INSIDEWOOD – A WEB RESOURCE FOR HARDWOOD ANATOMY

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SUMMARY

InsideWood is an Internet-accessible wood anatomy reference, research, and teaching tool. The InsideWood database has coded wood anatomical descriptions based on the IAWA List of Microscopic Features for Hardwood Identification and is accompanied by a collection of photomicrographs. As of November 2010 there were over 5,800 descriptions and 36,000 images of modern woods, and over 1,600 descriptions and 2,000 images of fossil woods. CITES-listed timber species and other endangered woody plants are included in this digital collection hosted by North Carolina State University's library. This web site has value in helping with wood identification because it has a multiple entry key that allows searching by presence or absence of IAWA features and it serves as a virtual reference collection whereby descriptions and images can be retrieved by searching by scientific or common name or other keywords.

Key words: Wood identification, InsideWood, hardwoods, photomicrographs, CITES, digital collection.

HISTORY

The starting point for the InsideWood database was the information recorded on marginally perforated Oxford cards when data were being gathered for "Anatomy of the Dicotyledons" (Clarke 1938; Metcalfe & Chalk 1950). This dataset used 86 features, and was computerized in 1981 for searching on a mainframe (Pearson & Wheeler 1981). Subsequently, information from various sources was added (*e.g.*, Brazier & Franklin 1961; Normand & Paquis 1976; Détienne & Jacquet 1983; post-1950 publications listed by Gregory 1980, 1994, and observations of slides in the David A. Kribs wood collection of North Carolina State University). The database was formatted so that it could be searched by the GUESS program for PCs and was distributed on diskette (Wheeler *et al*. 1986; LaPasha & Wheeler 1987).

In the late 1990's the 86-feature database was translated into the "IAWA List of Microscopic Features for Hardwood Identification" (IAWA Committee 1989). Many features had to be recorded as unknown (feature number followed by the symbol "?") because there was no information on that feature in the Oxford list. Over the last 20 years information on many of these "unknown" features has been added so that many "?" have been changed to "present", "absent", or "variable". Some features (disjunctive ray parenchyma, vessel-ray parenchyma pits restricted to marginal rows) remain "problematic", as their presence or absence is not mentioned in many descriptive wood

anatomy publications and they are features difficult to see in the photographs of most wood anatomical atlases. For instance, disjunctive ray parenchyma (feature 113) is recorded present for only 106 descriptions in InsideWood, but this feature is likely to be far more common. Information on the non-anatomical features (heartwood color and fluorescence, color and fluorescence of water and ethanol extracts, froth test, chrome-azurol-S test, and burning splinter) remains incomplete, although it is recorded for some commercially important woods.

With the advent of the World Wide Web, a natural progression was to make the database internet accessible and to add images. With the support of the N.C. State Libraries and two grants from NSF, InsideWood was created and made available on-line in 2004 (http://insidewood.lib.ncsu.edu). The highly collaborative network of IAWA members generously provided most of the images that are such an essential part of InsideWood.

INSIDEWOOD CONTENT

The modern wood database has more than 5,800 descriptions, including representatives of over 200 woody plant families and information on the anatomy of trees, shrubs, and vines. Coverage is worldwide. These 5,800+ descriptions represent at least 7,000 species. Many of the descriptions are based on wood anatomical surveys of families that had descriptions for entire genera, or species groups within a genus. Also, in some genera many species have similar wood anatomy, so that a single description applies to species groups, *e.g.*, the red oaks and white oaks. Currently, 649 descriptions are for "spp.". For instance, there is a description for "*Aceratium* spp." based on a generic description by Gasson (1996) and a description for "*Curtisia* spp." based on a generic description by Noshiro and Baas (1998).

An important part of InsideWood is the 36,000+ image collection, which includes contributions from over 15 individuals and institutions (see Acknowledgements section of InsideWood on the web). Some, but not all, of these images are attached to descriptions. Many images are scans of 35 mm film negatives and do not have scale bars.

Recent digital images with scale bars include images contributed by Frederic Lens, the PROTA woods (Peter Gasson), native U.S. woods and others I have photograph-ed. These images can be found by searching for the contributor's names.

