DOI: 10.29298/rmcf.v15i84.1453

Research article

Durabilidad natural de la madera de seis especies de importancia comercial en México

Natural durability of wood from six species of commercial importance in Mexico

Yolanda Ontiveros-Moreno[1], Serafín Colín-Urieta[2]*, Artemio Carrillo-Parra[3], Edgar Benjamín López-Camacho[4], José Javier Corral-Rivas[5], José Ciro Hernández-Díaz[3], José Ángel Prieto-Ruíz[5]

Fecha de recepción/Reception date: 6 de noviembre de 2023
Fecha de aceptación/Acceptance date: 14 de febrero del 2024

[1]Universidad Juárez del Estado de Durango, Programa Institucional de Doctorado en Ciencias Agropecuarias y Forestales. México.
[2]Universidad Intercultural Indígena de Michoacán. México.
[3]Universidad Juárez del Estado de Durango, Instituto de Silvicultura de la Industria de la Madera. México.
[4]Universidad Autónoma de Sinaloa, Escuela de Biología. México.
[5]Universidad Juárez del Estado de Durango, Facultad de Ciencias Forestales. México.

*Autor para correspondencia; correo-e: serafinscu@hotmail.com
*Corresponding author; e-mail: serafinscu@hotmail.com

Abstract

The natural durability of wood is defined as its intrinsic ability to resist degradation caused by biotic and abiotic factors. There are few records of natural wood durability in Mexico; in this study, it was determined based on the degradation of the wood of six commercial species: *Pinus durangensis*, *P. strobiformis*, *P. cooperi*, *Juniperus deppeana, Quercus sideroxyla*, and *Alnus acuminata*, in addition to *Fagus sylvatica* as the control. Test specimens were placed in contact with soil for 12 months at the *Mineral de Nuestra Señora de la Candelaria* Ecological Reserve of in *Cósala*, *Sinaloa*, and at the *Las Bayas* property in the state of *Durango*. Five specimens of each species were buried at 50 % of their length and analyzed following the UNE-EN 252:2015 European standard for determining degradation in wood, and UNE-EN 350:2016 for estimating durability. Due to the absence of normality (p<0.05) in the degradation data, the Kruskall-Wallis nonparametric test was used to determine statistical differences between species, locality, and puncture area. Statistical analysis was performed in the R-Studio program. According to UNE-EN 252:2015 and UNE-EN 350:2016, *J. deppeana* was the most durable wood classified as Class 1; *Q. sideroxyla*, *P. strobiformis*, *P. durangensis* and *F. sylvatica* (control) were Class 2 timbers, with slight damage; and *A. acuminata* and *P. cooperi* were classified as Class 3, with evident degradation. It is concluded that *J. deppeana* has the most durable wood.

Key words: Durability, *Fagus sylvatica* L., *Juniperus deppeana* Steud., soil, UNE-EN 252:2015, UNE-EN 350:2016.

Resumen

La durabilidad natural de la madera se define como la capacidad intrínseca que tiene para resistir la degradación ocasionada por factores bióticos y abióticos. Existen pocos registros de la durabilidad natural de la madera en México; en este estudio se determinó con base en la degradación de la madera de seis especies comerciales: *Pinus durangensis*, *P. strobiformis*, *P. cooperi*, *Juniperus deppeana*, *Quercus sideroxyla* y *Alnus acuminata*, además de

Fagus sylvatica como testigo. Se usaron probetas colocadas en contacto con el suelo por 12 meses en dos localidades: la Reserva Ecológica del Mineral de Nuestra Señora de la Candelaria en Cósala, Sinaloa, y el predio Las Bayas, Durango. Cinco probetas de cada especie se enterraron a 50 % de su longitud y se analizaron siguiendo la norma europea UNE-EN 252:2015 que determina la degradación en la madera, y la UNE-EN 350:2016 para la durabilidad. Debido a la ausencia de normalidad (p<0.05) en los datos de degradación, se usó la prueba no paramétrica de *Kruskall-Wallis* para determinar diferencias estadísticas entre especies, localidad y área de punzado. El análisis estadístico se realizó en el programa *R-Studio*. De acuerdo con las normas UNE-EN 252:2015 y UNE-EN 350:2016, *J. deppeana* fue la madera más durable clasificada como Clase 1; *Q. sideroxyla*, *P. strobiformis*, *P. durangensis* y *F. sylvatica* (control), fueron maderas Clase 2, con ligero daño; *A. acuminata* y *P. cooperi* clasificaron como Clase 3, con evidente degradación. Se concluye que *J. deppeana* presenta la madera más durable.

