Identification of endangered or threatened Costa Rican tree species by wood anatomy and fluorescence activity

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Abstract: Identificación de especies de árboles en peligro o amenazadas de Costa Rica basada en la anatomía de la madera y fluorescencia. A total of 45 native Costa Rican tree species are threatened or in danger of extinction, but the Convention on International Trade Endangered Species (CITES) includes only eight of these in its Appendices. However, the identification of other species based on their wood anatomy is limited. The present study objective was to describe and to compare wood anatomy and fluorescence activity in some endangered or threatened species of Costa Rica. A total of 45 (22 endangered and 23 threatened with extinction) wood samples of these species, from the xylaria of the Instituto Tecnológico de Costa Rica and the Forest Products Laboratory in Madison, Wisconsin, were examined. Surface fluorescence was positive in eight species, water extract fluorescence was positive in six species and ethanol extract fluorescence was positive in 24 species. Almost all species were diffuse porous except for occasional (*Cedrela odorata*, *C. fissilis*, *Cordia gerascanthus*) or regular (*C. salvadorensis* and *C. tonduzii*) semi-ring porosity. A dendritic vessel arrangement was found in *Sideroxylon capari*, and pores were solitary in *Guaiacum sanctum* and *Vantanea barbourii*. Vessel element length was shortest in *Guaiacum sanctum* and longest in *Humiriastrum guianensis*, *Minquartia guianensis* and *Vantanea barbourii*. Finally, anatomical information and fluorescence activity were utilized to construct an identification key of species, in which fluorescence is a feature used in identification. Rev. Biol. Trop. 61 (3): 1133-1156. Epub 2013 September 01.

Key words: fluorescence, Costa Rican woods, tropical woods, wood identification key.

For its size (51 000km^2) Costa Rica is one of the most biodiverse countries in the world. Of its 10 000 plant taxa, 1 300 are endemic and more than 25% of these are considered rare (Burger 1980). Nonetheless, intensive deforestation began at the start of the twentieth century, and reached levels in excess of 50 000ha per year in the 1970s (Alvarez 1986). Natural forest decreased to only 24.4% by 1987 (Sánchez *et al*. 2001).

Tree timber species receive the highest degree of protection, and two actions are used to protect them: the promulgation of laws and government decrees to stop the cutting of 18 commercial species (Costa Rica 1997) protected by international conventions such as CITES, and actions limiting harvesting in certain areas of the country (Costa Rica 1996a, 1996b). A number of important timber-producing species have been identified by some experts as threatened species due to their rarity (Jimenez 1999). Identification of these timber-producing species using floral and tree characteristics has been widely described (Jimenez 1999). In contrast, identification of these species based on their wood anatomy is limited to only a few species: examples are the species included in CITES Appendices I and II. The CITES Identification Guide-Tropical Wood (CITES 2002) has a general identification key with illustrations of the transverse sections of each species. The book is intended for non-experts (Gasson *et al*. 2010) and its use is limited. More recently, the International Association of Wood Anatomists (IAWA) published several wood descriptions of tree timbers included in CITES (Gasson 2011, Gasson *et al*. 2011).

Recently, wood anatomical identification has been accompanied by other analyses that together with special methods, can achieve precise identification that are useful in identification of endangered or threatened species. Some of these techniques are relatively easy to implement, for example, wood density, surface fluorescence, or fluorescence of water or ethanol extracts. (Miller & Wiemann 2006, Guzman *et al*. 2008, Wiemann & Ruffinatto 2012). Studies of anatomical features accompanied with complex statistical procedures, such as the use of multivariate analysis, helps to identify CITES species (Gasson *et al*. 2010, MacLanchlan & Gasson 2010).

The objective of the present study was to describe and compare wood anatomy, fluorescence, and density of endangered or threatened species of Costa Rica, and to use these characteristics to build an identification key. The key will allow monitoring of the use and commercialization of these tree species (endangered or threatened) in Costa Rica, and perhaps will be also useful to other countries in the region.

MATERIAL AND METHODS

Wood samples and permanent slides: A total 45 timber species growing in Costa Rica were analyzed from March to December of 2010, 22 of which are considered as endangered species by the Costa Rican Government (Costa Rica 1996a and 1996b, Costa Rica 1997) (Table 1). Another 23 timber species studied are considered to be in threat of extinction in this country (Jimenez 1999) (Table 2). Wood samples of all the species were obtained from the Forest Products Laboratory (FPL), Wisconsin-USA collection (MADw and SJRw) and the Instituto Tecnológico de Costa Rica (ITCR) collection (TECw). Their sample numbers are detailed in tables 1 and 2. In some cases only one sample and slide was available, so it was necessary to prepare additional permanent slides of these species. To do this, a block (1cm^3) was obtained from a wood sample and was softened in hot water. Tangential, radial and transverse sections were cut (12-15µm thick). These sections were stained with safranin and dehydrated with a series of alcohol (5 minutes each in 50, 70 and 95%); finally, sections were rinsed and mounted on microscope slides. Furthermore, a small piece was cut from each wood block to prepare macerated wood using Franklin's method (Ruzin 1999).

Wood anatomical description: The IAWA list (IAWA 1989) was used as the basis for choosing identification characteristics, with some modifications to allow for increased accuracy and subsequent species level separation. The quantitative anatomical features that were measured were: length and diameter of the fibers, lumen diameter, cell wall thickness, vessel length, diameter and frequency of pores, solitary pore frequency, diameter of intervessel pits, and height and width of rays. Fiber dimensions and vessel lengths were measured on macerated wood. Permanent slides were used for measurement of the other anatomical characters. Qualitative anatomical features were also determined using the IAWA List as a guide (IAWA 1989).

Additional information: Other important information about endangered or threatened species used was: endemic category if the species grows only in Costa Rica, wood density, traditional uses of species, and fluorescence. Wood density (weight/volume) was measured in the air-dry condition. The four traditional uses considered were light or heavy construction, flooring, furniture, and handicrafts. Heartwood fluorescence was observed directly the surface, in water extract, and in ethanol extract,

TABLE 1
Endangered timber species in Costa Rica (decreed by government)

Botanical Family	Species	Wood species	Endemic	Traditional used of wood	Wood density* (g/cm^3)	Wood samples observed	Permanent slides observed
Boraginaceae	*Cordia gerascanthus* L.	Angiosperm	No	Fu & LC	0.72	6	6
Caesalpiniaceae	*Sclerolobium costaricense* Zamora & Poveda	Angiosperm	Yes	HC & Fl	0.74	1	1
Caryocaraceae	*Anthodiscus chocoensis* Prance	Angiosperm	Yes	HC	0.88	1	1
Lauraceae	*Caryodaphnopsis burgeri* N. Zamora & Poveda	Angiosperm	Yes	HC	0.78	1	1
Lecythidaceae	*Couratari scottmorii* Prance	Angiosperm	Yes	HC	0.79	2	1
Meliaceae	*Cedrela fissilis* Vell.	Angiosperm	No	Fu & H	0.54	7	7
	Cedrela salvadorensis Standl.	Angiosperm	No	Fu & H	0.56	2	2
	Swietenia humilis Zucc.	Angiosperm	No	Fu & H	0.75	6	6
	Swietenia macrophylla King	Angiosperm	No	Fu & H	0.60	7	12
Mimosaceae	*Parkia pendula* Benth.	Angiosperm	No	LC	0.59	7	5
Papilionaceae	*Dipteryx panamensis* (Pittier) Record & Mell	Angiosperm	No	HC & Fl	0.85	1	3
	Hymenolobium mesoamericanum H.C. Lima	Angiosperm	No	LC	0.70	1	1
	Myroxylon balsamum (L.) Harms	Angiosperm	No	HC & Fl	0.91	7	7
	Paramachaerium gruberi Briz.	Angiosperm	Yes	HC	0.82	2	2
	Platymiscium curuense N. Zamora & Kiitgaard	Angiosperm	Yes	Fu, Fl & H	0.78	1|	1
	Platymiscium parviflorum Benth.	Angiosperm	No	Fu, Fl & H	0.79	1	1
	Platymiscium pinnatum var. *polystachyum* (Jacq.) Dugand	Angiosperm	Yes	Fu, Fl & H	0.80	1	1
	Platymiscium pinnatum (Jacq.) Dugand	Angiosperm	No	Fu, Fl & H	0.78	5	2
Podocarpaceae	*Podocarpus costaricensis* de Laub.	Gymnosperm	Yes	Fu	0.57	2	1
	Podocarpus guatemalensis Standl.	Gymnosperm	No	Fu	0.51	7	3
	Podocarpus macrostachys Parl.	Gymnosperm	No	Fu	0.55	6	7
Zygophyllaceae	*Guaiacum sanctum* L.	Angiosperm	No	HC, Fl & H	1.06	7	9

Source: Law decree No. 23700-MINAE, No. 25167-MINAE and No. 25663-MINAE.
Legend * Wood density was determined at 12% of moisture content.
LC=Light construction, HC=Heavy construction, Fl=flooring, Fu=furniture and H=handicrafts.