More than 3,000 species are represented in the InsideWood collection only by images without accompanying descriptions. Conversely, not all descriptions have accompany-ing images.

CAUTIONS

It is important to remember that while InsideWood is a large database there are thousands of species not included. Moreover, most descriptions are based on but a few samples and so cannot reflect the entire range of variation of that species. Not all descriptions are based on vouchered wood samples, and there is always the possibility that some woods may not have been correctly identified and were added to wood collections

under incorrect names and subsequently described in the literature. It is also well to remember that trees are large organisms and slides prepared for studying their microscopic anatomy only show tiny portions of them (cf. Wheeler & Baas 1998) and, as pointed out by Gasson (this issue), it usually is only practical to identify an isolated piece of wood to genus.

USING INSIDEWOOD

As with any other key, a prerequisite for using the InsideWood multiple entry key or interpreting its data is a familiarity with the terms, in this case, the microscopic anatomy of hardwoods and the definitions of features of the IAWA Hardwood List (IAWA Committee 1989).

With increased awareness of the need for responsible trading of timber and following CITES regulations, wood identification has gained in importance. Nearly a century ago Bailey (1917) noted that identifying commercial timbers needed to be done quickly as large numbers of samples often had to be examined and so only obvious macroscopic characters were practical to use. Recent guides to CITES timbers take that practical approach and highlight and illustrate obvious features visible with a handlens or to the naked eye (Miller *et al*. 2002; Richter *et al*. 2008; Koch *et al*. 2008a, 2008b; this issue). InsideWood with its emphasis on microscopic features can complement these publications by providing information on additional features of CITES-listed species as well as descriptions of species with anatomy similar to CITES species.

There are many useful keys, printed and electronic, to commercially important woods and woods from particular geographic regions or families (*e.g*., Richter & Dallwitz 2000-onwards; the FFPRI Database of Japanese Woods; Neumann *et al*. 2000; for a list of older keys see Wheeler & Baas 1998). Using these relatively small keys will work for identifying most unknowns. However, if the geographic origin of a wood is unknown or if the wood is geologically ancient (fossil wood), searching the large InsideWood database is useful because of its broad coverage. Fossil woods may be from extinct species or genera and often are related to taxa that occur on other continents; InsideWood can help with determining with which present-day families and genera these fossils may be related.

The InsideWood web resource shows its parentage as a continuation of a key based on using marginally perforated cards. Each description in InsideWood is equivalent to one of the cards in the stack of cards used in a multiple entry key. When sorting through the cards, feature-by-feature, the objective often was to get to a relatively short list of species, rather than to a single name. It was up to the key user to decide when the number of cards left was small enough so that it was practical to proceed to doing comparative work to determine and verify an identification. The same is true for InsideWood; it is good for generating lists of possibilities. A frustrating reality of wood identification is that some genera and species have similar anatomy and cannot be separated from one another. When you start an unknown identification, the unknown wood may be one that cannot be identified to species, species group, or a single genus. At the onset, it is difficult to know to what level an unknown can be identified.
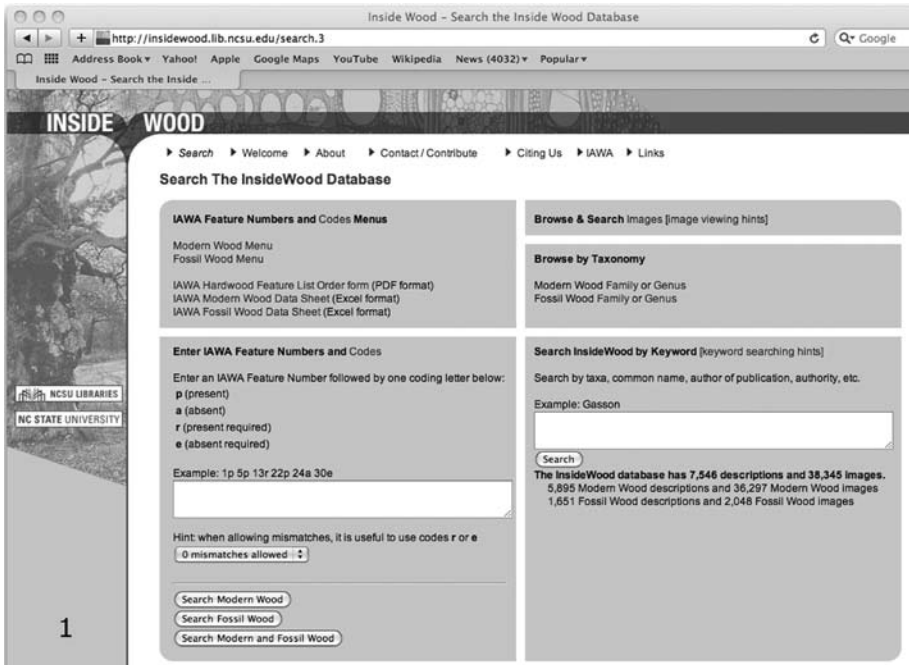
Figure 1. InsideWood screen showing search options.

