	—		C W R	hard / soft [TLS, RLS] measured Brinell value [TLS, RLS]
			Shrinkage	—	tangential radial	R R	value value
			Strength	—	bending compression shear tensile shock resistance MOE	R R R R R R	value value value value value value
			End use	—		R	list / bearing-non structural / exterior-interior
			Speed of moisture uptake	—		R	4 classes
			Amenability to liquid penetration	—		R	4 classes
			Gluing	—		R	3 classes
			Surface coating	—		R	2 classes
			Swelling	—	differential radial differential tangential dimensional stability	R R R	value value 4 classes
	Hardwood	Heartwood	Taste	—		H	
			Fluorescence	204		R W H	
			Water extract fluorescence	205		Ct W R	
			Water extract colour	206–209		R H	

Table 1 contd		Structure	Property	Feature (IAWA # if applicable)	Character	Source	Definitions / Notes
Non-anatomical features	Hardwood	Heartwood *contd*	Ethanol extract fluorescence	210		W R	
			Froth test	215		R	
			Burning splinter test	217–221		F I R	splinter burns to ash according to IAWA definition distinct "ash colour" and "to charcoal or partial ash"
			Oily surface	—		R I H	greasiness oily / waxy feel
			Corrosion of iron in presence of water	—		R	3 classes
		Rays	Colour	—		C	dark / pale
			Grain			R W R	interlocked [TLS, RLS] wavy / interlocked / straight [TLS, RLS] interlocked / roey / straight [TLS, RLS]
			Gum defects	—		H	[TR, TLS, RLS]
			Latex slits	—		H	[TLS, RLS]
			Pith flecks	—		H	[TR, TLS, RLS]
	Softwood		Texture	—	coarse / medium / fine	H	only for softwoods

Table 2. Macroscopic list of features for hardwood and softwood identification proposal. Implied plane of observation is transverse, if different or multiple planes are present, they are indicated in the "Character" column in square brackets as TR = transverse, TLS = tangential, RLS = radial.

		Structure	**Property**	**Character**	**Character states**	**Feature** (IAWA # if applic.)	**Macro-scopic feature #**
Anatomical features	Hardwood	Growth rings	Growth rings	Growth rings distinct	Present / absent / variable	1-2	1
				Growth rings per cm	Present / absent / variable	–	2
		Vessels	Porosity	Diffuse porous	Present / absent / variable	5	3
				Semi-ring porous	Present / absent / variable	–	4
				Ring porous	Present / absent / variable	3-4	5
				Number of rows of early-wood pores	One row / more than one row / variable / NA	–	6
				Widest tangential spacing between earlywood vessels	One earlywood vessel at most / more than one earlywood vessel	–	7
			Arrangement	Vessels in tangential bands	Present / absent / variable	6	8
				Vessels in radial pattern	Present / absent / variable	7	9
				Vessels in diagonal pattern (echelon)	Present / absent / variable	7	10
				Vessels in dendritic pattern (flame-like)	Present / absent / variable	8	11
			Groupings	Solitary and in radial multiples of 2–3 vessels	Present / absent / variable	–	12
				Exclusively solitary (90% or more)	Present / absent / variable	9	13
				Radial multiples of 4 or more common	Present / absent / variable / NA	10	14
				Clusters common	Present / absent / variable / NA	11	15
			Frequency	≤ 5 vessels per square mm	Present / absent / variable	46	16
				6–20 vessels / square mm	Present / absent / variable	47	17
				> 20 vessels / square mm	Present / absent / variable	48-49-50	18
			Vessel diameter/ pore visibility	Small (not visible to the naked eye, less than 80 µm)	Present / absent / variable	40-41	19
				Medium (just visible to the naked eye, 80–130 µm)	Present / absent / variable	41-42	20
				Large (commonly visible to the naked eye, larger than 130 µm	Present / absent / variable	42-43	21
			Latewood pore visibility	Latewood pores large, individually distinct, and few enough that they can be readily counted	Present / absent / variable / NA	–	22
			Vesselless bands	Vesselless tangential bands	Present / absent	–	23
			Tyloses	Tyloses common [TR, TLS, RLS]	Present / absent / variable	56	24

Table 2 contd		**Structure**	**Property**	**Character**	**Character states**	**Feature** (IAWA # if applic.)	**Macro-scopic feature #**
Anatomical features	Hardwood	Vessels *contd*	Vessel deposits	Gums and other deposits in heartwood vessels [TR, TLS, RLS]	Present / absent / variable	58	25
				Deposits white [TR, TLS, RLS]	Present / absent	58	26
				Deposits yellow [TR, TLS, RLS]	Present / absent	58	27
				Deposits dark [TR, TLS, RLS]	Pesent / absent	58	28
		Axial paren-chyma	Distribution	Diffuse	Present / absent / variable	76	29
				Diffuse-in-aggregates	Present / absent / variable	77	30
				Vasicentric	Present / absent / variable	78-79-84	31
				Lozenge-aliform	Present / absent / variable / unilateral	81-84	32
				Winged-aliform	Present / absent / variable / unilateral	82-84	33
				Confluent	Present / absent / variable / unilateral	83-84	34
				Banded	Majority wide / majority narrow / variable / absent	85-86	35
				Banded parenchyma distribution	Homogeneous / in late-wood only / in earlywood only / NA	–	36
				Parenchyma bands wider than rays	Present / absent / variable	–	37
				Parenchyma in marginal or seemingly marginal bands	Present / absent / variable	89	38
				Reticulate	Present / absent / variable	87	39
				Scalariform	Present / absent / variable	88	40
				Festooned	Present / absent / variable	–	41
				Predominant parenchyma pattern	Absent / diffuse / diffuse-in-aggregates / vasicen-tric / lozenge-aliform / winged-aliform / conflu-ent / banded / reticulate / scalariform / festooned	–	42
		Rays	Width	Ray visibility to the naked eye on the transverse sur-face	Rays not visible / all rays visible / only larger rays visible	96-97-98-99-103	43
				Ray visibility to the naked eye on the tangenial sur-face [TLS]	Rays not visible / rays vis-ible	96-97-98-99	44
				Ratio of ray width to pore diameter	Larger rays narrower than wider pores / larger rays as wide or wider than wider pores	–	45
				Noded rays	Present / absent / variable	–	46
			Storying	Ray storying [TLS]	Not storied (absent) / regular coarse storying / regular fine storying / irregular coarse storying / irregular fine storying	118	47