TABLE 2

Timber species considered to be in threat of extinction in Costa Rica

Botanical Family	Species	Wood species	Endemic	Traditional used of wood	Wood Density* (g/cm^3)	Wood samples observed	Permanent slides observed
Anacardiaceae	*Astronium graveolens* Jacq.	Angiosperm	No	HC, Fl & H	0.95	8	9
Bignoniaceae	*Tabebuia guayacan* (Seem.) Hemsl.	Angiosperm	No	HC & Fl	1.01	7	5
Caesalpiniaceae	*Copaifera aromatica* Dwyer	Angiosperm	No	LC, Fl & H	0.68	3	2
	Copaifera camibar Poveda, N. Zamora & P.E. Sánchez	Angiosperm	Yes	HC, Fl & Ha	0.78	1	1
	Cynometra hemitomophylla (Donn. Sm.) Britton & Rose	Angiosperm	No	LC	0.78	2	2
	Mora oleifera (Triana) Ducke	Angiosperm	No	LC & Fl	0.75	1	1
	Peltogyne purpurea Pittier	Angiosperm	No	HC, Fl & H	0.98	7	3
	Prioria copaifera Griseb.	Angiosperm	No	LC & Fl	0.48	6	9
	Tachigali versicolor Standl. & L.O. Williams	Angiosperm	No	LC & Fl	0.64	1	2
Caryocaraceae	*Caryocar costaricense* Donn. Sm.	Angiosperm	No	HC	0.72	6	2
Humiriaceae	*Humiriastrum guianensis* Cuatrec.	Angiosperm	No	HC	0.66	2	1
	Vantanea barbourii Standl.	Angiosperm	No	HC & Fl	0.91	6	1
Juglandaceae	*Oreomunnea pterocarpa* Oerst.	Angiosperm	Yes	LC	0.53	3	8
Lecythidaceae	*Couratari guianensis* Aubl.	Angiosperm	No	HC	0.69	5	1
	Lecythis ampla Miers.	Angiosperm	No	HC	0.78	5	1
Meliaceae	*Cedrela odorata* L.	Angiosperm	No	FU & H	0.44	7	9
	Cedrela tonduzii C.DC.	Angiosperm	No	FU & H	0.44	9	2
Olacaceae	*Minquartia guianensis* Aubl.	Angiosperm	No	HC & Fl	0.89	1	6
Papilionaceae	*Dalbergia retusa* Hemsl.	Angiosperm	No	HC, Fl & H	1.01	7	6
	Dussia macroprophyllata (Donn. Sm.) Harms	Angiosperm	Yes	LC	0.59	1	3
Podocarpaceae	*Prumnopitys standleyi* (Wild.) Ladd.	Gymnosperm	Yes	Fu	0.63	3	1
Sapotaceae	*Sideroxylon capari* (A. DC.) Pittier	Angiosperm	No	HC & Fl	0.79	1	1
Vochysiaceae	*Qualea paraensis* Ducke	Angiosperm	No	LC & Fl	0.37	2	8

Source: Jimenez 1999.
Legend: * Wood density was determined at 12% of moisture content.
LC=Light construction, HC=Heavy construction, Fl=flooring, Fu=furniture and H=handicrafts.

as described in the IAWA List (IAWA 1989). Surface fluorescence was determined in a dark-room from freshly prepared (planed or scraped) transverse and/or longitudinal surfaces exposed to a low intensity, long wave ultraviolet light (around 365nm). The specimens were recorded as either fluorescente (noting color and intensity) or not fluorescente. Only specimens which exhibited a definite yellow, green, orange or blue fluorescence were recorded as fluorescente. For water and ethanol extracts, color and intensity of fluorescence were scored. Froth tests were conducted and were scored as positive (high intensity) if one minute after shaking vigorously, froth was present and covered the entire surface of the solution, negative if all froth had disappeared, and variable if froth was still present around the edge of the test tube but did not extend over the entire surface of the liquid column.

RESULTS

General aspects: 22% (ten species) were Papilionaceae, 18% (eight species) were Caesalpiniaceae, 13% (six species) were Meliaceae, 9% (four species) were Podocarpaceae, 7% (three species) were Lecythidaceae, 4% (two species) each were Caryocaraceae or Humiriaceae; other families represented the 27% (12 species) of endangered or threatened timber species endemic to Costa Rica. Most of these species are used in heavy or light construction or handicrafts; however, species in the Meliaceae are utilized for furniture manufacturing. High wood density was a characteristic of most of the species, and the main use of the lumber was construction (Table 1 and 2).

Fluorescence test: Surface fluorescence was positive in 11 species. This represented 24% of the total number of species. Fluorescence in *Caryocar costaricense*, *Copaifera aromatica*, *Astronium graveolens*, *Mora oleifera* and *Myroxylon balsamum* was green, greenish, or weak green, whereas in *Dussia macroprophyllata*, *Lecythis ampla*, *Hymenolobium mesoamericanum*, *Peltogyne purpurea* and *Tachigali versicolor* it was yellow, yellowish or weak yellow (Table 3).

Water extract fluoresced in only nine species (Table 3). The fluorescence was yellow in *Copaifera* species, *H. mesoamericanum* and *P. purpurea* and green in *Cordia gerascanthus*, *A. graveolens*, *M. balsamum* and *Platymiscium* species (Table 3). *C. gerascanthus* and *Platymiscium* species did not show surface fluorescence, but they did show water extract fluorescence (Table 3).

Ethanol extract fluorescence was found in 31 of the species. The fluorescence was greenish blue or yellow, weak or light green, purple, yellowish or bluish (Table 3). Several species (*Cedrela odorata*, *Cedrela fissilis*, *Cedrela tonduzii*, *Couratari guianensis*, *Couratari scottmorii*, *Dalbergia retusa*, *Dipteryx panamensis*, *Guaiacum sanctum*, *Oreomunnea pterocarpa*, *Parkia pendula*, *Prioria copaifera*, *Qualea paraensis*, *Swietenia humilis, Swietenia macrophylla*, *Tabebuia guayacan* and *Vantanea barborii*) had positive ethanol extract fluorescence, but negative surface or water extract fluorescence (Table 3).

General features of endangered or threatened species: *Porosity:* Diffuse porosity was common in endangered or threatened species, being found in 39 species. Three species were both diffuse and semi-ring porous (*C. odorata*, *C. fissilis* and *C. gerascanthus*) and two species were semi-ring porous (*Cedrela salvadorensis* and *C. tonduzii*). *Sideroxylon capari* was unique with a radial or diagonal pore pattern (Fig. 1a). Almost all of the species had solitary pores and pore multiples. However, the percentage of solitary pores was higher than 85% in *G. sanctum* and *V. barbourii*, so these species can be classified as pores exclusively solitary. Higher frequency of multiple pores (>15 pores/mm^2) was measured in three species: *C. guianensis*, *P. purpurea* and *T. guayacan*. Pores frequency was the highest in *Guaiacum sanctum*, and *M. balsamo*. Lower pore frequencies (<2 pores/mm^2) were observed in *C. tonduzii*, *D. retusa*, *D.*

TABLE 3

Results of fluorescence test and vessels characteristics of endangered and threat of extinction species in Costa Rica

Species	Heartwood fluorescence			Vessels elements characteristics									
	SF	WEF	EEF	Porosity and arrangement	PSP	PF	LV	DV	PP	Deposits	DIP	Vestured	VRP*
Anthodiscus chocoensis	-	-	-	D	66	3.6	357	174	S	G-T	4.2	-	30
Astronium graveolens	greenish	weak green	greenish blue	D	87	4.7	428	129	S	G-T	8.7	-	30-32
Caryocar costaricense	weak green	-	-	D	56	4.3	267	152	S	T	4.0	-	30-35
Caryodaphnopsis burgeri	-	-	-	D	34	5.1	462	188	S	T	6.2	-	30-32
Cedrela odorata	-	-	light green	D-S	79	3.7	240	105	S	G	2.7	-	30
Cedrela fissilis	-	-	weak green	D-S	77	2.1	369	140	S	G	2.5	-	30
Cedrela salvadorensis	-	-	-	S	75	3.3	267	150	S	G	3.0	-	30
Cedrela tonduzii	-	-	variable	S	66	1.8	332	210	S	G	5.6	-	30
Copaifera aromatica	greenish	weak yellow	yellowish	D	72	3.9	374	144	S	G	5.8	+	30
Copaifera camibar	greenish	weak yellow	yellowish	D	86	5.8	311	118	S	G	7.1	+	30
Cordia gerascanthus	-	weak green	greenish yellow	D-S	75	16.3	202	114	S	G-T	5.4	-	30
Couratari guianensis	-	-	weak green	D	27	2.2	244	116	S	T	4.2	-	30-31-32-33
Couratari scottmorii	-	-	weak green	D	61	3.7	366	164	S	T	10.4	-	30
Cynometra hemitomophylla	-	-	-	D	69	2.0	352	140	S	G	6.9	+	30
Dalbergia retusa	-	-	yellowish green	D	93	1.8	153	201	S	G	2.8	+	30
Dipteryx panamensis	-	-	weak yellow	D	65	9.9	225	206	S	G	12.0	+	30
Dussia macroprophyllata	weak yellow	-	greenish blue	D	70	1.3	450	261	S	A	11.4	+	30
Guaiacum sanctum	-	-	purple	D	99	23.2	93	58	S	G	2.6	-	30
H. mesoamericanum	weak yellow	weak yellow	greenish	D	81	1.3	463	243	S	G	9.0	+	30
Humiriastrum guianensis	-	-	-	D	96	10.8	1018	101	Sc	G	2.0	-	30
Lecythis ampla	yellowish	-	weak green	D	62	1.8	352	204	S	T	3.8	-	30
Minquartia guianensis	-	-	-	D	43	12.7	930	89	Sc	T	12.3	-	32
Mora oleifera	greenish blue	-	-	D	79	3.6	287	102	S	G	5.4	+	30
Myroxylon balsamum	greenish	-	greenish blue	D	44	19.4	441	66	S	G	1.6	+	30
Oreomunnea pterocarpa	-	-	light green	D	56	3.8	408	318	S	T	9.4	-	30-31-32
Paramachaerium gruberi	-	-	-	D	85	5.9	263	106	S	G	6.0	+	30
Parkia pendula	-	-	weak green	D	92	3.0	344	230	S	G	1.7	+	30

TABLE 3 (Continued)

Results of fluorescence test and vessels characteristics of endangered and threat of extinction species in Costa Rica

Species	Heartwood fluorescence			Vessels elements characteristics									
	SF	WEF	EEF	Porosity and arrangement	PSP	PF	LV	DV	PP	Deposits	DIP	Vestured	VRP*
Peltogyne purpurea	yellow	-	yellow	D	29	7.2	308	149	S	G	7.7	+	30
Platymiscium curuense	-	light green	greenish	D	81	1.6	285	168	S	G	9.1	+	30
Platymiscium parviflorum.	-	light green	greenish	D	79	3.1	172	172	S	G	6.4	+	30
Platymiscium pinnatum	-	light green	greenish	D	75	2.8	226	177	S	G	6.6	+	30
P. pinnatum var. *polystachyum*	-	light green	greenish	D	41	2.4	240	170	S	G	6.1	+	30
Podocarpus costaricensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Podocarpus guatemalensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Podocarpus macrostachys	-	-	-	-	-	-	-	-	-	-	-	-	-
Prioria copaifera	-	-	weak green	D	59	2.9	249	167	S	G	2.3	+	30
Prumnopitys standleyi	-	-	-	-	-	-	-	-	-	-	-		-
Qualea paraensis	-	-	weak green	D	77	10.6	306	166	S	T	6.1	+	30
Sclerolobium costaricense	-	-	light green	D	62	3.8	371	189	S	A	5.5	+	30
Sideroxylon capari	-	-	-	D-DE-R	39	8.4	240	86	S	T	2.5	-	30
Swietenia humilis	-	-	light green	D	64	5.2	349	118	S	G	1.6	-	30
Swietenia macrophylla	-	-	weak green	D	70	13.3	150	137	S	G	2.8	-	30
Tabebuia guayacan	-	-	yellowish	D	31	6.8	313	172	S	G	3.6	-	30
Tachigali versicolor	yellowish	-	bluish	D	69	3.9	315	51	S	G	1.3	+	30
Vantanea barbourii	-	-	light green	D	95	4.5	1160	211	Sc	A	11.0	-	30-32-35

Legend: SF=surface fluorescence, WEF=Water extract fluorescence, EEF: Ethanol extract fluorescence. D=diffuse-porous, S=semi-ring porous, DE=Vessels in dendritic pattern, R=Vessels in radial or diagonal pattern, PSP=Percentage of solitary pores, PF=Pores frequency (pores/mm^2), LV=Length of vessels (µm), DV=Diameter of vessels (µm), PP=Perforation plates, S=simple perforations plate, Sc=scalariform perforations plate, Deposits: T=tyloses, G=gums, A=absent, DIP=diameter of intervascular pits (µm), VRP=Vessels-ray pitting according to IAWA class: 30: Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell, 31: Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular, 32: Vessel-ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical, 33: Vessel-ray pits of two distinct sizes or types in the same ray cell, 35: Vessel-ray pits restricted to marginal rows (IAWA, 1989). "-" anatomical feature absent, "+" anatomical feature present, "?" unknown feature.