Palabras clave: Durabilidad, *Fagus sylvatica* L., *Juniperus deppeana* Steud., suelo, UNE-EN 252:2015, UNE-EN 350:2016.

Introduction

The term “durability of wood” refers to the intrinsic capacity of the woody material to resist degradation caused by attacks by fungi, bacteria, insects, and marine borers, as well as wear and tear caused by chemical and mechanical agents and weathering (photochemical degradation). The durability of wood is different from the organisms and environmental factors that can degrade it. In addition, the type and time of exposure also affect the speed of its deterioration (Sandberg *et al.*, 2021). The wood’s degree of rot allows to determine the natural or induced durability of a species. The level of weathering and rot is related to climatic conditions, incidence of UV rays, humidity, degree of soil aeration, amount of organic matter, pH, nutrients, presence of microorganisms, and time of exposure to degradation agents (Taraborelli *et al.*, 2020; Moreno *et al.*, 2022). Naturally, the durability of wood varies between species; it even differs according to what part of the tree the piece of wood is obtained from and the type of soil to which the tree is exposed (Ypushima, 2015).

Heartwood is more resistant than sapwood. The greatest durability is found at the base of the tree and decreases toward the upper parts of the stem. In some species, the relationship between durability and tree growth rate is inverse, so that low growth rates generate high-durability timbers (Hermoso *et al.*, 2015). Field and laboratory tests over long periods (from one to five years) to determine the natural durability of the wood are required to quantify damage from insects, microorganisms, and weathering, and to predict the useful life of the wood (Larsson-Brelid *et al*., 2011; Ibáñez *et al.*, 2016; Elgueta *et al.*, 2019).

De la Cruz *et al.* (2018) analyzed seven commercial timber species and classified *Juniperus deppeana* Steud., *P. cooperi* C. E. Blanco and *P. durangensis* Martínez as Class 3 (moderately durable); *P. teocote* Schltdl. & Cham. as Class 4 (less durable); and *P. strobiformis* Engelm., *Quercus sideroxyla* Bonpl. and *Arbutus* spp. as Class 5 (not durable).

In Mexico, given the competition in the market for wood and its substitution by other materials, such as plastic moldings, styrofoam and even foamy, the natural durability of some commercial woods is being studied. Based on durability research, sustainable development can be fostered by avoiding unnecessary logging and promoting good forest management. The objective of this work was to determine the natural durability of wood of six commercially important species and one control; the work was carried out in one location in the state of *Sinaloa* and another in the state of *Durango*; the durability category to which each taxon belongs, was determined according to the parameters of the UNE-EN 252:2015 (*Asociación Española de Normalización*, 2015) and UNE-EN 350:2016 (*Asociación Española de Normalización*, 2017) European standards.

Materials and Methods

Study areas

Two sites were selected to expose the wood of the studied species to the elements, both of which were considered to have different conditions of environmental humidity and temperature, as well as soil type (Table 1), and had no traces of crops, nor were they exposed to changes caused by humans.

Table 1. Climatic and soil description of the study sites.

Sites		*Las Bayas, Durango*	REMNSCC, *Sinaloa*
Geographical coordinates		23°22´ N and 104°48´ W	23°29´ N and 106°29´ W
[1]Climate type		CE (w_1) semicold-subhumid	AC (w_0) semiwarm-subhumid
Soil type		Sandy-silt and clay	Red and yellow clay
[2]pH		5.8 (medium-acid)	6.4 (lightly acidic)
[3]*EC* (mS cm^{-1})		0.49 (normal)	1.5 (very slightly salty)
[4]Organic matter (%)		0.28 (very low)	0.33 (very low)
[5]Texture	Sand (%)	37.6	39.6
	Silt (%)	35.6 (slightly clayey crumb)	35.6 (sandy crumb)
	Clay (%)	26.7	24.7

[1]Site climate type; [2]Soil pH; [3]Soil electrical conductivity; [4]Percentage of soil organic matter; [5]Soil texture.