Table 2 contd		Structure	Property	Character	Character states	Feature (IAWA # if applic.)	Macro-scopic feature #
Anatomical features	Hardwood	Rays *contd*	Height	Ray height [TLS]	Highest rays less than 5 mm high / highest rays more than 5 mm high	102	48
			Rays per mm	Rays per mm	≤ 4 mm / 5–12 mm / > 12 mm / NA	114-116	49
			Wood rayless	Wood rayless	Present / absent	117	50
		Fibres	Arrangement	Fibres in radial arrangement	Present / absent	–	51
		Canals	Intercellular canals	Axial canals	Absent / diffuse / in short tangential lines / in long tangential lines	127-128-129	52
				Traumatic canals	Present	131	53
				Radial canals [TLS]	Present / absent	130	54
		Phloem	Included	Included phloem	Absent / diffuse / concentric	133-134	55
	Softwood	Growth rings	Earlywood / latewood transition	Earlywood / latewood transition	Abrupt transition from earlywood to latewood / gradual transition from earlywood to latewood / variable	42-43	56
		Axial canals	Axial canals	Axial canals	Large / small / absent	109-113	57
		Axial parenchyma	Visibility	Axial parenchyma visible with hand lens	Scarce diffuse / tangentially zonate / absent	–	58
Non-structural features	Hardwood + Softwood	Heartwood	Colour	Heartwood colour darker than sapwood colour	Present / absent	196	59
				Heartwood basically brown or shades of brown	Present / absent	197	60
				Heartwood basically red or shades of red	Present / absent	198	61
				Heartwood basically yellow or shades of yellow	Present / absent	199	62
				Heartwood basically white to grey	Present / absent	200	63
				Heartwood with streaks	Present / absent	201	64
			Density	Density	Density low: < 0.40 g/cm^3 / density medium: 0.40–0.75 g/cm^3 / density high: > 0,75 g/cm^3	193	65
			Odour	Odour	Absent / distinctly present and pleasant (sweet, spicy, floral) / distinctly present and unpleasant (sour, bitter, foetid)	203	66
			Oily surface	Oily surface	Present / absent	–	67
			Habit	Tree	Present / absent / variable	189	68
				Shrub	Present / absent / variable	190	69
				Vine / liana / climber	Present / absent / variable	191	70
			Geographical distribution	Europe and temperate Asia (Brazier and Franklin region 74)	Present / absent	164	71
				Europe, excluding Mediterranean	Present / absent	165	72

Table 2 contd		**Structure**	**Property**	**Character**	**Character states**	**Feature** (IAWA # if applic.)	**Macro-scopic feature #**
Non-structural features	Hardwood + Softwood		Geographical distribution *contd*	Mediterranean including Northern Africa and Middle East	Present / absent	166	73
				Temperate Asia (China), Japan, USSR	Present / absent	167	74
				Central South Asia (Brazier and Franklin region 75	Present / absent	168	75
				India, Pakistan, Sri Lanka	Present / absent	169	76
				Burma	Present / absent	170	77
				Southeast Asia and the Pacific (Brazier and Franklin region 76)	Present / absent	171	78
				Thailand, Laos, Vietnam, Cambodia (Indochina)	Present / absent	172	79
				Indomalesia: Indonesia, Philippines, Malaysia, Brunei, Singapore, Papua New Guinea, Solomon Islands	Present / absent	173	80
				Pacific Islands (including New Caledonia, Samoa Hawaii, and Fiji)	Present / absent	174	81
				Australia and New Zealand (Brazier and Franklin region 77)	Present / absent	175	82
				Australia	Present / absent	176	83
				New Zealand	Present / absent	177	84
				Tropical mainland Africa and adjacent islands (Brazier and Franklin region 78)	Present / absent	178	85
				Tropical Africa	Present / absent	179	86
				Madagascar & Mauritius, Reunion & Comores	Present / absent	180	87
				Southern Africa (south of the Tropic of Capricorn) (Brazier and Franklin region 79)	Present / absent	181	88
				North America, north of Mexico (Brazier and Franklin region 80)	Present / absent	182	89
				Neotropics and temperate Brazil (Brazier and Franklin region 81)	Present / absent	183	90
				Mexico and Central America	Present / absent	184	91
				Caribbean	Present / absent	185	92
				Tropical South America	Present / absent	186	93
				Southern Brazil	Present / absent	187	94
				Temperate South America including Argentina, Chile, Uruguay and S. Paraguay (Brazier and Franklin region 82)	Present / absent	188	95