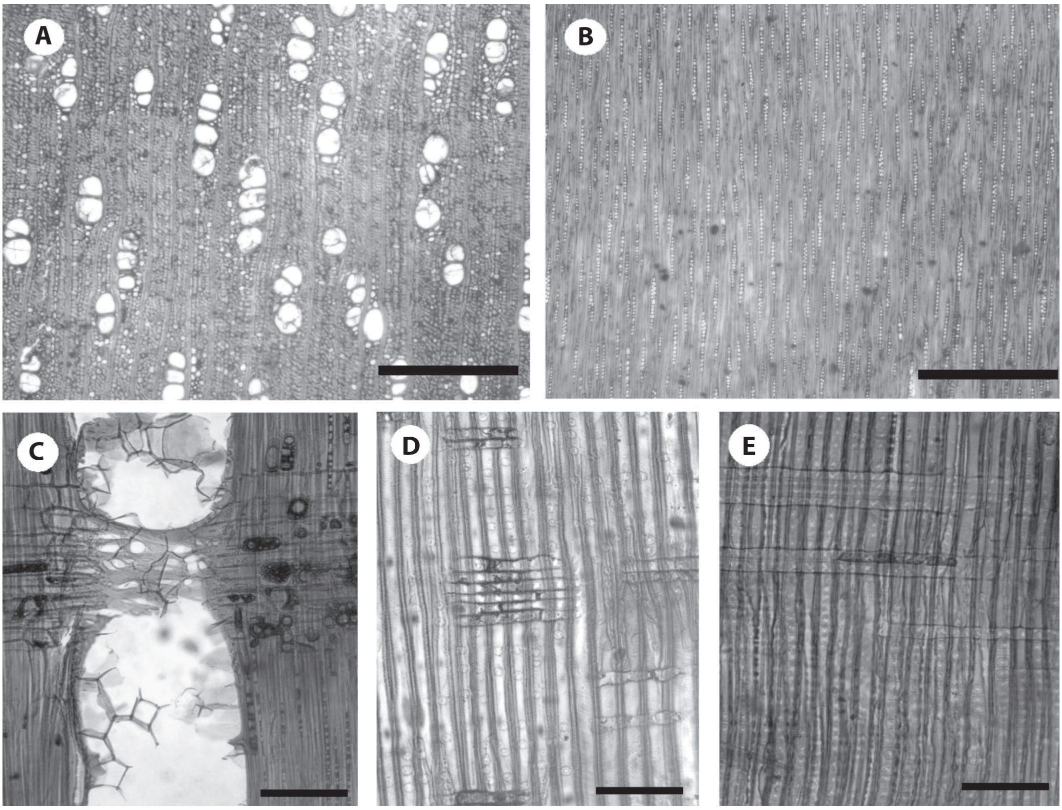

Fig. 1. (a) Cross-section of *Sideroxylon capari* showing vessels in radial pattern, (b) tangential sections of *Sclerolobium costaricense* showing uniseriate rays, (c) Vessel-rays pitting of *C. burgeri*, (d) tracheids and cross-field pitting in radial sections of *Prumnopitys standleyi* and (e) tracheids and cross-field pitting in radial sections of *Podocarpus guatemalensis*. Bar: 500µm in (a) and (b) and 200µm in (c), (d) and (e).

macrophylla, *H. mesoamericanum*, *L. ampla* and *Platymiscium curuense*.

Vessel lengths for these species varied from 93 to 1 160µm (Table 3). Vessel length was shortest in *G. sanctum* and longest in *H. guianensis*, *M. guianensis* and *V. barbourii*. Small diameter vessels (from 50-100µm) were found *G. sanctum*, M. *guianensis*, *M. balsamo*, *S. capari* and *T. versicolor*. Large diameter vessels were found only in *O. pterocarpa*. Vessel diameters from 100-300µm were found in the other species.

Simple perforation plates were found in almost all species (Table 3). However, *H. guianensis* (with 10-20 bars), *M. guianensis* (with <=10 bars) and *V. barbourii* (with <=20 bars) had scalariform perforations.

Tyloses, deposits or gum were found in the vessels of almost all of the angiosperm species (Table 3). Gum was the most common substance in vessel lumina. Nevertheless, neither substance was observed in three of the angiosperm species: *D. macroprophyllata*, *Sclerolobium costaricense* and *V. barbourii*.

All angiosperm species had alternate polygonal pits. Their diameter was minute (<4µm) in 14 species and large (>=10µm) in five species. Pits in the other species were from 4 to 10µm in diameter (Table 3).

Vestured pits were found in all species of Fabaceae (Caesalpixiaceae, Mimosaceae, Papilionaceae) and in *V. barbourii* (Table 3). Vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell, were common. They were found in almost all species. Other pits shapes were found in *C. guianensis* (Table 3). Vessel-ray pits were restricted to marginal rows in *C. costaricense*. Vessel-ray pits with much reduced borders to apparently simple, with pits rounded or angular and horizontal (scalariform, gash-like) to vertical (palisade) were found in *A. graveolens* and *Caryodaphnopsis. burgeri* (Fig. 1c), *C. guianensis*, and *O. pterocarpa*. Vessel-ray pits were restricted to marginal rows in *V. barbourii*. *L. ampla* had vessel-ray pits with much reduced borders to apparently simple: the pits were horizontal (scalariform, gash-like) to vertical (palisade).

Fibers: as expected, gymnosperm species tracheids were longer than most of the angiosperm fibers, being almost 2mm length. However, the fiber length of *V. barbourii* was the longest of any species at 2.45mm. Fiber length varied from 1.50 to 1.95mm in *C. costaricense*, *C. burgeri*, *C. gerascanthus*, *D. macroprophyllata*, *H. mesoamericanum*, *H. guianensis*, *M. guianensis* and *M. balsamum*. The shortest fiber lengths were found in *G. sanctum*, although *C. odorata*, *C. salvadorensis*, *D. retusa*, *O. pterocarpa* and *S. capari* also had short fibers (Table 4). Fiber lumen diameter was widest in *D. macroprophyllata*, *O. pterocarpa*, *H. guianensis*, *P. macrostachys* and *V. barbourii*, and narrowest in *T. guayacan*. Narrow fibers (<15µm) were also found in *C. fissilis*, *C. guianensis*, *G. sanctum*, *Paramachaerium gruberi* and *S. costaricense*. The lumen diameter varied from 15 to 55µm in other species (Table 4). Fibers with very thick-walls (>7µm) were found in *D. retusa*, *H. guianensis*, *M. guianensis*, *M. balsamum*, S. *capari* and *V. barbourii*. Thin-walled fibers were found in species of *Cedrela* and in *C. guianensis*, *P. copaifera*, *S. costaricense* and *S. humilis*. Cell wall thickness of other endangered and threatened species varied from 3 to 7µm (Table 4). Septate fibers were observed only in *A. graveolens*, *G. sanctum* and *Swietenia* species (Table 4). In the angiosperms, fibers with simple to minutely bordered pits were most common in *H. guianensis*, *L. ampla* and *V. barbourii*. Distinctly bordered pits were common in both radial and tangential fiber walls. The tracheids of species of the Podocarpaceae had, as expected, bordered pits in radial walls. Many of the angiosperm species had storied fibers (Table 4). Crystals were only found in the fibers of *P. gruberi*.

Ray parenchyma: Ray height over 1mm was observed in five species (*C. costaricense*, *C. gerascanthus*, *M. guianensis*, *P. purpurea* and *Q. paraensis*), representing 11% of the species. Rays were exclusively uniseriate in eight species (Fig. 1b): four Podocarpaceae (Fig. 1d and 1e) and four angiosperms (*G. sanctum* and *Platymiscium* species). Rays 1-3 cell in width were the most common, represented by 23 species (51% of total species) (Table 4). Large rays (over 8 cells in width) were observed in eight species (18% of total species) (Table 4). The rays of *C. aromatica*, *C. gerascanthus* and *P. purpurea* were 4-10 seriate. Ray frequency varied from 2 to 20 rays per mm (Table 4). The lowest frequencies were found in *C. burgeri* and *L. ampla* and the highest ones (>14 rays/mm) were in *Cynometra hemitomophylla*, *G. sanctum* and *H. guianensis*. Rays composed mostly of procumbent cells were observed in 17 species (38% of total species) and heterogeneous rays were in 19 species (42% of total species). Nine species had both homogeneous and heterogeneous rays (Table 4). Storied rays were found in 14 species (Table 4). Two heights were found in *D. macrophylla*, *P. purpurea* and *Swietenia* species. Crystals were observed in ray cells of 27 species (60% of total species); in 11 species (24%) crystals were found in the marginal ray cells only (Table 4). Silica bodies were present in *Anthodiscus chocoensis*, *Couratari* species, *L. ampla*, *Q. paraensis* and *T. versicolor*. Sheath cells were only observed in *C. gerascanthus*.