Search Options in InsideWood (Fig. 1 shows opening search page)
For identification of an unknown or determining the incidence of wood anatomical features

1) Choose the IAWA Hardwood feature menu and the pull-down options to score for presence or absence of features (Fig. 2). Absence of features often is as important as the presence of features for identifying a wood.

2) Choose to directly enter feature numbers followed by codes for presence or absence (Fig. 1, bottom left option). This option may be more convenient for those familiar with the IAWA Hardwood feature numbers and who fill out IAWA hardwood list datasheets for an unknown.

These first two options return lists of species with descriptions with the numbers of the IAWA Hardwood features present listed (Fig. 3). Each description can be expanded to see the feature definitions and the thumbnails of any images associated with that description (Fig. 4). At the end of the description, references used to create or edit the description are listed and at times comments are included on anatomical details not covered by the IAWA Hardwood feature list. In all cases and especially if only one or fewer than 10 names are returned, it is important to verify the suggested identification by examining reliably identified samples in a wood collection or in a wood anatomical pictorial atlas or other literature. Enlarging the thumbnails (requires having the web browser set to allow pop-up windows) to view details of a description's accompanying images is useful. Multiple image windows can be open at one time so that details of different species can be compared.

Figure 2. Menu for selecting features to search.

Figure 3. Results screen, features used in a search are shown at the top, descriptions with images have a camera icon next the them.

Figure 4. Portion of a screen with a single description, thumbnails of images at the top, each image can be enlarged and viewed in a separate screen which can be kept open for comparison to other enlarged images.

Note: The problems with wood identification and the reasons for not reaching an accurate identification are the same for wood as those long recognized for any biological material (Pankhurst 1978) and include: 1) An inadequate basis for comparison because a) the unknown lacks critical features, as in decayed wood or poorly preserved fossil wood, or b) an inadequate reference base, because not all species are included in a key and the full range of variability of a taxon might not be known, and 2) Difficulty in using keys because of errors in feature recognition, either incorrectly interpreting a feature in an unknown because of the observer's lack of background or training, or interpreting a feature differently from the way a key constructor intended.

Retrieving information

3) Searching the image collection. The bulk of the images are ones taken with compound light microscopes, but there are some macroscopic images as well, *e.g.* images of samples in the Utrecht wood collection taken by L.Y.T. Westra. The image collection can be searched by family, species, photographer, common names, and institutional affiliation of the photographer, wood collection abbreviation, section illustrated, and combinations thereof.

4) Browsing by scientific name, family or genus. Names are listed in alphabetical order. This search returns species with descriptions (with associated images if available) as well as species only with images. If you have used options 1 or 2 to try to identify an unknown, it can be useful to search on generic names so as to view images of other species in the genera that were suggested as matches for an unknown.

5) Searching by keywords, singly or in combination. This includes scientific name, common name, references, wood collection, all of the IAWA features, and any phrase or word used in an annotation.