Table 2 contd		Structure	Property	Character	Character states	Feature (IAWA # if applic.)	Macro-scopic feature #
Non-structural features	Hardwood	Heart-wood	Surface fluo-rescence	Fluorescence colour	Absent / basically yellow / basically green / other colours / variable	204	96
				Fluorescence intensity	Weakly fluorescent / strongly fluorescent / NA	–	97
			Extractives	Water extract fluorescence	Absent / basically blue / basically green / bluish green / variable	205	98
				Ethanol extract fluores-cence	Absent / basically blue / basically green / bluish green / variable	210	99
				Water extract colour	Colourless / brown or shades of brown / red or shades of red / yellow or shades of yellow / other shades	206-207-208-209	100
				Ethanol extract colour	Colourless / brown or shades of brown / red or shades of red / yellow or shades of yellow / other shades	211-212-213-214	101
			Froth test	Froth after shaking in water	Positive / weakly positive / negative	215	102
			Burning splin-ter test	Splinter burns to:	Charcoal / partial ash / full ash (white) / full ash (yel-low-brown) / full ash (other)	217-218-219-220-221	103
			Chrome Azurol-S test	Chrome Azurol-S test	Positive / negative	216	104
			Grain	Interlocked grain	Present	–	105
			Surface marks	Surface marks	Pith flecks / gum depo-sits / kino veins / pitch pockets	–	106

PROPOSED FEATURE LIST

Growth rings

1 – *Growth rings distinct* [present / absent / variable]

Growth rings with an abrupt structural change at the boundaries between them (IAWA 1989).

Growth ring boundaries can be marked by one or more of the following structural changes:

a. Thick-walled and radially flattened latewood fibres or tracheids versus thin-walled earlywood fibres or tracheids, macroscopically visible as a difference in colour intensity (lighter in earlywood).
b. Distinct differences in colour between earlywood (light) and latewood (dark) (softwoods and ring-porous hardwoods).
c. Marked difference in vessel diameter between latewood and earlywood of the following ring as in ring- and semi-ring-porous woods (hardwoods).
d. Marginal parenchyma, terminal or initial (hardwoods).
e. Decreasing frequency of parenchyma bands towards the latewood resulting in distinct fibre zones (hardwoods).
f. Distended or noded rays (hardwoods) (Richter & Oelker 2002, adapted from IAWA 1989).

General comments:

Although plant stems are typically round with some random irregularity, some species have characteristic undulated or indented growth ring boundaries. This is a variable trait in a number of species, but it is consistent enough in some to be useful in identification (*e.g. Carpinus* spp.). This characteristic should be recorded in the notes.

2 – *Growth rings per cm* [numerical value / NA]

Growth ring width is not used to separate different species of wood, but can sometimes be used as an indicator of whether an unknown is from a plantation or a natural stand of trees. Generally speaking, plantation-grown species grow more rapidly than the same species does in nature, resulting in abnormally wide growth rings (Wiedenhoeft 2011).

Section A – Wood with vessels (hardwoods)

Porosity

3 – *Diffuse-porous* [present / absent / variable]

Wood in which the vessels have more or less the same diameter throughout the growth ring. The vast majority of tropical species and most temperate species show this pattern. In some temperate diffuse-porous woods the latest formed vessels in the latewood may be considerably smaller than those of the earlywood of the next ring, but vessel diameter is more or less uniform throughout most of the growth ring (IAWA 1989).

4 – *Semi-ring porous* [present / absent / variable]

1) Wood in which the vessels in the earlywood are distinctly larger than those in the latewood of the previous growth ring, but in which there is a gradual change to narrower vessels in the intermediate and latewood of the same growth ring; or 2) Wood with a distinct ring of closely spaced earlywood vessels that are not markedly larger than the latewood vessels of the preceding ring or the same growth ring (IAWA 1989).

5 – *Ring-porous* [present / absent / variable]

The vessels in the earlywood are distinctly larger than those in the latewood of the previous growth ring and of the same growth ring, and form a well-defined zone or ring, and in which there is an abrupt transition to the latewood of the same growth ring (IAWA 1989).

6 – *Number of rows of earlywood pores* [one row / more than one row / variable / NA]

In a description, characteristics of the earlywood ring of ring-porous woods should be noted, *i.e.*, describe how many vessels, radially, comprise the earlywood. Such characteristics can be useful in distinguishing between species (IAWA 1989).

7 – *Widest tangential spacing between earlywood vessels* [one earlywood vessel at most / more than one earlywood vessel]

The earlywood of some ring-porous woods exhibits characteristic spacing between earlywood vessels. In many woods spaces are less than the diameter of one earlywood vessel (*e.g. Carya illinoiensis*), whereas in others the distance between earlywood vessels is sometimes greater than two or more earlywood vessel diameters (*Ulmus thomasii*) (authors and Wheeler *et al*. 1989).

General comments:

Caution: Slow-grown ring-porous woods have narrow growth rings with very little latewood. Be careful not to confuse the closely spaced earlywood zones of slow-grown ring-porous woods with a tangential pattern, or to interpret such woods as diffuse-porous (IAWA 1989).

Vessel arrangement

8 – *Vessels in tangential bands* [present / absent / variable]

Vessels arranged perpendicular to the rays and forming short or long tangential bands; these bands can be straight or wavy (IAWA 1989).