Axial parenchyma: Apotraqueal parenchyma was present in 21 species (48% of total species) (Table 5). Parenchyma diffuse and diffuse-in-aggregates was seen in *D. retusa*, *G. sanctum*, *M. guianensis* and *S. capari*, and it was the only parenchyma type in *C.*

TABLE 4
Fiber or tracheid and ray parenchyma characteristics of species that are endangered or considered to be in threat of extinction in Costa Rica

Species	Fibers or tracheids								Ray parenchyma					
	FL	LD	WCT	FC	SF	GTF	PFRT	FS	RH	RW	RF	RT	RS	R (C)
Anthodiscus chocoensis	1.5	17.4	6.5	-	-	SBD	-	-	590	1-3, U (>)	6.1	Ht	-	S(+)
Astronium graveolens	1.2	22.1	3.6	-	+	SBD	-	-	850	1-3, 4-10	3.2	Ht	-	U+ P(-)
Caryocar costaricense	1.7	24.1	5.3	-	-	SBD	-	-	>1	1-3	7.8	Ht	-	-
Caryodaphnopsis burgeri	1.8	21.3	6.6	-	-	SBD	-	-	580	3-10	2.0	Ht	-	-
Cedrela odorata	0.9	24.4	3.3	-	-	SBD	-	-	250	1-3	3.5	Ho-Ht	-	U+P(-)
Cedrela fissilis	1.4	15.0	2.1	-	-	SBD	-	-	335	1-3	3.6	Ht	-	U+ P(-)
Cedrela salvadorensis	0.9	17.8	2.5	-	-	SBD	-	-	342	1-3, 4-10	4.8	Ht	-	U+ P(-)
Cedrela tonduzii	1.2	20.1	2.7	-	-	SBD	-	-	390	1-3	3.7	Ht	-	U+ P(-)
Copaifera aromatica	1.2	17.0	3.1	-	-	SBD	-	-	360	4-10	6.7	Ho-Ht	-	U+ P(-)
Copaifera camibar	1.2	19.1	3.4	-	-	SBD	-	-	292	1-3	6.4	Ho-Ht	-	-
Cordia gerascanthus	1.6	22.6	5.1	-	-	SBD	-	-	290>1	4-10	6.8	Ht	-	U+ P(+)
Couratari guianensis	1.3	13.1	2.5	-	-	SBD	+?	-	440	1-3, 4-10	6.2	Ho-Ht	-	S(+)
Couratari scottmorii	1.4	16.7	4.2	-	-	SBD	-	-	380	1-3	6.8	Ho-Ht	-	S(+)
Cynometra hemitomophylla	1.3	23.7	4.6	-	-	SBD	-	-	306	1-3	14.9	Ht	-	-
Dalbergia retusa	0.6	19.2	7.7	-	-	SBD	-	+	134	1-3	16.6	Ho-Ht	+	-
Dipteryx panamensis	1.0	16.3	6.3	-	-	SBD	-	+	194	1-3	6.6	Ho	+	-
Dussia macroprophyllata	1.7	32.7	6.4	-	-	SBD	-	-+	323	1-3	6.6	Ho-Ht	+-	-
Guaiacum sanctum	0.5	11.6	3.6	-	-+	SBD	-	+	67	1	14.4	Ho	+	-
H. mesoamericanum	1.8	22.8	6.3	-	-	SBD	-	+	360	1-3, 4-10	5.9	Ht	+	-
Humiriastrum guianensis	1.6	25.8	5.5	-	-	BD	+	-	400	1-3, U (>)	19.7	Ht	-	-
Lecythis ampla	1.3	15.5	4.0	-	-	BD	+	-	480	1-3	2.8	Ho-Ht	-	S(+)
Minquartia guianensis	1.7	18.2	7.5	-	-	SBD	-	-	>1	1-3, U (>)	7.0	Ht	-	U+ P(-)
Mora oleifera	1.3	14.4	6.2	-	-	SBD	-	-	330	1-3	10.0	Ho	-	-
Myroxylon balsamum	1.7	17.3	7.0	-	-	SBD	-	+	170	1-3	11.6	Ht	+	U+ P(-)
Oreomunnea pterocarpa	0.8	29.3	6.9	-	-	SBD	-	-	535	1-3	9.5	Ht	-	-
Paramachaerium gruberi	0.9	14.2	3.9	+	-	SBD	-	+	190	1-3	12.4	Ho	+	-
Parkia pendula	1.1	19.2	4.6	-	-	SBD	-	-	224	1-3	5.8	Ho	-	-
Peltogyne purpurea	0.9	15.3	5.3	-	-	SBD	-	-	>1	4-10	5.7	Ho	+-	-
Platymiscium curuense	1.1	19.4	4.3	-	-	SBD	-	-+	202	1	10.4	Ho	+	-

TABLE 4 (Continued)
Fiber or tracheid and ray parenchyma characteristics of species that are endangered or considered to be in threat of extinction in Costa Rica

Species	Fibers or tracheids								Ray parenchyma				
	FL	LD	WCT	FC	SF	GTF	PFRT	FS	RH	RW	RF	RT	RS	R (C)
Platymiscium parviflorum	1.2	21.5	3.6	-	-	SBD	-	+	170	1	8.9	Ho	+	-
Platymiscium pinnatum	1.0	18.4	4.4	-	-	SBD	-	-+	160	1	6.0	Ho	+	-
P. pinnatum var. *polystachyum*	1.1	19.9	4.9	-	-	SBD	-	-+	160	1	9.6	Ho	+	-
Podocarpus costaricensis	2.4	31.5	6.3	-	-	T	-	+	71	1	4.2	Ho	-	-
Podocarpus guatemalensis	3.2	35.4	3.1	-	-	T	-	+	55	1	5.6	Ho	-	-
Podocarpus macrostachys	2.9	26.5	4.6	-	-	T	-	+	111	1	7.7	Ho	-	-
Prioria copaifera	1.0	21.8	2.9	-	-	BD	-	-	550	1-3	5.9	Ht	-	-
Prumnopitys standleyi	2.5	31.4	5.7	-	-	T	-	-	90	1	4.7	Ho	-	-
Qualea paraensis	1.1	18.3	4.4	-	-	SBD	-	-	260, >1	1-3	4.1	Ho-Ht	-	S(+)v
Sclerolobium costaricense	1.1	14.6	2.7	-	-	SBD	-	-	250	1	11.0	Ho	-	-
Sideroxylon capari	0.8	17.0	8.9	-	-	SBD	-	-	224	1-3	12.1	Ht	-	U+ P(-)
Swietenia humilis	1.0	18.8	2.9	-	+	SBD	-	-+	330	1-3, 4-10	7.0	Ht	+-	U+ P(-)
Swietenia macrophylla	0.8	21.0	3.6	-	- +	SBD	-	-+	147	1-3, 4-10	8.1	Ht	+-	U+ (-)
Tabebuia guayacan	0.9	6.2	3.8	-	-	SBD	-	+	190	1-3	9.5	Ho	+	-
Tachigali versicolor	0.9	17.7	3.1	-	-	SBD	-	-	227	1-3	8.2	Ho	-	S(+)
Vantanea barbourii	1.6	33.1	6.8	-	-	BD	+	-	650	1-3	11.1	Ht	-	-

Fiber: FL=Fiber or tracheids length (mm), LD=lumen or tracheids diameter (µm), WCT=wall cell thick (µm), FC=Fibers crystals, SF=Septate fibers, GTF=ground tissue fiber, SBD=simple to minutely bordered pits, BD=Fibers with distinctly bordered pit, T=tracheids, PFRT=Fiber pits common in both radial and tangential, FS=Fibers stored. Ray parenchyma: RH=ray height (µm), RW=ray width cell (µm), U(>)=mainly uniseriate, RF=ray frequency (ray/mm), RT=ray type, Ht=heterogeneous, Ho=homogenous, RS=ray stored, R(C)=crystals presence in ray, U=crystals in upright cells, P=procumbent cells, S=Silica bodies presence, "-" anatomical feature absent, "+"anatomical feature present.

TABLE 5

Fiber, ray parenchyma and axial parenchyma characteristics of endangered and threatened species in Costa Rica

	Axial parenchyma							Others anatomical features
	AP	Type	Parenchyma arrangement	Banded Parenchyma	Stored	Cell	AP (C)	
Anthodiscus chocoensis	-	-	Vc	-	-	>8	-	Radial canals
Astronium graveolens	+	Diff	Sca & Vc	Mar	-	3-8	-	
Caryocar costaricense	+	Diff-Agg	Sca	-	-	3-8	+ (+)	Radial canals
Caryodaphnopsis burgeri	+	Diff	Sca	Nar	-	3-8	+ (+)	
Cedrela odorata	+	Diff	Sca-Vc	Mar	-	3-8	+ (-+)	
Cedrela fissilis	+	Diff	Sca-Vc-Loz	Mar	-	3-8	+ (-+)	
Cedrela salvadorensis	+	Diff	Vc-Con	Mar	-	3-8	+ (-+)	
Cedrela tonduzii	+	Diff	Sca & Vc	Mar	-	3-8	+ (-+)	
Copaifera aromatica	-	-	Vc	Mar	-	3-8	+ (+)	Axial & ray canals & sheath cells
Copaifera camibar	-	-	Vc, Loz-alif & Con	Wid	-	3-8	+ (+)	Axial & ray canals & sheath cells
Cordia gerascanthus	+	Diff	Sca, Vc & Con	Mar	-	2 & 3-4	-	
Couratari guianensis	-	-	-	Wid-Nar-Ret-Scal	-	3-8	+ (+)	
Couratari scott-morii	-	-	-	Nar-Ret-Scal	-	3-8	+ (+), S(+)	
Cynometra hemitomophylla	-	-	-	Nar-Ret-Mar	+ ves	5-8	+ (+)	
Dalbergia retusa	+	Diff-Agg	Sca & Vc	Nar-Mar	+ ves	2 & 3-4	+ (+)	
Dipteryx panamensis	-	-	Loz-alif, win-alif & Uni	Mar	+ wae	2 & 3-4	+ (+)	
Dussia macroprophyllata	-	-	Con	Wid	+ wae	3-8 & >8	+ (+)	
Guaiacum sanctum	+	Diff-Agg	Sca	Nar	+ ves	2	+ (+)	
H. mesoamericanum	-	-	Loz-alif, Con, Vc	Wid	+ wae	2 & 3-4	+ (+)	
Humiriastrum guianensis	-	-	Vc, Loz-alif, Win-alif & Uni	-	-	3-8 & >8	+ (+)	Traumatic canals
Lecythis ampla.	+	Diff	-	Wid-Ret-Mar	-	3-8	+ (+)	
Minquartia guianensis	+	Diff-Agg	Sca	-	-	5-8	+ (+)	Vasicentric tracheids
Mora oleifera	-	-	Vc, Loz-alif, win-alif & Con	Mar	-	3-5	+ (+)	
Myroxylon balsamum	-	-	Sca, Vc, Con & Uni	-	+- wae	2, 3-4	+ (+)	
Oreomunnea pterocarpa	-	-		Nar-Ret-Mar	-	5-8	+ (+)	
Paramachaerium gruberi	+	Diff	Sca, Loz-alif & wing-alif	Nar	+ wae	2	+ (-+)	Crystals in enlarged cells
Parkia pendula	-	-	Loz-alif & Con		-	3-5	+ (-+)	
Peltogyne purpurea	-	-	Loz-alif & Con & Uni	Mar	+ ves	3-4	+ (+)	
Platymiscium curuense	-	-	Loz-alif & Con	Nar	-	2	+ (+)	