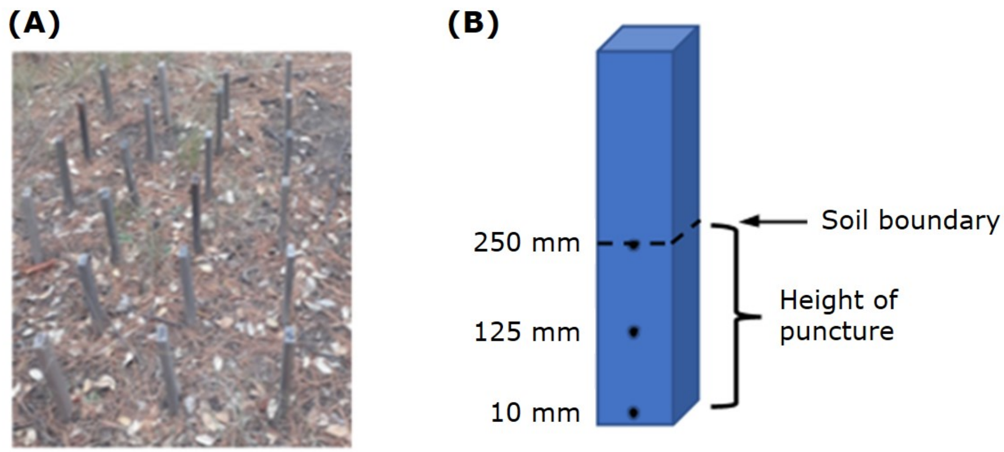
The first site was located in *Las Bayas* private property, *Pueblo Nuevo* municipality, *Durango*, which belongs to the *Universidad Juárez del Estado de Durango* (*UJED*); located at 23°22' N and 104°48' W, at 1 867 masl; the dominant vegetation is pine-oak forest, and its monthly temperature varies from 7 to 25 °C; the average monthly precipitation from January to May is 11 to 13 mm, from June to September it varies from 59 to 91 mm, and from October to December, from 33 to 17 mm (Raymundo *et al.*, 2012).

The second site was located in the *Mineral de Nuestra Señora de la Candelaria* Ecological Reserve in *Cósala*, *Sinaloa* (REMNSCC), which belongs to the *Universidad Autónoma de Culiacán* (*UAC*); which is located at 23°29' N and 106°29' W, at 418 masl; its orography is of hills and slopes up to 45°; the dominant vegetation is tropical deciduous forest, and its average monthly temperature varies from 10 to 35 °C; the average monthly precipitation from January to May is 2 mm, from June to August, 33 to 64 mm, and from September to December, 2 to 33 mm (Rubio *et al.*, 2010) (Table 1).

Analyzed species

The wood of *Juniperus deppeana*, *Quercus sideroxyla*, *Pinus cooperi*, *P. durangensis*, *P. strobiformis* and *Alnus acuminata* Kunth. was analyzed. The results were compared to *Fagus sylvatica* L., wood used as control, according to the European standards adopted for the analysis.

The dimensions of the wood specimens of all species were 50 mm×25 mm×500 mm in width, thickness, and length, respectively, as established by UNE-EN 252:2015 (*Asociación Española de Normalización*, 2015). Five specimens of the seven taxa were randomly placed at each site, amounting to 35 specimens total, placed in a 3 m×3 m plot. The specimens were positioned vertically, buried in the ground at half their 50 cm length, 30 cm apart from one another (Figure 1A).



A = Placement of specimens (below the ground); B = Distribution of incisions in 500 mm specimens.