9 – *Vessels in radial pattern* [present / absent / variable]

Vessels arranged radially independently from their grouping (adapted from IAWA 1989).

10 – *Vessels in diagonal pattern* (echelon) [present / absent / variable]

Vessels arranged intermediate between tangential and radial (IAWA 1989).

11 – *Vessels in dendritic pattern* (flame-like) [present / absent / variable]

Vessels arranged in a branching pattern, forming distinct tracts, separated by areas devoid of vessels (IAWA 1989).

General comments:

These features often occur in combination. All applicable features should be recorded. When rings are narrow these patterns are not obvious. In ring-porous woods, only the intermediate-wood and latewood are examined for vessel arrangement description (IAWA 1989).

'No specific pattern' is a term of convenience; the majority of hardwoods do not feature a specific vessel arrangement (Richter & Oelker 2002).

Vessel groupings

12 – *Solitary and in radial multiples of 2–3 vessels* [present / absent / variable]

Variable proportions of solitary vessels (less than 90 %) and in relatively short radial multiples of 2–3(–4) vessels. This is the most common character state for vessel grouping.

13 – *Exclusively solitary (90% or more)* [present / absent / variable]

90 % or more of the vessels are completely surrounded by other cells than vessels, *i.e.*, 90 % or more appear not to contact another vessel (IAWA 1989).

14 – *Radial multiples of 4 or more common* [present / absent / variable / NA]

Radial files of 4 or more adjacent vessels of common occurrence (IAWA 1989).

15 – *Clusters common* [present / absent / variable / NA]

Groups of 3 or more vessels having both radial and tangential contacts, and of common occurrence (IAWA 1989).

General comments:

Features 14 and 15 should be used only when they are of common occurrence. Clusters and radial multiples are not mutually exclusive and can occur in combination (adapted from IAWA 1989).

Vessel frequency

16 – *≤ 5 vessels per square millimetre* [present / absent / variable]
17 – *6–20 vessels per square millimetre* [present / absent / variable]
18 – *> 20 vessels per square millimetre* [present / absent / variable]

General comments:

All vessels are counted as individuals, *e.g.*, a radial multiple of four would be counted as four vessels. Vessel frequency is not computed for ring-porous woods (IAWA 1989). In practice this number is determined by counting vessels within a given area and then dividing by the amount needed to have the /sq. mm number (adapted from Ilic 1990).

There are no further classes after the "20 vessels per square millimetre" because such woods have vessels too small to count accurately with a hand lens. The number of vessels per square mm can be more easily determined with the aid of a transparent reference grid.

Vessel diameter / Pore visibility

19 – ***Small (not visible to the naked eye, less than 80 µm)*** [present/absent/variable]
20 – ***Medium (just visible to the naked eye, 80-130 µm)*** [present / absent / variable]
21 – ***Large (commonly visible to the naked eye, larger than 130 µm)*** [present / absent / variable]

General comments

Large vessels are clearly visible to the naked eye on longitudinal surfaces, on which they appear as minute grooves, thus helping in the distinction between medium and large vessels.

Latewood pore visibility

22 – ***Latewood pores large, individually distinct and few enough that they can be readily counted*** [present / absent / variable / NA]

This feature applies only to ring-porous woods. All the latewood pores must be distinct and countable. This is contrasted with latewood pores which are numerous and indistinct, where they are impossible to see and count individually. This feature is used, for instance, for the separation of the red oak group (feature present) from the white oak one (feature absent) (adapted from Hoadley 1990).

Vesselless bands

23 – ***Vesselless tangential bands*** [present / absent]

Long more or less continuous tangential zones within the growth ring without vessels, the radial extent of which is at least two times the tangential vessel diameter of the vessels in the adjacent portions of the growth ring. If the bands are consistently present in a given domain within a growth ring, this can be recorded in the notes.

Tyloses

24 – ***Tyloses common*** [present / absent / variable]

Tyloses are best recognized on account of strong light reflection from the numerous facets producing a distinctive glitter (much like the iridescent glitter of soap bubbles). Likewise, tyloses can be observed on longitudinal surfaces filling the vessel lines. Tyloses may be few or many, ranging from all vessels filled with many tyloses to a few vessels with a few tyloses. This feature applies only when tyloses are not of sporadic occurrence (Richter & Oelker 2002).

In some taxa, tyloses are also characteristically small and densely packed (*e.g. Robinia pseudoacacia*), of typical size and appearance (*Quercus alba*), or with a characteristic multicoloured reflective pattern (*e.g. Fraxinus americana*). These characteristics can be recorded in a comments section in a description.

Vessel deposits

25 – *Gums and other deposits in heartwood vessels* [present / absent / variable]
26 – *Deposits white* [present / absent]
27 – *Deposits yellow* [present / absent]
28 – *Deposits dark* [present / absent]

General comments
"Gums and other deposits" includes a wide variety of chemical compounds, which are variously coloured (white, yellow, red, brown, black) (IAWA 1989).
In dark coloured woods, some deposits are seen as chalky streaks on longitudinal surfaces (Ilic 1990).

Axial parenchyma distribution

29 – *Axial parenchyma diffuse* [present / absent / variable]

Diffuse parenchyma appears as small dots of generally lighter coloured cells scattered among the fibres (Wiedenhoeft 2011).

Diffuse parenchyma may be very difficult to see with a hand lens when devoid of cell contents and of equal wall-thickness as the surrounding fibres, but is more easily seen when the cells are crystalliferous or the fibres thick-walled, or both.