TABLE 5 (Continued)
Fiber, ray parenchyma and axial parenchyma characteristics of endangered and threatened species in Costa Rica

	Axial parenchyma							Others anatomical features
	AP	Type	Parenchyma arrangement	Banded Parenchyma	Stored	Cell	AP (C)	
Platymiscium parviflorum.	-	-	Loz-alif & Con	Nar	+ ves	2	+ (+)	
Platymiscium pinnatum	-	-	Loz-alif & Con	Nar	+ ves	2	+ (+)	Traumatic canals
P. pinnatum var. polystachyum	-	-	Loz-alif & Con	Nar	+ ves	2	+ (+)	
Podocarpus costaricensis	+	Diff	-	-	-	<4	-	
Podocarpus guatemalensis	+	Sca	-	-	-	<4	-	
Podocarpus macrostachys	+	Diff	-	-	-	<4 and 5-15	-	
Prioria copaifera	-	-	Vc, Loz-alif & Con	Wid-Nar	+ ves	2 & 3-4	+ (+)	Axial canals diffuse
Prumnopitys standleyi	+	Sca	-	-	-	<4	-	
Qualea paraensis	+	Diff	Vc, Loz-alif, win-alif & Con	-	-	3-8	+ (-+)	Vessels of 2 distinct diameter
Sclerolobium costaricense	-	-	Vc	-	-	3-8	+ (+)	Helical thickening in vessels
Sideroxylon capari	+	Diff-Agg	-	-	-	3-4	+ (-+)	
Swietenia humilis	+	Diff	Sca	Mar	-	5-8	+ (-+)	
Swietenia macrophylla	+	Diff	Sca	Mar	-	5-8	+ (-+)	
Tabebuia guayacan	-	-	Vc, Loz-alif & Uni	Mar	+ wae	2 & 3-4	-	
Tachigali versicolor	-	-	Sca-Vc	-	-	2 & 3-4	+ (+)	
Vantanea barbourii	+	Diff	Sca-Uni	-	-	5-8 & 8>	+ (+-)	

AP=apotraqueal parenchyma, Diff=diffuse. Diff-Agg=diffuse in aggregates, Sca=scanty, Con=confluent, Vc=vasicentric, Loz-alif=lozenge-aliform: Loz-w=lozenge-winged, uni=unilateral, Mar=marginal, Nar=narrow band, Wid=wide band, ret=reticulate, Scal=Scalarifom band, S=Silica bodies present, AP(C)=crystals present in axial parenchyma (chambered present), ves=vessel elements storied, ae=axial elements storied.

costaricense. Almost all the species of angiosperms had paratracheal parenchyma (Table 5). Scanty paratracheal parenchyma was present in sixteen species, and vasicentric parenchyma was found in *A. graveolens*, *C. odorata*, *C. fissilis*, *C. tonduzii*, *C. gerascanthus* and *T. versicolor*. Three or more different paratracheal types were observed in 17 species (38% of total species). Aliform and confluent parenchyma was very common in several species. Banded parenchyma was observed in 30 species (68 of total species; 73% of angiosperm species). Parenchyma marginal or in wide bands (more than 3 cells wide) were the most common banded parenchyma (Table 5). Axial parenchyma was reticulate in *Couratari* species, *C. hemitomophylla*, *L. ampla* and *O. pterocarpa*. Axial parenchyma was storied in 13 species (Table 5). Fusiform cells were found in *Platymiscium* species, *Paramachaerium grugeri*, *M. balsamo*, *P. copaifera*, *T. guayacan* and *T. versicolor*. Crystals were present in chambered axial parenchyma in almost all gymnosperm species (Table 5). They were found enlarged in *P. gruberi*. *A. chocoensis*, *A. graveolens*, *C. gerascanthus* and *Podocarpus* species, *T. guayacan* did not have any crystals. Silica bodies were present in *Couratari* species.

Other anatomical features: some species had other distinctive anatomical features, which are detailed in table 5. They could be used to facilitate wood identification. For example, radial or axial canals are found in *A. chocoensis*, *C. costaricense*, *C. aromatica* and *P. copaifera*. Traumatic canals were observed in *C. camibar*, *H. guianensis* and *Platymiscium pinnatum*. Pores with two distinct diameters are found in *D. retusa* and *Q. paraensis*. *C. gerascanthus* was a unique species with sheath cell in the rays. Finally, helical thickenings were observed in some vessels elements of *S. costaricense*.

Specific species: Major differences among species groups are included in the next few paragraphs.

Meliaceae species: Two genera of Meliaceae were analyzed: four species of Cedrela (*C. odorata*, *C. salvadorensis*, *C. fissilis* and *C. tonduzii*), and two species of Swietenia (*S. macrophylla* and *S. humilis*). The wood anatomy of these species, especially *C. odorata*, *C. fissilis* and *S. macrophylla*, has been described by several authors (Panshin 1933, White & Gasson 2008). Four species of Meliaceae (*C. salvadorensis*, *C. fissilis*, *S. macrophylla* and *S. humilis*) are considered as endangered and their cutting has been prohibited in the natural forest in Costa Rica (Costa Rica 1996a). Felling of the other species, *C. odorata* and *C. tonduzii*, is permitted. Therefore, it is important to have a method to separate the species. The species of *Swietenia* are easily separated from species of Cedrela by anatomical features such as storied rays (Fig. 2g, h, i) and diffuse porosity in *Swietenia* but not in *Cedrela* (Fig. 2a-2i).

Platymiscium species: some differences were found among species of *Platymiscium* include presence of traumatic canals in *Platymiscium parviflorum* (Fig. 3a) but not in the other species (Fig. 3b). *Platymiscium pinnatum* var. *polystachyum* had irregularly storied rays (Fig. 4c) whereas in the other species storing was well-defined (Fig. 4a, 4b and 4d). The parenchyma was paratracheal in *P. pinnatum* var. *polystachyum* but not in other Platymiscium species. It was scanty, unilateral paratracheal, winged-aliform in *P. pinnatum* var *polystachyum* (Fig. 3b), but lozenge-aliform in the other species. We also found marginal parenchyma in *P. pinnatum* var *polystachyum* (Fig. 3b).

Couratari species: The two *Couratari* species can be distinguished by several differences. *C. scottmorii* has narrow reticulate parenchyma bands that are two cells wide (Fig. 5b), whereas reticulate bands in *C. guianensis* are up to four cells wide (Fig. 5a). Rays are 1-3 seriate in *C. scottmorii* (Fig. 5d), but up to 5-seriate in *C. guianensis* (Fig. 5c). The frequency of silica bodies is different among species, with, the highest frequency observed

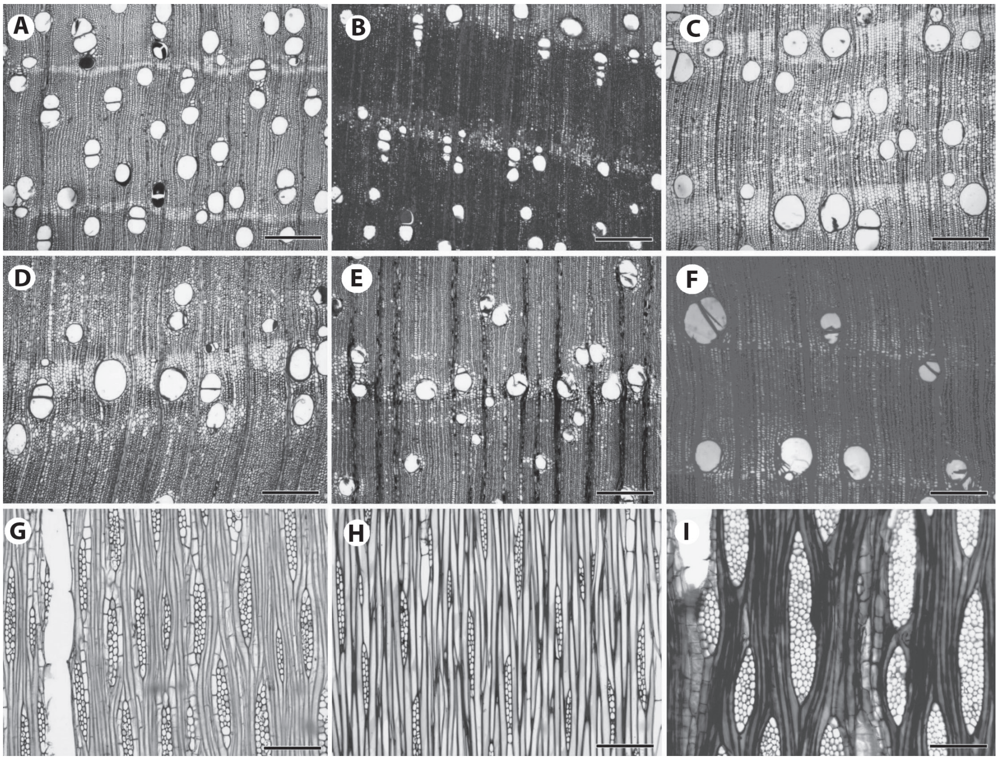

Fig. 2. Transverse sections of (A) *Swietenia macrophylla*, (B) *Swietenia humilis*, (C) *Cedrela odorata*, (D) *Cedrela fissilis*, (E) *Cedrela salvadorensis*, (F) *Cedrela tonduzii*, and tangential sections of (G) *Swietenia macrophylla*, (H) *Cedrela odorata* and (I) *Cedrela salvadorensis*. Bar: 500µm in (A) - (F) and 200µm in (G) - (I).

in *C. guianensis*. The vessels-ray pits in *C. scottmorii* have much reduced borders and the pits are rounded or angular, unlike those of *C. guianensis* which are horizontal (scalariform, gash-like) to vertical (palisade).