Examples of such searches would be:

a) For a single word, *e.g.*, PROTA to retrieve species descriptions done for the Plant Resources of Tropical Africa project, CITES for descriptions of CITES-listed species, Mennega to get descriptions based on publications by A.M.W. Mennega or photographs she took, Lens to get a list of woods whose descriptions include information from Lens's publications (*e.g.*, Lens *et al.* 2004, 2007).

b) For multiple terms, *e.g.*, Meliaceae *and* Africa to get a list of the African members of the mahogany family, PROTA *and* Icacinaceae to get a list of woods of the Icacinaceae described as part of the PROTA project, Rosaceae *and* "multiple perforation plates" for a list of Rosaceae with feature 19, note that if you do a keyword search for Rosaceae *and* 19, this retrieves not only descriptions with feature 19, but all Rosaceae with any feature in the 190s such as habit, commercial importance, specific gravity, or color categories.

Suggestions on Search Strategies for Identifying an Unknown

Only use features whose presence or absence you are sure of. Because InsideWood includes shrubs and vines as well as trees, if it is obvious the wood is from a tree, *e.g.*, a sample from a large board, be sure to use that feature (code 189p or 189r). I usually begin by using presence or absence of fewer than 10 features.

Some features are not common in hardwoods as a whole and so, if used in a search, can quickly reduce the number of possible matches. An analysis of the InsideWood database gives the frequency occurrence of the different hardwood list features (Wheeler *et al.* 2007a). Features that occur in fewer than 10 % of the database include: ring porous, semi-ring porous, vessels arranged in tangential bands, vessels arranged in a dendritic pattern, vessel clusters common, intervessel pits scalariform, sclerotic tyloses, axial parenchyma bands more than three cells wide, fusiform axial parenchyma cells, rays with the multiseriate portions as wide as uniseriate portions, aggregate rays, radial canals, laticifers or tanniferous tubes, all rays storied, prismatic crystals in chambered upright and/or square ray parenchyma cells, prismatic crystals in non-chambered axial parenchyma cells, prismatic crystals in enlarged cells, and silica bodies present.

Be willing to be flexible. If no matches are found for an unknown or if too many matches are found, choose "Refine Menu Selections" and search again.

If a search returns "No results found for search criteria … Please try a different search", one way of refining the unknown's description would be to allow one mismatch, in other words, get a list of species that have all but one of the features in the unknown's

description. When allowing mismatches it is advisable to require the presence or absence of features you are sure you have interpreted correctly. For instance, specifying that the results include only those species that have simple perforation plates (13r) and alternate intervessel pitting (22r) by coding r for required present, and species without homocel-lular rays (104e) by coding e for required absence (see Fig.1). When mismatches are allowed, the mismatched feature/s will be shown in the search results.

When evaluating the results of a search it is helpful to appreciate which features may be variable within a species or might be interpreted or measured differently by different anatomists. If these variable features are among the mismatched features, they would not be a basis for discounting that species as a match. Such features include distinct or indistinct growth rings (a special problem for tropical woods), presence or absence of crystals, ray widths (exclusively uniseriate in some samples of a species, feature 96, and 1–3-seriate in other samples, feature 97).

If an overwhelming number of matches are found, enter more features. The search program for InsideWood does not suggest which features might be useful in separating species in a long list. However, it is possible to export description results to a spread-sheet and then to sort by feature. To do so, first, check the box for "select all description results" on the output screen or check boxes next to individual descriptions of species that your experience suggests are reasonable matches. After you do that, you will see at the left hand top of the page "View/Export Selected Results" and after clicking on that you will see the species lists that you can e-mail in tsv format. When the list is received it can be renamed to be an Excel file or opened from within Excel, and the descriptions can be sorted by feature.

The export function is most useful for long lists, not for 10 or fewer species. When there are only a few species that match the search criteria, it is easier to print the page/s to examine them.