30 – *Axial parenchyma diffuse-in-aggregates* [present / absent / variable]

Parenchyma appearing as short discontinuous tangential lines of generally lighter coloured cells scattered among the fibres (Wiedenhoeft 2011).

31 – *Axial parenchyma vasicentric* [present / absent / variable]

Lighter coloured cells appearing as a halo or sheath around a solitary vessel or vessel multiple (adapted from Wiedenhoeft 2011).

32 – *Axial parenchyma lozenge-aliform* [present / absent / variable / unilateral]

Lighter coloured cells appearing as a halo or sheath with lateral (tangential) extensions forming a diamond-shaped outline (adapted from IAWA 1989).

33 – *Axial parenchyma winged-aliform* [present / absent / variable / unilateral]

Lighter coloured cells appearing as a halo or sheath with elongated and narrow lateral (tangential) extensions (adapted from IAWA 1989).

34 – *Axial parenchyma confluent* [present / absent / variable / unilateral]

Coalescing vasicentric or aliform parenchyma connecting two or more vessels (adapted from IAWA 1989).

35 – *Axial parenchyma banded* [majority wide / majority narrow / variable / absent]

Continuous tangential lines, variable in terms of straightness, width, frequency, and with regard to specific patterns formed with the rays running perpendicular to the bands. This feature should be coded only when parenchyma bands constitute a distinct characteristic of the transverse section. Parenchyma bands may be mainly independent of the vessels (apotracheal), definitely associated with the vessels (paratracheal), or both. Bands may be wavy, straight, continuous or discontinuous (the latter often intergrading with confluent (see axial parenchyma 'confluent'). Prominent bands will cause, like all concentric structures, V-shaped or U-shaped markings on tangential faces, with a more or less regular (straight bands) or rather jagged (undulating bands) course. Parenchyma in narrow bands are usually not or only barely visible to the unaided eye. Parenchyma bands wide are usually visible to the unaided eye (Richter & Oelker 2002).

36 – *Banded parenchyma distribution* [throughout the ring / in latewood only / in earlywood only / NA]

Banded parenchyma present through the entire growth ring, only within the latewood, or only within the earlywood. This character can be interpreted across the entire early or late portion of the growth ring or can be restricted. For example, pecan and true hickory (both *Carya* spp.) can be separated by the absence of bands between the earlywood vessels in the latter (adapted from Hoadley 1990, based on Taras & Kukachka 1970).

37 – *Parenchyma bands wider than rays* [present / absent / variable]

The radial extent of tangential parenchyma bands as compared to the apparent average ray width. In those woods with two-sized rays (*e.g. Grevillea robusta*), the comparison is between the parenchyma bands and the wider rays.

38 – *Parenchyma in marginal or seemingly marginal bands* [present / absent / variable]

Parenchyma bands forming a more or less continuous layer of variable width at, or appearing to be at, the margins of a growth ring. With a hand lens, and without developmental study, marginal parenchyma formed at the beginning (initial) or the end (terminal) of the growth season cannot be distinguished. Axial parenchyma bands which are not marginal are typically more frequent and more closely spaced (also found between marginal bands), and often follow a more irregular course (wavy, interrupted) than marginal bands (adapted from Richter & Oelker 2002).

39 – *Axial parenchyma reticulate* [present / absent / variable]

Parenchyma in continuous tangential lines of approximately the same width as the rays, regularly spaced and forming a network with them. The distance between the rays is approximately *equal to lower* the distance between the parenchyma bands (adapted from IAWA 1989).

40 – *Axial parenchyma scalariform* [present / absent / variable]

Parenchyma in fairly regularly spaced tangential lines or bands, appreciably more closely spaced than the rays and with them producing a ladder-like appearance in cross section. The distance between the rays is greater than the distance between parenchyma bands (adapted from IAWA 1989).

41 – *Axial parenchyma festooned* [present / absent / variable]

Parenchyma in fairly regularly spaced lines or bands arranged in arcs perpendicular to rays. This pattern, typical of most Proteaceae (*e.g. Cardwellia, Grevillea*), can occur in other taxa too (*e.g. Pterygota*).

42 – *Predominant parenchyma pattern* [absent / diffuse / diffuse-in-aggregates / vasicentric / lozenge-aliform / winged-aliform / confluent / banded / reticulate / scalariform / festooned]

While most woods will exhibit several different parenchyma types that can and should be coded separately, with hand lens observation there is often a predominant apparent parenchyma pattern that best describes the overall axial parenchyma pattern. This can be a useful sorting tool to avoid character redundancy. Also, this character permits incorporating data from broader references, or references in which the character state definitions differ appreciably from the more detailed ones we propose here.

General comments:

Axial parenchyma is often recognized by its lighter colour (thin-walled cells with high light reflectivity) and the resulting colour contrast with the surrounding darker ground tissue (fibres with thicker cell walls). Axial parenchyma is present in nearly all hardwoods, but can be so sparingly developed that it is not visible, even with a hand lens. On longitudinal surfaces, well-developed vasicentric and aliform axial parenchyma is often visible as a lighter coloured border to the vessel lines. The various types of axial parenchyma often co-occur and/or intergrade within a given taxon (Richter & Oelker 2002).

Unilateral parenchyma forms semicircular hoods or caps only on one side of the vessels, which can extend tangentially or obliquely in an aliform or confluent or banded pattern, and is used in this list as a modifier for each of the parenchyma types (IAWA 1989).