Copaifera species: The two *Copaifera* species differed mainly by paratracheal parenchyma and ray dimensions. Paratracheal parenchyma is more abundant in *C. aromatica* than in *C. camibar*. It is vasicentric 2-3 cells in width in *Copaifetra aromatica* (Fig. 6a), but scanty paratracheal or vasicentric 1-2 cells in *C. camibar* (Fig. 6b). The rays are 1- 3 cells wide and high in *C. camibar* (Fig. 6d), but were commonly 4-10 seriate and low in *C. aromatica* (Fig. 6c). There is no difference in the resin canals of the species.

Podocarpaceae species: We looked at two genera: three species of *Podocarpus* (*P. costaricensis*, *P. guatemalensis* and *P. macrostachys*), and one species of *Prumnopitys* (*P. standleyi*). Axial parenchyma is present in *P. macrostachys* and *P. costaricensis* (Fig. 7a-7b) and is scanty in *P. guatemalensis* and *Prumnopitys standleyi* (Fig. 7c-7d). The highest proportion of axial parenchyma was observed in *P. macrostachys* (Fig. 7a), it was rare to moderately abundant in *P. costaricensis* (Fig. 7b) and scanty in *P. guatemalensis* (Fig. 7d). Another important difference between *Podocarpus* and *Prumnopitys* is ray height. Rays were highest in *P. macrostachys* (5 to 10 cells) (Fig. 8a), but they were only 2-4 cells high in *P. costaricensis* (Fig. 8b). Ray frequency is highest in *P. guatemalensis* (Fig. 7c). The rays of

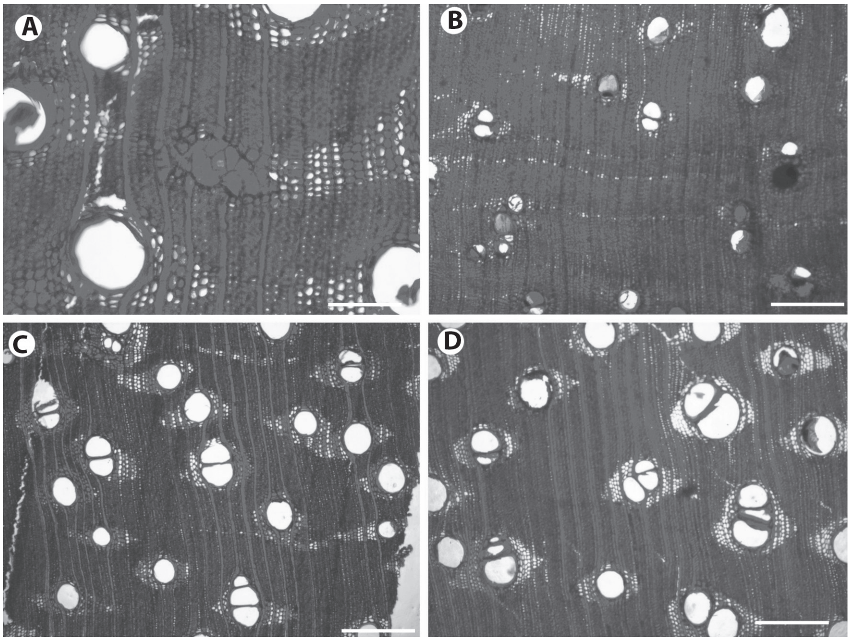

Fig. 3. Transverse sections of (A) *Platymiscium parviflorum* showing traumatic canals, (B) *Platymiscium pinnatum* var *polystachyum*, (C) *Platymiscium pinnatum* and (D) *Platymiscium curuense*. Bar: 200 µm.

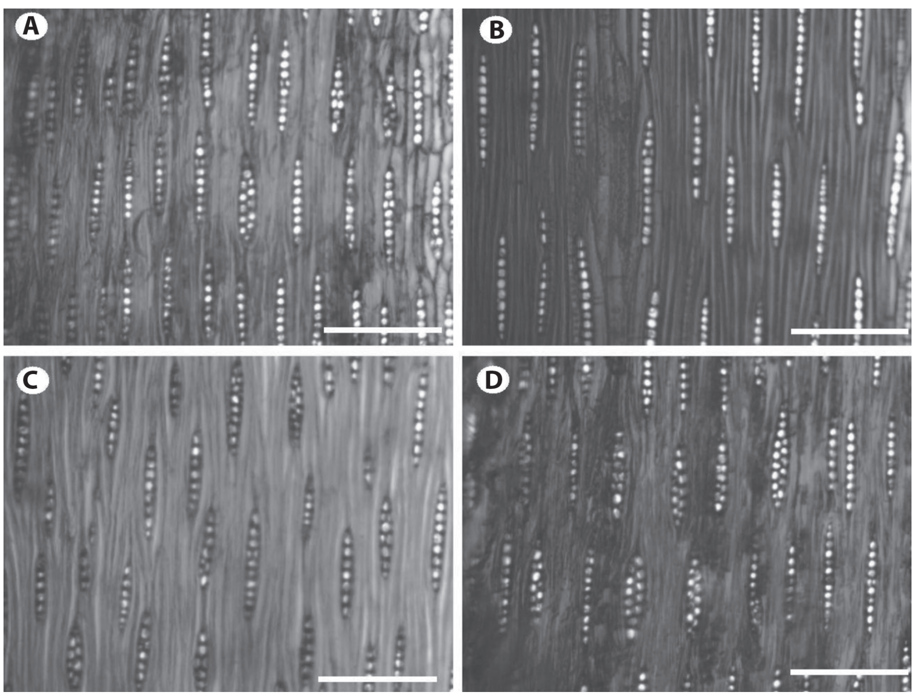

Fig. 4. Tangential sections of (A) *Platymiscium parviflorum*, (B) *Platymiscium pinnatum*, (C) *Platymiscium pinnatum* var *polystachyum* and (D) *Platymiscium curuense*. Bar: 200µm.

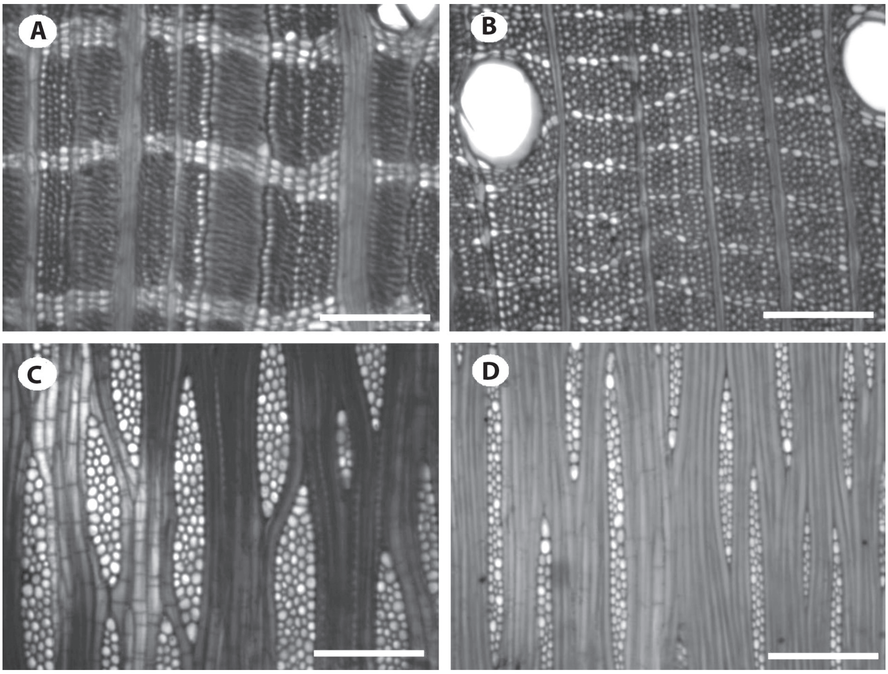

Fig. 5. Cross and tangential sections of Couratari species. (A) cross-section of *Couratari guianensis*, (B) cross-section of *Couratari scott-morii*, (C) tangential section showing ray width in *Couratari guianensis* and (D) tangential section showing ray width in *Couratari scott-morii*. Bar: 200µm.

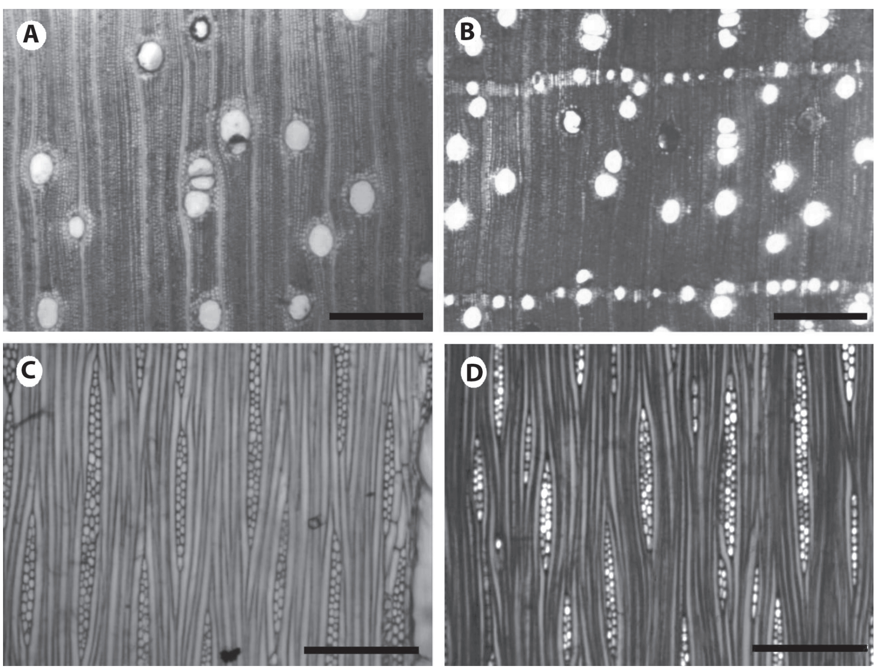

Fig. 6. Cross and tangential sections of Copaifera species. (A) cross-section of *Copaifera aromatica,* (B) cross-section of *Copaifera camibar*, (C) tangential section showing ray width in *Copaifera aromatica* and (D) tangential section showing ray width in *Copaifera camibar*. Bar: 500µm in (A) and (B), 200µm in (C) and (D).