THE USE AND IMPACT OF INSIDEWOOD

An application that the N.C. State library uses to track electronic databases shows that InsideWood is used worldwide. This application does not show individual e-mails or names, but users' locations, as well as other web page statistics, such as numbers of pages viewed and duration of visit. Figure 5 is a "Geo Map Overlay" for October 2010 that shows 500 of the 721 locations where InsideWood was used (the maximum number of locations that can be shown on the map is 500). It is hard not to wonder who these users are and for what projects they are using InsideWood. How many of these users are at universities or research institutes, how many are consultants, forensic scientists, antique dealers, or customs agents, and how many are serious amateurs and wood collectors looking for information? Admittedly, the bulk of these dots represent only 1–3 visits of viewing only 1–3 pages, but many dots represent serious users. For the first two weeks of November 2010, a selection of the activity from 12 locations follows: La Victoria, Peru, 54 visits with an average of 18 pages viewed/visit; Cor-rientes, Argentina, 10 visits averaging 79 pages/visit; Denver, Colorado, USA, 24 visits averaging 15 pages/visit; Madison, Wisconsin, USA, 62 visits averaging 42
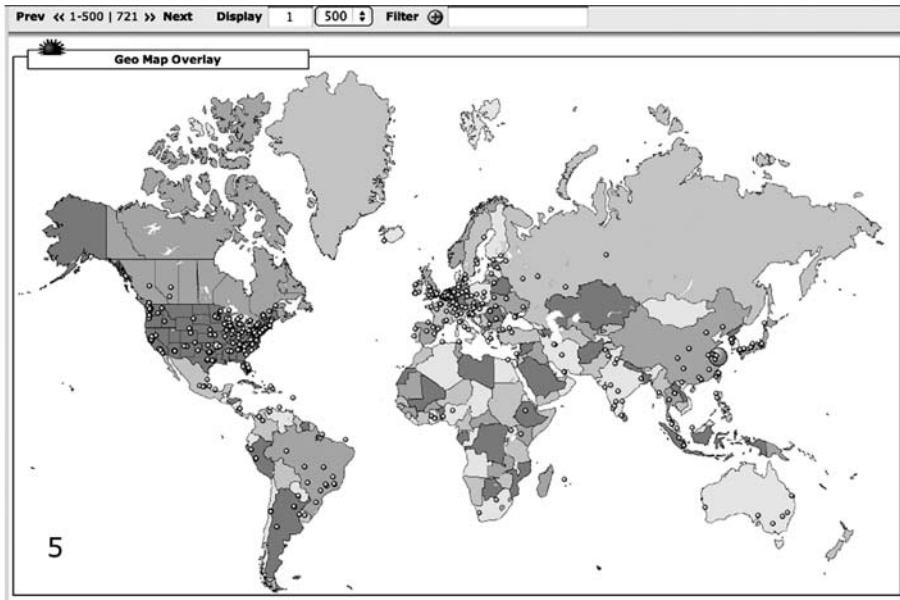
Figure 5. Geomap showing location of InsideWood users during October 2010.

pages/visit; Paris, France, 56 visits averaging 28 pages/visit; Moscow, Russia, 76 visits averaging 31 pages/visit; Ankara, Turkey, 8 visits averaging 33 pages/visit; Tokyo, Japan, 119 visits averaging 47 pages/visit; Nanjing, China, 34 visits averaging 28 pages/visit; Tehran, Iran, 18 visits averaging 19 pages/visit; Azerbaijan, 2 visits averaging 94 pages/visit; Zambia, 12 visits, averaging 34 pages/visit. Statistics for the months of January–October indicate that InsideWood use increased from 2009 to 2010; as shown by summing the number of locations visits come from during a month (6383 in 2010, 5460 in 2009, an increase of 17%) and by the number of visits where more than 20 pages are viewed (6925 in 2010 vs. 6053 in 2009, an increase of 14%).

Some of InsideWood's uses are shown by citations in publications in archeology (*e.g.*, Jiang *et al.* 2009; Froyd *et al.* 2010) and paleobotany (*e.g.*, Wheeler *et al.* 2007b; Estrada-Ruiz *et al.* 2010; Pan 2010) where InsideWood is used to help identify woody remains, global analyses of functional traits where InsideWood is a source of data on the frequency and distribution of wood anatomical features (*e.g.*, Westoby & Wright 2006; Boura & DeFranceschi 2007; Chave *et al.* 2009; Zanne *et al.* 2010), systematic, ecologic and physiologic wood anatomy where it has been used as a source of information on the characteristics of particular taxa (Gupta & Agarwal 2008; DeMicco & Aronne 2009; Rabney *et al.* 2010). Ruffinato *et al.* (2010) and Heady *et al.* (2010) used InsideWood in combination with the IAWA Hardwood list as an analytical tool for the study and restoration of cultural heritage. Papers in this issue cite the intensive use of InsideWood in identifying timbers suspected to be from illegally logged or traded species (Gasson 2011).