Macroscopically, vasicentric tracheids and vascular tracheids have more or less the same appearance as axial parenchyma and as such are not treated as separate characters in this list. Only by reference to the microscopic anatomy can the true nature of those cells be known. It is expected that taxa with well-developed vasicentric tracheids (*e.g. Eucalyptus* spp.) will be coded by most students of macroscopic wood structure as "vasicentric parenchyma present".

Ray width

43 – *Ray visibility to the naked eye on the transverse surface* [rays not visible / all rays visible / only larger rays visible]

On transverse surfaces, rays appear as more or less straight lines running perpendicular to the growth rings (Wiedenhoeft 2011).

44 – *Ray visibility to the naked eye on the tangential surface* [rays not visible / rays visible]

On tangential surfaces, rays appear like small axially-oriented lines, usually darker than the background (Wiedenhoeft 2011).

45 – ***Ratio of ray width to pore diameter*** [larger rays narrower than wider pores / larger rays as wide or wider than wider pores]

Ray width estimated by comparison with the tangential diameter of largest pores (Ilic 1990).

46 – ***Noded rays*** [present / absent / variable]

In some woods, rays appear to flare or become swollen as they cross the growth-ring boundary; this can be useful in identification and also indicates distinct growth rings (Hoadley 1990).

General comments:

When rays are broad, about 0.5 mm or more in width, they are easily visible with the unaided eye both on the transverse and on the tangential surface (adapted from Richter & Oelker 2002).

On the transverse surface even uniseriate rays will be detectable with a hand lens.

Ray storying

47 – ***Ray storying*** [not storied (absent) / regular coarse storying / regular fine storying / irregular coarse storying / irregular fine storying]

Rays arranged in tiers (horizontal series) as viewed on the tangential surface. Tiers of rays are visible with the unaided eye or a hand lens, and appear as fine horizontal striations or ripple marks on the tangential surface. These series can be described as horizontal/straight (regular storying), or wavy/oblique/only locally present (irregular storying) (adapted from IAWA 1989).

Coarse storying is characterized by 3 rows or less per axial millimeter, fine storying by 4 rows or more per axial millimetre (adapted from CITES 2002).

Ray height

48 – ***Ray height*** [highest rays less than 5 millimetres high / highest rays more than 5 millimetres high]

Determine total ray height on the tangential surface, in the axial direction (IAWA 1989).

Rays per mm

49 – ***Rays per mm*** [≤ 4/mm / 5–12/mm / >12/mm / NA]

The number of rays per mm determined macroscopically on the transverse section. The number of rays per mm cannot sensibly be determined in woods with two distinct size classes including very broad rays (adapted from IAWA 1989).

The number of rays per mm can be easily determined with the aid of a transparent reference grid.

Wood rayless

50 – Wood rayless

Wood with only axial elements. Rayless woods are restricted to a small number of families. Some examples are *Arthrocnemum macrostachyum* (Chenopodiaceae), *Heimerliodendron brunonianum* (Nyctaginaceae), *Hebe salicifolia*, *Veronica traversii* (Scrophulariaceae) (IAWA 1989).

Fibres

51 – *Fibres in radial arrangement* [present / absent]

Fibres aligned in straight radial rows, typically most evident in fibres with rectangular outlines and large lumina.

Intercellular canals

52 – *Axial canals* [absent / diffuse / in short tangential lines / in long tangential lines]

Diffuse: randomly distributed solitary canals; in short tangential lines: two to five axial canals in a tangential line; in long tangential lines: more than five canals in a line (IAWA 1989).

Axial canals can be very similar to pores on the end grain surface. They are often distinguished from pores only by means of a special arrangement, *e.g.*, in continuous tangential bands, by consistent differences in diameter, or by exuding resin. The irregular outline of axial canals due to the lack of a single bounding cell wall may also be of some help in distinguishing them from vessels of similar size. In woods with a diffuse distribution of canals, and with a diameter similar to that of the vessels, they can be easily overlooked unless betrayed by exuding resin (adapted from Richter & Oelker 2002).

53 – *Traumatic canals* [present]

Timbers which do not have normal resin canals may still form so-called "traumatic" resin canals or gum ducts. Traumatic canals form as a response to injury and therefore may not occur consistently in a given taxon, this is why their absence is not of diagnostic value. Traumatic resin canals usually differ from normal canals, by their large size, irregular outline, and/or by clustering into short to extremely long tangential groups (adapted from Richter & Oelker 2002).

54 – *Radial canals* [present / absent]

Rays in which radial canals occur are generally sporadic, and require special care in observation. Radial canals can be sparse and small with colourless contents or large, abundant, and with coloured contents, or any combination of these. Exudation of resin, gums or latex by the canals can greatly improve the ease of observation (adapted from Ilic 1990).

On the transverse surface, radial canals appear as apparently wider, broken, or distended radial cavities, somewhat similar in appearance to vessel lines on the radial or tangential surfaces.

Included phloem

55 – *Included phloem* [absent / diffuse / concentric]

Included phloem may have an appearance similar to axial parenchyma and can be irregularly organized in concentric (tangential bands) or diffuse (scattered and isolated) patterns. Concentric included phloem very often intergrades with diffuse included phloem. In species with concentric included phloem the phloem bands may branch and anastomose, and the conjunctive parenchyma sometimes forms radial extensions resembling rays. (adapted from Ilic 1990 and IAWA 1989).