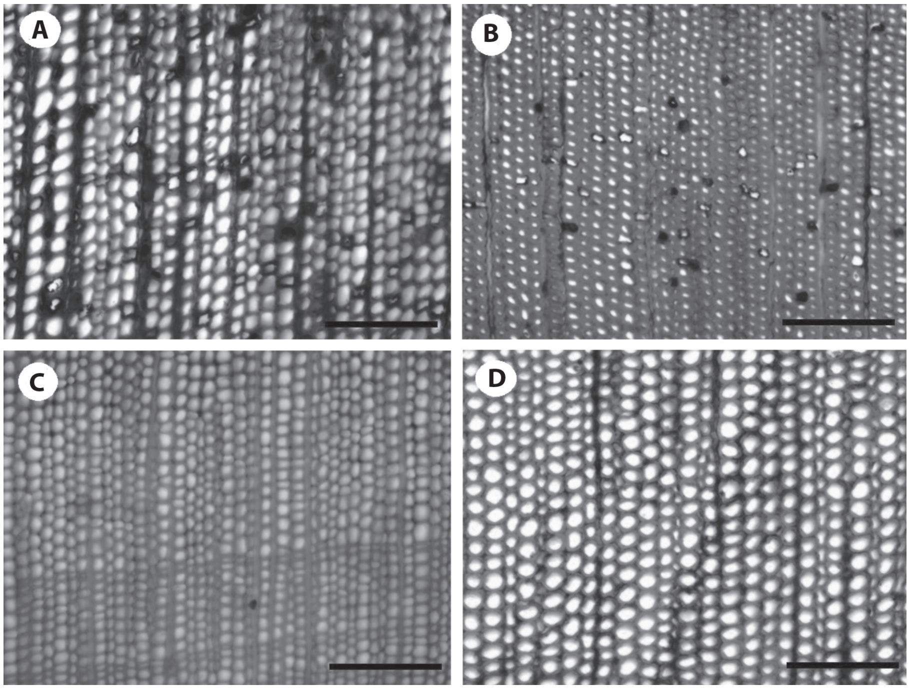

Fig. 7. Transverse sections of (A) *Podocarpus macrostachys*, (B) *Podocarpus costaricensis*, (C) *Podocarpus guatemalensis* and (D) *Prumnopitys standleyi*. Bar: 200µm.

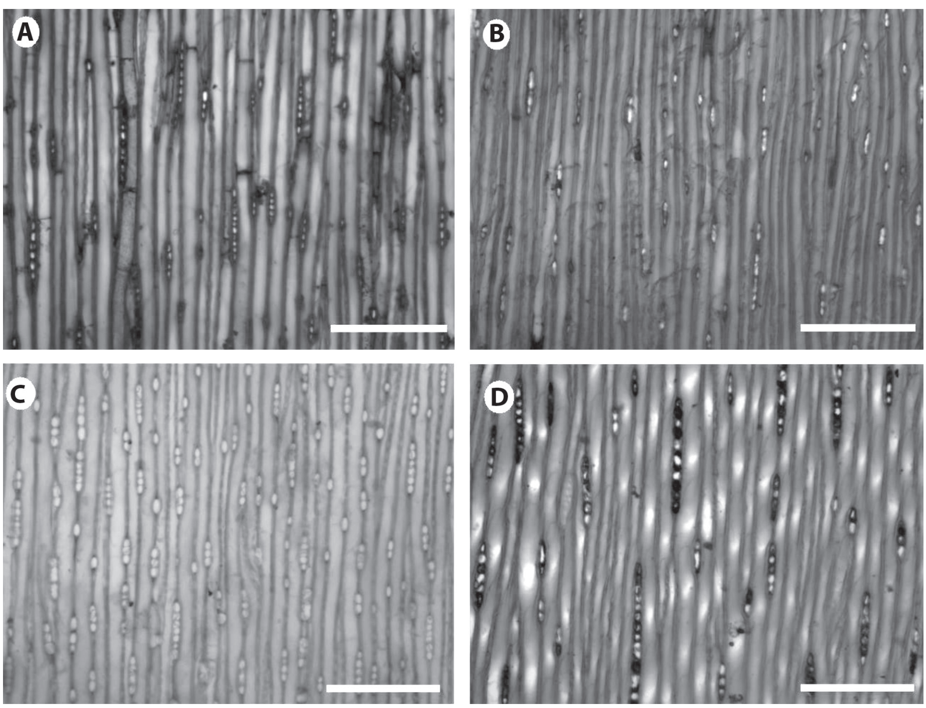

Fig. 8. Tangential sections of (A) *Podocarpus macrostachys*, (B) *Podocarpus costaricensis*, (C) *Podocarpus guatemalensis* and (D) *Prumnopitys standleyi*. Bar: 200µm.

Key for identification

The following identification key was developed to distinguish among the 45 timber species considered to be endangered or threatened in Costa Rica. This key use microscopic wood features as well and fluorescence and wood density.

1.	Gymnosperm	3
2.	Angiosperm	6
3a.	Parenchyma present and rays 2-4 cells in height	4
3b.	Parenchyma abundant sparse and rays 2-10 cells in height	5
4a.	Parenchyma abundant	*Podocarpus macrostachys*
4b.	Parenchyma scanty	*Podocarpus guatemalensis*
5a.	Parenchyma sparse.	*Podocarpus costaricensis*
5b.	Axial Parenchyma absent	*Prumnopitys standleyi*
6a.	Negative fluorescence	7
6b.	Positive fluorescence	14
7a.	Pores solitarys and in groups	8
7b.	Pores solitary or pores in dendritic or diagonal and/or radial pattern	13
8a.	Scalariform perforations; ray height over 1 mm, axial parenchyma diffuse and diffuse-in-aggregates, paratracheal scanty; vasicentric tracheids	*Minquartia guianensis*
8b.	Simple perforations	9
9a.	Semi-ring porous, parenchyma diffuse, paratracheal scanty, vasicentric and in marginal or in seemingly marginal bands	*Cedrela salvadorensis*
9b.	Diffuse porous	10
10a.	Rays not storied	11
10b.	Ray storied, axial parenchyma apotraqueal diffuse, scanty , lozenge-aliform, winged-aliform, and banded in narrow bands or lines up to three cells wide	*Paramachaerium gruberi*
11a.	Ray 1-3 cells in width	12
11b.	Axial parenchyma apotracheal diffuse, scanty, vasicentric, and in narrow bands or lines up to three cells wide, with 3-5 or 5-8 cells per parenchyma strand	*Carydaphnopsis burger*
12a.	Paratraqueal parenchyma with over eight cells per parenchyma strand	*Anthodiscus chocoensis*
12b.	Parenchyma in marginal or in seemingly marginal bands, narrow banded or reticulate; rays and axial elements irregularly storied, ray frequency high	*Cynometra hemitomophylla*
13a.	Pores solitary, scalariform perforation plates, axial parenchyma vasicentric, lozange-aliform, winged-aliform and confluent and traumatic canals	*Humiriastrum guianensis*
13b.	Vessels in dendritic or diagonal and/or radial pattern, rays heterogeneous, 1-3 seriate and parenchyma diffuse and diffuse-in-aggregates	*Sideroxylon capari*
14a.	Fluorescence in surface only	15
14b.	Fluorescence in ethanol extract only	16
14c.	Fluorescence in surface and ethanol extract	31
14d.	Fluorescence in water and ethanol extract.	35
14e.	Fluorescence in surface, water and ethanol extract	37
15a.	Parenchyma vasicentric, lozenge-aliform, winged-aliform, confluent and in marginal or in seemingly marginal bands, with 3-4 and 5-8 cells per parenchyma strand	*Mora oleifera*
15b.	Ray height over 1 mm, parenchyma diffuse, paratracheal scanty and in marginal or in seemingly marginal bands and radial canals	*Caryocar costaricense*
16a.	Pores solitarys	17
16b.	Pores solitarys and in groups	18
17a.	Ray frequency high, fibers septate and storied, apotraqueal parenchyma diffuse and diffuse-in-aggregates	*Guaiacum sanctum*
17b.	Perforation plates scalariform, axial parenchyma diffuse, scanty paratracheal and unilateral	*Vantanea barbourii*
18a.	Semi-ring porous	19
18b.	Diffuse porous	21
19a.	Semi-ring porous, parenchyma vasicentric, rays heterogeneous ray and 1-3 seriates in width	*Cedrela odorata*
19b.	Semi-ring to diffuse porous	20