Figure 1. Site with the cemetery-type test tubes installed and diagram of the distribution of the incisions

After a 12-month exposure period at the sites, the specimens were transferred to the laboratory (*Instituto de Silvicultura de la Madera*, *Isima*, of the *Universidad Juárez del Estado de Durango*) to evaluate their level of degradation. The section area of each specimen (1 250 mm^2) corresponded to the multiplication of 50 mm×25 mm, which was determined at the beginning, while the remaining area measured at the end of the test corresponded to the difference between the second and the initial measurements, expressed as a percentage. The analysis was performed following the parameters established in the UNE-EN 252:2015 (*Asociación Española de Normalización*, 2015) European standard, which classifies the durability of wood according to the deterioration of its surface that occurred when it was in contact with soil (Table 2), and in UNE-EN 350:2016 (*Asociación Española de Normalización*, 2017), which classifies wood according to its degree of durability when in contact with the ground (Table 3).

Table 2. Classification of degradation of wood specimens in contact with soil, according to the UNE-EN 252:2015 European standard.

Interval		Description of the condition	Maximum depth deteriorated	Minimum cross-sectional area	
			[mm]	[mm^2]	[%]
0	No attacks	No evidence of spoilage, softening or weakening caused by microorganisms	0	1 250	100
1	Light attack	Little evidence of deterioration, not significant up to a certain depth	1	1 104	88
2	Moderate attack	Significant evidence of deterioration, with deteriorated areas (softening or weakened wood) to a certain depth	3	836	67
3	Severe attack	Deterioration, softening and weakening, typical extensive fungal decay over large areas down to a certain depth	5	600	48
4	Failure	Fracture of specimens due to a bending test	50	0	0

Source: UNE-EN 252:2015 (*Asociación Española de Normalización*, 2015).

Table 3. Durability classification of wood specimens placed in contact with the ground, according to the UNE-EN 350:2016 European standard.

Durability classification	**Description**	***x*-value**
1	Very durable	$x>5$
2	Durable	$3<x\leq5$
3	Moderately durable	$2<x\leq3$
4	Less durable	$1.2<x\leq2$
5	Not durable	$x\leq1.2$

Source: UNE-EN 350:2016 (*Asociación Española de Normalización*, 2017).

In addition to the provisions of the aforementioned standards, the durability of the specimens was monitored through incisions no deeper than 5 mm at three heights of the part of the specimen exposed to the soil. To determine the degradation, an incision was made with a dissecting needle, the tip of which was marked with red. The first incision was made at a height of 250 mm, the second, at 125 mm, and the third, at 10 mm from the base of the specimen (Figure 1B).

Statistical analysis

Due to the absence of normality ($p<0.05$) in the data, the Kruskall-Wallis nonparametric test was used to determine if there were statistical differences between the factors analyzed (site, species, and area at puncture height). Statistical analyses were performed with RStudio (version 3.6.3) software (RStudio Team, 2020).