FUTURE OF INSIDEWOOD

InsideWood is fortunate to be treated as a digital collection within a university library (North Carolina State University libraries). For now, this is as safe a site for a web resource as is imaginable because library IT staff are charged with maintaining on-line databases in the library's collections, consistent with their broad mission to provide information to the public and the university community.

InsideWood is not a static resource. Although external funding for InsideWood ended in 2007, editing of the database has continued. New images and descriptions have been added. Existing descriptions have been edited and corrected as additional information became available. The editing interface allows adding comments to the descriptions, *e.g.* giving exact values for quantitative features, noting that uniseriate rays are rare or that there are more than ten chambers in chambered crystalliferous axial parenchyma strands. Library colleagues Shirley Rodgers (co-PI on the NSF grants) and Cristyn Kells developed a password-protected editing interface that allows editing of all parts of the database.

Additions to InsideWood during 2010 include data for the 134 African species examined during the workshop for PROTA Timber Volume II, images from R.B. Miller and Pierre Détienne's (2001) atlas of Guyana woods, and descriptions based on new publications about fossil and modern wood (Bosio *et al*. 2010; Choi *et al*. 2010; Cosmo *et al*. 2010; Estrada-Ruiz *et al*. 2010; Feng *et al*. 2010; Franco & Brea 2010; Rebollar-Domínguez & Tapia-Torres 2010).

The links section of InsideWood provides access to some instructional material for wood anatomy, but additional tutorials on wood anatomy in general and how to use the InsideWood site in particular are needed. Such material could include podcasts or videos posted on the web and pdfs of instructional slide sets. There is a facebook page for InsideWood with posts on updates to the site. Suggestions for other ways of increasing wood anatomy literacy are welcome.

A REQUEST TO WOOD ANATOMISTS AND INSIDEWOOD USERS

The "Contact/Contribute" option on the InsideWood menu is a means of sending corrections, additional information, and references that might be useful for adding or editing descriptions. Please do so, this is important to improving the quality of the data and the coverage of the database. If you are able to provide images of reliably identified and vouchered specimens, please contact me. Also, it would help the library in justifying housing this resource if anyone who uses InsideWood could now and then e-mail details of how InsideWood has been of value to them.

ACKNOWLEDGMENTS

REFERENCES

Bailey, I.W. 1917. The role of the microscope in the identification and classification of the timbers of commerce. J. Forestry 15 (2): 1–13 [III plates].

Bosio, F., P. Soffiatti & M.R. Torres Boeger. 2010. Ecological wood anatomy of *Miconia sellowiana* (Melastomataceae) in three vegetative types of Paraña State, Brazil. IAWA J. 31: 179–190.

Boura, A. & D. DeFranceschi. 2007. Is porous wood structure exclusive of deciduous trees? Comptes Rendus - Palevol 6: 385–391.

Brazier, J.D. & G.L. Franklin. 1961. Identification of hardwoods. A microscope key. Forest Products Research Bulletin No. 46, 96 pp.

Chave, J., D. Coomes, S. Jansen, S.L. Lewis, N.G. Swenson & A.E. Zanne. 2009. Towards a worldwide wood economics spectrum. Ecology Letters 12: 351–366.

Choi, S-K., K. Kim, E-K. Jeong, K. Terada, M. Suzuki & H. Uematsu. 2010. Fossil woods from the Miocene in the Yamagata Prefecture, Japan. IAWA J. 31: 95–117.

Clarke, S.H. 1938. A multiple-entry perforated-car key with special reference to the identification of hardwoods. New Phytologist 38: 369–374.

Cosmo, N.L., Y.S. Kuniyoshi & P.C. Botosso. 2010. Wood anatomy of *Sebastiania commersoniana* (Baillon) Smith & Downs (Euphorbiaceae): functional and ecological aspects. Acta Botanica Brasilica 24: 747–755.

DeMicco, V. & G. Aronne. 2009. Seasonal dimorphism in wood anatomy of the Mediterranean *Cistus incanus* L. subsp. *incanus*. Trees 23: 981–989.