Section B – Wood without vessels (softwoods)

Note: vesselless dicotyledonous woods are relatively uncommon and are distinguished from coniferous wood by tall multiseriate rays. For vesselless hardwoods, microscopic analysis is necessary for identification (IAWA 1989).

Earlywood / latewood transition

56 – *Earlywood / latewood transition* [abrupt transition from earlywood to latewood / gradual transition from earlywood to latewood / variable]

The intra-annual transition between earlywood and latewood is marked by structural changes, usually a change in tracheid wall thickness and radial dimension. Earlywood tracheids are thin-walled and have a wide lumen (light coloured) whereas latewood tracheids are thicker-walled with a smaller radial diameter (dark coloured). Although this feature is commonly employed in softwood identification, its diagnostic power is limited as both states may occasionally be present in a given species or specimen (Richter & Oelker 2002).

Axial canals

57 – *Axial canals* [large / small / absent]

Axial canals in softwoods are best seen on transverse surfaces as spots darker or lighter than the background tissue, typically appearing as a halo of lozenge aliform parenchyma. The rather crude distinction between “large” and “small” is arbitrarily defined around the threshold of about 100 μm: canals more than 100 μm in diameter are considered large, *i.e.*, visible with the unaided eye; canals less than 100 μm in diameter are considered small, *i.e.* generally not discernable by the unaided eye. This metric includes all the associated parenchyma comprising the entire structure, the resin canal complex (Wiedenhoeft & Miller 2002), i.e., the canal as differentiated from the tracheids (adapted from Richter & Oelker 2002).

Axial parenchyma

58 – *Axial parenchyma visible with hand lens* [scarce diffuse / tangentially zonate / absent]

Axial parenchyma in softwoods is generally less developed than in hardwoods; if present it can usually be seen as scattered solitary or tangentially zonate cells with dark cellular contents and thus differentiable from the tracheids. Parenchyma cells surrounding axial canals are not included in this feature (adapted from Wiedenhoeft 2011).

Section C – Non-structural features – hardwood + softwood

Heartwood colour

59 – Heartwood colour darker than sapwood colour [present / absent]

Sapwood is typically a light, neutral shade of tan, yellow, or near-white. In absence of both heartwood and sapwood on the same sample, a darker colour of heartwood can be inferred on those presenting a distinct colour (adapted from Hoadley 1990).

60 – *Heartwood basically brown or shades of brown* [present / absent]

61 – *Heartwood basically red or shades of red* [present / absent]

62 – *Heartwood basically yellow or shades of yellow* [present / absent]

63 – *Heartwood basically white to grey* [present / absent]

64 – *Heartwood with streaks* [present / absent]

General comments:

The variety of colours, shades, and combinations of heartwood colour make it impossible to categorize all of them. In general, the colour of heartwood is either brown, red, yellow, white, or some shade or combination of these colours. Basically brown heartwood is very common; basically red and basically yellow are rather rare; basically white or grey is rather frequent. The heartwood colour of many taxa is not restricted to one colour, but to a combination of colours and, when appropriate, various combinations should be recorded and may be used when identifying an unknown. In addition, wood colour may change from the green to the dry state, and that of dry wood is often subject to changes resulting from light and/or contact with oxygen (air). For these reasons heartwood colour should always be determined on a freshly planed tangential surface of a dry specimen. Do not use heartwood colour features for ancient samples, archaeological material, or other samples whose colour has been altered by burial, time, treatment, or decay. Be particularly careful when using the feature "heartwood basically white to grey", because a whitish coloured sample may represent sapwood and not heartwood (IAWA 1989; Richter & Oelker 2002).

Heartwood density

65 – *Density* [density low: < 0.40 g/cm^3 / density medium: 0.40–0.75 g/cm^3 / density high: $> 0{,}75$ g/cm^3]

Average air-dry density (12% to 15% MC) is the wood weight and volume ratio with a moisture content at equilibrium with atmospheric conditions, usually around 12% MC in temperate and 15% MC in tropical regions [g/cm^3] (Richter & Oelker 2002).

Heartwood odour

66 – *Odour* [absent / distinctly present and pleasant (sweet, spicy, floral) / distinctly present and unpleasant (sour, bitter, foetid)]

Follow the procedure described in IAWA (1989).

Heartwood oily surface

67 – *Oily surface* [present / absent]

Wood feels oily or tacky to touch. Rubbing the wood surface of these timbers with the flat of the hand (exerting considerable pressure) will give a sensation of stickiness, an admittedly secondary feature which can nevertheless be of some use in wood identification (Richter & Oelker 2002).