Results and Discussion

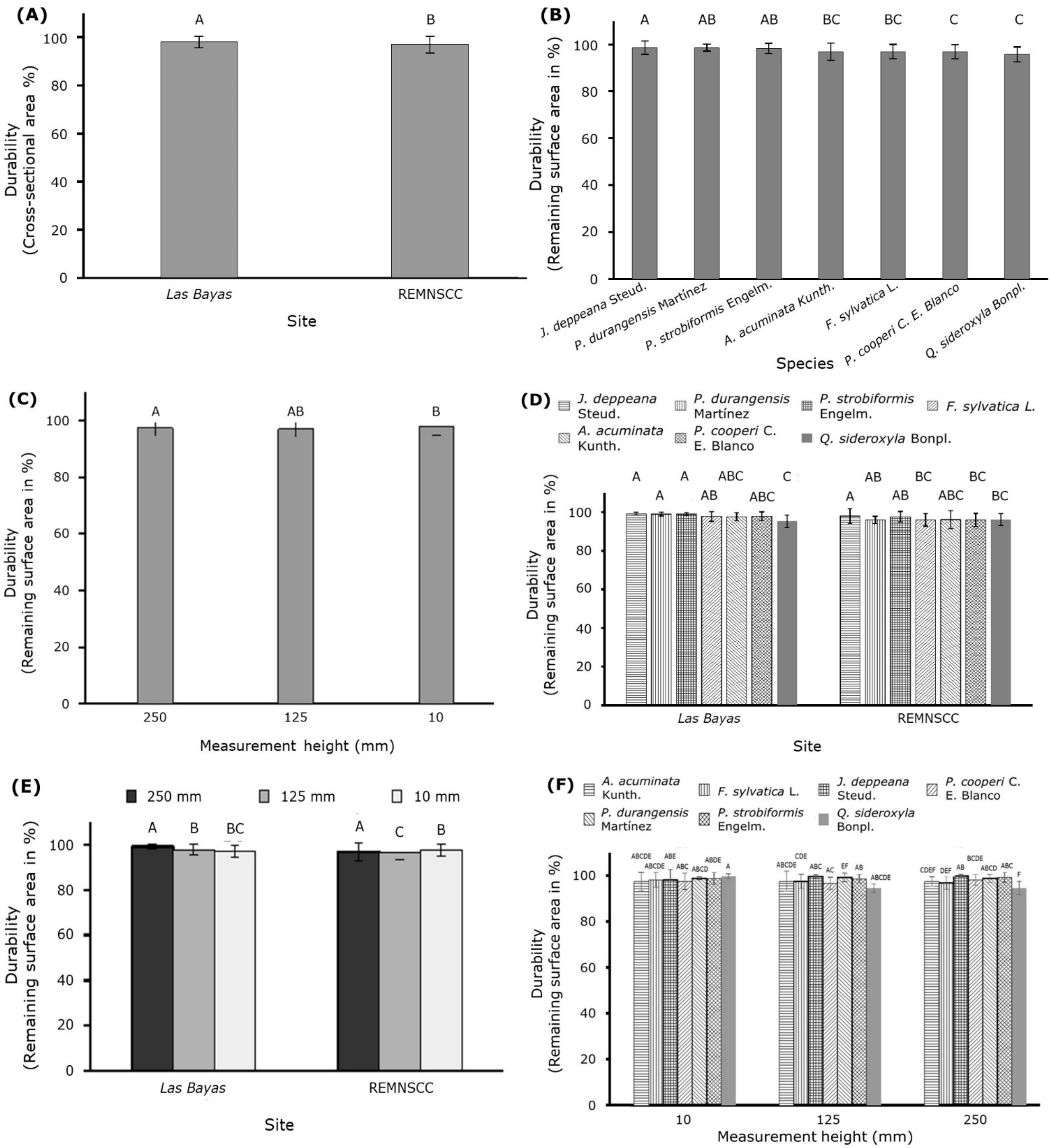
Wood durability

Wood durability, determined by the percentage of surface area remaining on the specimens after one year of exposure to soil, showed significant statistical differences ($p<0.05$) between sites, species, puncture areas, and their interactions (Table 4). In the comparison between sites, the wood from *Las Bayas* was more durable than that from the REMNSCC site, the mean values for all taxa were 98 and 96 %, respectively (Figure 2A). Although the durability of the wood differed significantly between the sites, in both cases the wood was classified as Class 1.

Table 4. Kruskal-Wallis (*H*) tests of wood durability of six commercially important species in Mexico and the control *Fagus sylvatica* L.

Factor	*H*	*df*	(p<0.05)
Site (S)	4.04	1	0.04
Species (Sp)	23.51	6	0.006
Area of puncture (A)	7.01	2	0.02
S:Sp	31.05	13	0.003
S:A	20.34	5	0.001
Sp:A	52.29	20	0.001
S:Sp:A	78.95	41	0.003

H = Kruskal-Wallis test value; *df* = Degrees of freedom.



A = Comparison between sites (*Las Bayas* and REMNSCC); B = Comparison between species; C = Comparison between heights of puncture (10 mm, 125 mm and 250 mm); D = Species/Site interaction; E = Site/Heights of puncture interaction; F = Species/Height of the area of puncture interaction.

Figure 2. Natural durability of the wood of the studied species according to the UNE-EN 252:2015 European standard.

The natural durability of wood showed significant statistical differences ($p<0.05$) between species; the remaining surface area of the specimens after one year of exposure to soil ranged between 95.73 and 98.61 % (Figure 2B). The most durable taxa (with least deterioration and softening) were *J. deppeana*, located in the highest statistical group, followed by *P. durangensis* and *P. strobiformis*; in turn, followed by *A. acuminata* and the control species, *F. sylvatica*; and, finally, *Q. sideroxyla* and *P. cooperi* (Figure 2B).