Détienne, P. & P. Jacquet. 1983. Atlas d'identification des bois de l'Amazonie et des régions voisines. Centre Technique Forestier Tropical, Nogent s/Marne. 640 pp.

Estrada-Ruiz, E., H.I. Martínez-Cabrera & S.R.S. Cevallos-Ferriz. 2010. Upper Cretaceous woods from the Olmos Formation (Late Campanian-Early Maastrichtian), Coahuila, Mexico. Amer. J. Bot. 97: 1179–1194.

Feng, Xin-Xin, Tie-Mei Yi & Jian-Hua Jin. 2010. First record of *Paraphyllanthoxylon* from China. IAWA J. 31: 89–94.

FFPRI Wood Identification Database Team. 2004. Database of Japanese woods. http://f030091. ffpri.affrc.go.jp/index-E1.html

Franco, M.J. & M. Brea. 2010. *Microlobiusxylon paranaensis* gen. et sp. nov. (Fabaceae, Mimosoideae) from the Pliocene-Pleistocene of Ituzaingo Formation, Parana Basin, Argentina. Rev. Bras. Paleontol. 13: 103–114.

Froyd, C.A., J.A. Lee, A.J. Anderson, S.G. Haberle, P.E. Gasson & K.J. Willis. 2010. Historic fuel use in the Galápagos Islands: identification of charred remains. Veget. Hist. Archaeobot. 19: 207–217.

Gasson, P. 1996. Wood anatomy of the Elaeocarpaceae. Pp 47–71 in L.A. Donaldson, A.P. Singh, B.G. Butterfield & L.H. Whitehouse (eds.), Recent Advances in Wood Anatomy. New Zealand Forest Research Institute Limited.

Gasson, P. 2011. How precise can wood anatomy be? Wood anatomy's role in support of the legal timber trade, especially CITES. IAWA J. 32 [this issue]: 137–154.

Gregory, M. 1980. Wood identification: an annotated bibliography. IAWA Bull. n.s. 1: 3–41.

Gregory, M. 1994. Bibliography of systematic wood anatomy of dicotyledons. IAWA Journal, Supplement 1.

Gupta, S. & M. Agarwal. 2008. Wood anatomy of Anacardiaceae from India with special reference to the systematic position of *Rhus*. IAWA J. 29: 79–106.

Heady, R.D., G.N. Peter & P.D. Evans. 2010. Identification of the woods to make the Riley cabinet – A historically-significant example of early Australian, convict-built, furniture. IAWA J. 31: 385–397.

IAWA Committee. 1989. IAWA list of microscopic features for hardwood identification IAWA Bull. n.s. 10: 219–332.

Jiang, H-E., Y-B. Zhang, X. Li, Y-F. Yao, D.K. Ferguson, E-G. Lu & C-S. Lin. 2009. Evidence for early viticulture in China: proof of a grapevine (*Vitis vinifera* L., Vitaceae) in the Yanghai Tombs, Xinjiang. J. Archaeol. Sci. 36: 1458–1465.

Koch, G., H.G. Richter & U. Schmitt. 2008a. CITES and wood data bases: computer-aided identification and description of CITES protected trade timbers. Landbauforschung vTI agriculture and forestry research - Sonderheft, Band 321: 61–66 (in English).

Koch, G., H.G. Richter & U. Schmitt. 2008b. Computer-aided identification and description of CITES protected trade timbers. Bois et Forêts des Tropiques N° 297 (3): 69–73.

Koch, G., H.G. Richter & U. Schmitt. 2011. Design and application of CITES*woodID* – Computer-aided identification and description of CITES-protected timbers. IAWA J. 32 [this issue]: 213–.220.

LaPasha, C.A. & E.A. Wheeler. 1987. A microcomputer based system for computer-assisted wood identification. IAWA Bull. n.s. 8: 347–354.

Lens, F., J. Schönenberger, P. Baas, S. Jansen & E. Smets. 2007. The role of wood anatomy in phylogeny reconstruction of Ericales. Cladistics 23: 229–254.

Lens, F., E. Smets & S. Jansen. 2004. Comparative wood anatomy of Andromedeae s.s., Gaulterieae, Lyonieae and Oxydendreae (Vaccinioideae, Ericaceae, s.l.). Bot. J. Linn. Soc. 144: 161–179.