Habit (according to IAWA 1989)

68 – ***Tree*** [present / absent / variable]
69 – ***Shrub*** [present / absent / variable]
70 – ***Vine / Liana / Climber*** [present / absent / variable]

Geographical distribution (according to IAWA 1989)

71 – ***Europe and temperate Asia*** (Brazier and Franklin region 74) [present / absent]
  72 – ***Europe, excluding Mediterranean*** [present / absent]
  73 – ***Mediterranean incl. Northern Africa and Middle East*** [present / absent]
  74 – ***Temperate Asia (China), Japan, USSR*** [present / absent]
75 – ***Central South Asia*** (Brazier and Franklin region 75) [present / absent]
  76 – ***India, Pakistan, Sri Lanka*** [present / absent]
  77 – ***Burma*** [present / absent]
78 – ***Southeast Asia and the Pacific*** (Brazier and Franklin region 76) [present / absent]
  79 – ***Thailand, Laos, Vietnam, Cambodia (Indochina)*** [present / absent]
  80 – ***Indomalesia: Indonesia, Philippines, Malaysia, Brunei, Singapore, Papua New Guinea, and Solomon Islands*** [present / absent]
  81 – ***Pacific Islands (incl. New Caledonia, Samoa, Hawaii, and Fiji)*** [present / absent]
82 – ***Australia and New Zealand*** (Brazier and Franklin region 77) [present / absent]
  83 – ***Australia*** [present / absent]
  84 – ***New Zealand*** [present / absent]
85 – ***Tropical mainland Africa and adjacent islands*** (Brazier and Franklin region 78) [present / absent]
  86 – ***Tropical Africa*** [present / absent]
  87 – ***Madagascar & Mauritius, Reunion & Comores*** [present / absent]
88 – ***Southern Africa (south of the Tropic of Capricorn)*** (Brazier and Franklin region 79) [present / absent]
89 – ***North America, north of Mexico*** (Brazier and Franklin region 80) [present / absent]
90 – ***Neotropics and temperate Brazil*** (Brazier and Franklin region 81) [present / absent]
  91 – ***Mexico and Central America*** [present / absent]
  92 – ***Caribbean*** [present / absent]
  93 – ***Tropical South America*** [present / absent]
  94 – ***Southern Brazil*** [present / absent]
95 – ***Temperate South America incl. Argentina, Chile, Uruguay, and S. Paraguay*** (Brazier and Franklin region 82) [present / absent]

Section D – Non-anatomical features – hardwood only

Heartwood fluorescence

96 – ***Surface fluorescence colour*** [absent / basically yellow / basically green / other colours / variable]
97 – ***Surface fluorescence intensity*** [weakly fluorescent / strongly fluorescent / NA]

General comments:

Follow the procedures described in IAWA (1989).

Note: Only one softwood species, *Taiwania cryptomerioides* (Cupressaceae), is known to have fluorescent heartwood (weakly).

Heartwood extractives

98 – ***Water extract fluorescence*** [absent / basically blue / basically green / bluish-green / variable]
Follow the procedure described in IAWA (1989).

99 – ***Ethanol extract fluorescence*** [absent / basically blue / basically green / bluish-green / variable]
Follow the procedure described in IAWA (1989).

100 – ***Water extract colour*** [colourless / brown or shades of brown / red or shades of red / yellow or shades of yellow / other shades]

101 – ***Ethanol extract colour*** [colourless / brown or shades of brown / red or shades of red / yellow or shades of yellow / other shades]
Note: as a rule, extractives features are not used in softwood identification.

Heartwood froth test

102 – ***Froth after shaking in water*** [positive / weakly positive / negative]
Follow the procedure described in IAWA (1989).
Note: As a rule, the froth test is not used in softwood identification.

Heartwood burning splinter test

103 – ***Splinter burns to:*** [charcoal / partial ash / full ash (white) / full ash (yellow-brown) / full ash (other)]
Follow the procedure described in IAWA (1989).
Note: As a rule, the burning splinter test is not used in softwood identification.

Chrome Azurol-S test

104 – ***Chrome Azurol-S test*** [positive / negative]
Follow the procedure described in IAWA 1989.
Note: Historically, Chrome Azurol-S is not used in softwood identification.

Grain

105 – ***Interlocked grain*** [present]

Interlocked grain can be of common occurrence among tropical hardwoods, rare among those from temperate regions, and almost unknown in softwoods. Interlocked grain occurs when the axial elements are aligned at an angle to the vertical axis (spiral grain) but alternately in right-handed and left-handed helices over time, and is best observed when the wood is split in the radial plane. Because interlocked grain can be of sporadic occurrence in many taxa, its absence is not of diagnostic value, but it is commonly present in some taxa. The presence of other alterations of grain direction (*e.g.* wavy or spiral) are known to be unreliable for wood identification, except in rare cases of known mutant wood phenotypes (Fan *et al.* 2013).

Surface marks

106 – *Surface marks* [pith flecks / gum deposits / kino veins / pitch pockets]

Several agents can cause damage to the cambium (mining insects, woodpeckers, etc.), which can result in pith flecks, gum deposits, pitch pockets, or kino veins, depending on the taxon. These structures appear as dark brown oval or oblong spots in cross section and as intermittent streaks or cavities on longitudinal surfaces (Hoadley 1990).

Although typical of specific taxa, they can be of sporadic occurrence, therefore their absence is not of diagnostic value and should be treated as positive characters. Some species of *Eucalyptus* are known to produce kino veins in response to various injuries, and others do not form them (Eyles & Mohammed 2003).

Note: As a rule, pith flecks and gum deposits are not used in softwood identification.

CONCLUSION

Standardizing the nomenclature and character definitions is a critical first step in expanding the ease of use, practical relevance and effectiveness of macroscopic wood identification as a diagnostic instrument both within and outside the field's traditional boundaries.

By reviewing and trying to reconcile the most widely-used English-language sources, we provide a draft list of characters and definitions for macroscopic wood identification that we hope will serve as a basis for international discussion. A standard lexicon and illustrated glossary to describe wood at the macroscopic level will simplify the preparation of identification documents and permit the ready translation of keys and other references for easy use and deployment around the world.

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