20a. Parenchyma aliform, rays heterogeneous and 1-3 seriate . . . . *Cedrela fissilis*
20b. Parenchyma diffuse, paratracheal scanty and vasicentric and in marginal or in seemingly marginal bands . . . . *Cedrela tonduzii*
21a. Rays uniseriate, pits vestured, axial parenchyma vasicentric, vessels with helical thickenings . . . . *Sclerolobium costaricense*
21b. Rays multiseriate 22
22a. Rays 1-10 cells wide, irregularly storied or storied, parenchyma apotracheal diffuse, scanty paratracheal and in marginal or in seemingly marginal bands . . . . *Swietenia macrophylla* or *Swietenia humilis*
22b. Rays 1 to 3 seriate 23
23a. Axial canals, parenchyma vasicentric, lozange-aliform; confluent, and wide band banded with 2 and 3-4 cells per parenchyma strand . . . . *Prioria copaifera*
23b. Axial canals absent 24
24a. Rays storied 25
24b. Ray not storied. 27
25a. Ray homogeneous 26
25b. Ray heterogeneous, 1-3 cells wide, parenchyma apotracheal diffuse and diffuse-in-aggregates, scanty, vasicentric, in narrow bands or lines up to three cells wide and in marginal or in seemingly marginal bands. . . . . *Dalbergia retusa*
26a. Parenchyma lozenge-aliform, winged-aliform and unilateral parenchyma, and prismatic crystals in chambered cells . . . . *.Dipteryx panamensis*
26b. Parenchyma vasicentric, lozenge-aliform, unilateral, and in marginal or in seemingly marginal bands . . . . *Tabebuia guayacan*
27a. Ray heterogeneous. 28
27b. Ray homogeneous, parenchyma lozenge-aliform and confluent with 3-5 cells per parenchyma strand . . . . *Parkia pendula*
28a. Ray 1-3 seriate 29
28b. Ray 1-10 seriate, fibers pits common on both radial and tangential walls, two distinct sizes or types in the same ray cell; parenchyma bands more than three cells wide, reticulate and in marginal or in seemingly marginal bands. . . . . *Couratari guianensis*
29a. Apotracheal parenchyma absent 30
29b. Apotracheal parenchyma diffuse, vasicentric, lozenge-aliform winged-aliform and confluent, vessels with 2 distinct diameters, ray height over 1mm . . . . *Qualea paraensis*
30a. Rays homogeneous and heterogeneous, parenchyma in bands 2 cells wide, reticulate and in marginal or in seemingly marginal bands, reticulate bands 2 cells in width . . . . *Couratari scottmorii*
30b. Parenchyma in marginal or in seemingly marginal bands, narrow banded or reticulate with 5-8 cells per parenchyma strand . . . . *Oreomunnea pterocarpa*
31 a. Ray storied 32
31b Rays not storied 34
32a. Rays 1 to 3 seriate 33
32b. Larger rays commonly 4-10 seriate, ray height over 1mm, pits vestured; parenchyma lozenge-aliform, confluent, unilateral, in marginal or in seemingly marginal bands . . . . *.Peltogyne purpurea*
33a. Parenchyma confluent and banded, more than three cells wide . . . . *Dussia macroprophyllata*
33b. Parenchyma scanty paratracheal, confluent vasicentric and unilateral . . . . *Myroxylon balsamum*
34a. Pits vestured, axial paratracheal scanty and vasicentric with 2 and 3-5 cells per parenchyma strand. . . . . *Tachigali versicolor*
34b. Fibers with distinctly bordered pits, parenchyma diffuse and in bands more than three cells wide, reticulate and in marginal or in seemingly marginal bands . . . . *Lecythis ampla*
35a. Rays exclusively uniseriate; pits vestured. 36
35b. Rays 4-10 seriate, semi-ring or diffuse porous, parenchyma apotracheal diffuse, rays heterogeneous with sheath cells, higher than 1mm . . . . *.Cordia gerascanthus*
36a. Rays irregularly storied, parenchyma scanty, unilateral paratracheal, winged-aliform, marginal banded . . . . *Platymiscium pinnatum* var *polystachyum*
36b. Rays storied, parenchyma lozenge-aliform with long wings, and confluent . . . . *.Platymiscium pinnatum*
36c. Parenchyma lozenge-aliform and confluent . . . . *.Platymiscium curuense*
36d. Parenchyma lozenge-aliform and confluent, traumatic canals sometimes present. . . . . . . *.Platymiscium parviflorum*
37a. Axial canals present. 38
37b. Axial canals absent 39

38a. Parenchyma vasicentric, lozenge-aliform, confluent and in seemingly marginal bands . . . . *Copaifera camibar*
38b. Parenchyma vasicentric 1-2 cells in width, and in seemingly marginal bands. . . . . *Copaifera aromatica*
39a. Fibers septate; parenchyma diffuse, paratracheal scanty; vasicentric and in marginal or in seemingly marginal bands . . . . *Astronium graveolens*
39b. Ray 1-10 cells in width, storied, axial parenchyma lozenge-aliform, confluent, vasicentric and in bands more than three cells wide . . . . *Hymenolobium mesoamericanum*

Prumnopitys standleyi are similar in shape and frequency to the rays of *P. macrostachys*. No differences were seen among species in cross-field pit apertures.

DISCUSSION

Forty-five Costa Rican timber species are considered endangered or threatened. The Costa Rican government has decreed that 51% of these species are endangered and 49% of them are considered to be threatened. The CITES Appendices includes only eight of these species (*S. humilis*, *S. macrophylla*, *D. panamensis*, *G. sanctum*, *C. costaricense*, *O. pterocarpa*, *C. odorata* and *D. retusa*) (CITES 2002). All gymnosperms growing in the Costa Rican tropics are cataloged as endangered or threatened. However, most of the gymnosperm species in tropical areas around the world are in same situation; they are in decline or are restricted to isolated areas (Farjon *et al*. 1993).

The development of identification keys, like the one presented in this study, requires knowledge of wood characteristics and structure, as described in IAWA standards (IAWA 1989). Fluorescence provides a quick test for wood identification and it had been utilized by several authors for species separation. For example, Miller & Wiemann (2006) found differences in water and ethanol fluorescence between *Dalbergia nigra* and *D. spruceana*. Guzmán *et al*. (2008) found fluorescence species in the Anacardiaceae, Leguminose and Rubiaceae from Brazil and South Africa. Fluorescence is one of the important distinguishing characteristics of endangered or threatened timber species, although surface and water extract fluorescence can separate only six and eight timber species, respectively. Although, ethanol extract fluorescence was present in many timber species, the color of fluorescence was sometimes the same. However, three species were atypical in ethanol extract fluorescence color, the purple color found in *G. sanctum*, yellow in *P. purpurea* and bluish in *T. versicolor*, make them easy to identify. Guzmán *et al*. (2008) established that for Mexican timber identification it is necessary to use mixture of fluorescence tests and other characteristics, such as color or anatomical features. Likewise, identification of the endangered or threatened timber species from Costa Rica also requires anatomical studies. Species of *Cedrela* are easily separated from each other based on pore arrangement and axial parenchyma types. According to White & Gasson (2008), *C. odorata* is more ring-porous with more aliform parenchyma than *C. fissilis*. *Cedrela tonduzii* is similar to *C. odorata* and *C. fissilis*, although *C. tonduzii* is less ring porous. Aliform parenchyma is well defined in *C. tonduzii*, but not in *C. odorata*, *C. salvadorensis* or *C. fissilis. C. odorata* is considered to be easy to identify by its reddish color and distinct odor. Another important difference among *C. tonduzii* and other *Cedrela* species is that *C. tonduzii* has lower wood density than the other four species. *C. salvadorensis* has distinctive anatomical features that facilitate its identification; its rays are larger, commonly 4-10 seriate, than the rays of other *Cedrela* species, which are 1-3 seriate in width. Furthermore, its rays are heterogeneous and homogenous, but the rays of the other *Cedrela* species are not. However, Bonilla *et al*. (2004) reported that *C. salvadorensis* has 1-3 seriate rays, similar to those of other *Cedrela*. Therefore, we attribute the wider rays that we found in *C. salvadorensis* in Costa Rica to regional differences.

In species of *Platymiscium*, traumatic canals were seen in *P. parviflorum*, but not in other species. Traumatic canals have not been previously reported in *Platymiscium* (Espinoza & León 2002). Storied rays have been reported for most *Platymiscium*, for example *P. lasiucarpium*, *P. duckei*, *P. pinnatum* and *P. yucatanum* (Pérez 1993, Espinoza & León 2002). However, Detienne & Jacquet (1983) reported that rays are irregularly storied in *P. ulei*, similar to P. *pinnatum* var *polystachyum*.

The differences found in *Couratari* species agreed with previous research, which has also reported differences. For example Leon (2008) separated *C. guianensis* from *C. multiflora* by ray width, and Richter (1982) maintained that parenchyma distribution as well as type and configuration of inorganic contents can be employed for separating species of Lecythidaceae.

Canessa (1989) agreed with our results in *Copaifera* species; he found that the axial parenchyma in *C. camibar* was different than that of *C. officinalis* and *C. pubiflora*. Parenchyma is reported to be vasicentric, aliform to confluent, and aliform of the lozenge type in these species (Melandri & Espinoza de Pernía 2009). The ray dimensions and axial parenchyma of some Copaifera species are characterized by high anatomy variation (Regina *et al*. 2002), and our results confirm that.

On the other hand, Patel (1967) found similar results in Podocarpaceae species when he evaluated axial parenchyma. They mentioned that numerous species of the genus *Podocarpus* are characterized by diffuse axial parenchyma and a considerable variation of trached cross-field pit apertures (size, form, number per cross-field). Scanty axial parenchyma in *P. guatemalensis* can be used for separating this species from other Podocarpaceae in Costa Rica. This is in agreements with *P. spicatus* growing in New Zealand, in which the lack of axial parenchyma is the main feature to separating it from other *Podocarpus* species. Abundant axial parenchyma also separates *P. macrostachys* from *P. costaricensis* and *P. guatemalensis*. Patel (1967) agreed with this result: he found that *P. dacrydioides* can be separated from *P. totara*, *P. hallii* and *P. acutifolius* by the abundance of axial parenchyma. Bauch *et al*. (2006) mentioned that *P. costarricensis* has more axial parenchyma than the commercially important species *P. salignus* growing in Chile and Argentina.

Many of the Costa Rican species included in this study, are also present in other tropical regions, and our results, both as wood descriptions and the identification key, and are applicable to the wider region. Species conservation is a goal for many countries, especially in countries where deforestation of natural forests has increased in the last few years. There is a strong interest to protect timber species which have been over-exploited for many years. This identification key and wood descriptions will assist in the protection of species categorized as endangered or threatened, and will promote reliable conservation plans.

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RESUMEN

Un total de 45 especies de árboles de Costa Rica se catalogaron como amenazadas o en peligro de extinción, de las cuales, CITES (Convention on International Trade Endangered Species) incluye solamente ocho en sus Apéndices. Sin embargo, la identificación de las especies basadas en su anatomía es muy limitada. El presente estudio tiene el objetivo describir y comparar la anatomía y la fluorescencia de las especies amenazadas o en peligro de extinción de Costa Rica. Muestras de madera de las especies en peligro de extinción o amenazadas de la xiloteca del Instituto Tecnológico de Costa Rica y del Laboratorio de Productos Forestales de los Estados Unidos en Wisconsin se examinaron, se describió su anatomía, se evaluó su actividad fluorescente y se midió su densidad. La superficie de la madera fue fluorescente en ocho especies, el extracto en agua fue fluorescente en seis especies y el extracto en etanol fue positivo en 24 especies. Muchas de las especies presentaban porosidad difusa, excepto algunas *Cedrela odorata*, *C. fissilis*, *Cordia gerascanthus C. salvadorensis* y *C. tonduzii* que presentaban porosidad semi-anular. Vasos con distribución déndrica se encontró en *Sideroxylon capari* y poros solitarios en *Guaiacum sanctum* y *Vantanea barbourii*. Los vasos más cortos se encontraron en *Guaiacum sanctum* y los vasos más largos en *Humiriastrum guianensis*, *Minquartia guianensis* y *Vantanea barbourii*. Finalmente, la información de la anatomía y de su fluorescencia se utilizó para construir una clave de identificación, donde la actividad de fluorescencia juega un papel importante en la identificación.

Palabras clave: fluorescencia, madera de Costa Rica, maderas tropicales, clave de identificación.

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