Metcalfe, C.R. & L. Chalk. 1950. Anatomy of the Dicotyledons. 2 Vol. Clarendon Press, Oxford.

Miller, R.B. & P. Détienne. 2001. Major timber trees of Guyana. Tropenbos International, Wageningen, 218 pp.

Miller, R., A. Wiedenhoeft & M-J. Ribeyron. 2002. CITES Identification Guide – Tropical Woods. Guide to the Identification of Tropical Woods Controlled under the Convention on International Trade in Endangered Species of Wild Fauna and Flora. Wildlife Enforcement and Intelligence Division, Enforcement Branch, Environment Canada.

Neumann, K., W. Schoch, P. Détienne & F.H. Schweingruber. 2000. Woods of the Sahara and the Sahel. An anatomical atlas. Eidg. Forschungsanstalt WSL, Birmensdorf, Verlag Paul Haupt.

Normand, D. & J. Paquis. 1976. Manuel d'identification des bois commerciaux. Tome 2. Afrique guinéo-congolaise. Centre Technique Forestier Tropical, Nogent s/Marne, 335 pp.

Noshiro, S. & P. Baas. 1998. Systematic wood anatomy of Cornaceae and its allies. IAWA J. 19: 43–97.

Pan, A.D. 2010. Rutaceae leaf fossils from the Late Oligocene (27.23 Ma) Guang River flora of northwestern Ethiopia. Rev. Palaeobot. Palynol. 159: 188–194.

Pankhurst, R.J. 1978. Biological identification. The principles and practice of identification methods in biology. University Park Press, Baltimore.

Pearson, R.G. & E.A. Wheeler. 1981. Computer identification of hardwood species. IAWA Bull. n.s. 2: 37–40.

Rabney, D., F. Lens & E. Smets. 2010. The phylogenetic significance of vestured pits in Bora-ginaceae. Taxon 59: 510–516.

Rebollar-Domínguez, S. & N.A. Tapia-Torres. 2010. Anatomía de la madera de dos especies de *Eugenia* (Myrtaceae) de Quintana Roo, México. Madera y Bosques 16: 85–98.

Richter, H.G. & M.J. Dallwitz. 2000-onwards. Commercial timbers: descriptions, illustrations, identification, and information retrieval. In English, French, German, and Spanish. Version: 18th October 2002. http://www.biologie.uni-hamburg.de/b-online/wood/html

Richter, H.G., K. Gembruch & G. Koch. 2008. Software program: CITESwoodID version 1.0. BFH German Federal Agency for Nature Conservation, Berlin.

Ruffinato, F., M. Macchioni, G. Boeto, P. Baas & R. Zanuttini. 2010. Reflected light microscopy as a non-invasive identification tool for wooden artefacts. IAWA J. 31: 317–331.

Westoby, M. & I.J. Wright. 2006. Land-plant ecology on the basis of functional traits. Trends in Ecology & Evolution 21: 261–268.

Wheeler, E.A. & P. Baas. 1998. Wood identification – a review. IAWA J. 19: 241–264.

Wheeler, E.A., P. Baas & S. Rodgers. 2007a. Variations in dicot wood anatomy: a global analysis based on the InsideWood database. IAWA J. 28: 229–258.

Wheeler, E.A., R.G. Pearson, C.A. LaPasha, W. Hatley & T. Zack. 1986. Computer-aided wood identification. Station Bulletin No. 474, N.C. Ag. Res. Serv., Raleigh, N.C., 160 pp.

Wheeler, E.A., M.C. Wiemann & J.G. Fleagle. 2007b. Woods from the Miocene Bakate Formation, Ethiopia: anatomical characteristics, estimates of original specific gravity and ecological inferences. Rev. Palaeobot. Palynol. 146: 193–207.

Zanne, A.E., M. Westoby, D.S. Falster, D.A. Ackerly, S.R. Loarie, S.E.J. Arnold & D. Coomes. 2010. Angiosperm wood structure: global patterns in vessel anatomy and their relation to wood density and potential conductivity. Amer. J. Bot. 97: 207–215.