As for the heights of the specimens in which the durability was evaluated, significant differences were recorded ($p<0.05$). Durability ranged from 97.07 to 97.91 % (Figure 2C); at all heights, it was classified as Class 1 (little evidence of deterioration >88 %). However, at the incision height of 250 mm, the durability was located in the top group, followed by the height at 125 mm, and, finally, the height of 10 mm in all the species studied (Figure 2C). These results reveal that at ground level there was less deterioration of the seven analyzed species, whereas the greatest deterioration occurred at a height of 10 mm (base of the specimen). Therefore, the durability is reduced as the specimen sinks deeper; this suggests a direct relationship between burial depth and the degree of deterioration.

The natural durability of wood in the Site/Species interaction also exhibited significant statistical differences, with values ranging between 95.29 and 99.24 % (Figure 2D). The specimens that proved to have the highest durability (>88 %, little evidence of deterioration), placed in *Las Bayas*, corresponded to *J. deppeana*, *P. durangensis* and *P. strobiformis*; while only the *J. deppeana* specimens placed in the

REMNSCC showed the same degree of deterioration in both sites. On the other hand, the *Q. sideroxyla* specimens in both *Las Bayas* and REMNSCC exhibited the lowest durability among the studied species (Figure 2D).

It is worth mentioning that durability depends on the environmental conditions, which can have a huge impact on it (Meyer *et al.*, 2012); for example: wood will be more susceptible to decay in hot, humid conditions than in cold, dry climates; and its susceptibility will also increase if it is in contact with the ground.

The natural durability of wood in the Site/Measurement height interaction had significant statistical differences ($p<0.05$). Values ranged from 96.39 to 99.16 % (Figure 2E). The results presented four statistical groups, in which *Las Bayas* site at 250 mm recorded the least degradation, showing little evidence of deterioration or softening by microorganism attack. On the other hand, specimens from the REMNSCC site at 125 mm exhibited the lowest durability; however, they were included in the Class 1 category (little evidence of deterioration >88 %) (Figure 2E).

Colín-Urieta *et al.* (2018) point out that the combination of the visual assessment by UNE-EN 252:2015 standard and the puncture test allows to determine the value of deterioration in wood. Likewise, the combination of a warm, sub-humid climate with clay-sandy soil corresponds to an environment where the conditions favor wood decay (Ali *et al.*, 2011).

The durability in the Site/Species/Puncture height interaction exhibited significant statistical differences ($p<0.05$). Its values ranged from 93.43 to 99.68 % and it was rated Class 1 (little evidence of impairment >88 %). Statistically, 16 groups were identified; the puncture heights exhibited similar durability, showing little deterioration, softening or weakening attributable to microorganisms. However, in *P. cooperi*, a slight deterioration was observed at puncture heights two and three, corresponding to 10 and 125 mm in both soils (Figure 2F). Table 5 shows the results as percentages of natural durability of the analyzed species, according to site and puncture height, per the UNE-EN 252:2015 (*Asociación Española de Normalización*, 2015) and UNE-EN 350:2016 (*Asociación Española de Normalización*, 2017) standards.

Table 5. Natural durability according to the percentage of remaining cross-sectional area by site, species, and puncture height of the studied species.

Site	Height of puncture (mm)	Species						
		***Juniperus deppeana* Steud.**	***Alnus acuminata* Kunth.**	***Quercus sideroxyla* Bonpl.**	***Pinus durangensis* Martínez**	***Pinus strobiformis* Engelm.**	***Pinus cooperi* C. E. Blanco**	***Fagus sylvatica* L.**
Las Bayas	250	99.12	95.90	93.43	98.64	99	96.8	96.16
	125	98.92	99.5	93.44	99.16	98.68	97.0	98.33
	10	99.68	97.53	99.0	99.28	99.32	99.6	98.96
REMNSCC	250	99.40	97.81	94.63	98.52	98.36	98.4	96.43
	125	99.24	94.46	94.55	97.33	97.40	95.0	95.81
	10	95.28	96.14	99.36	98.76	97.09	95.2	96.11

The percentage of the remaining cross-sectional area was calculated by dividing the final area by the initial area and then multiplying the result by 100.

Natural durability

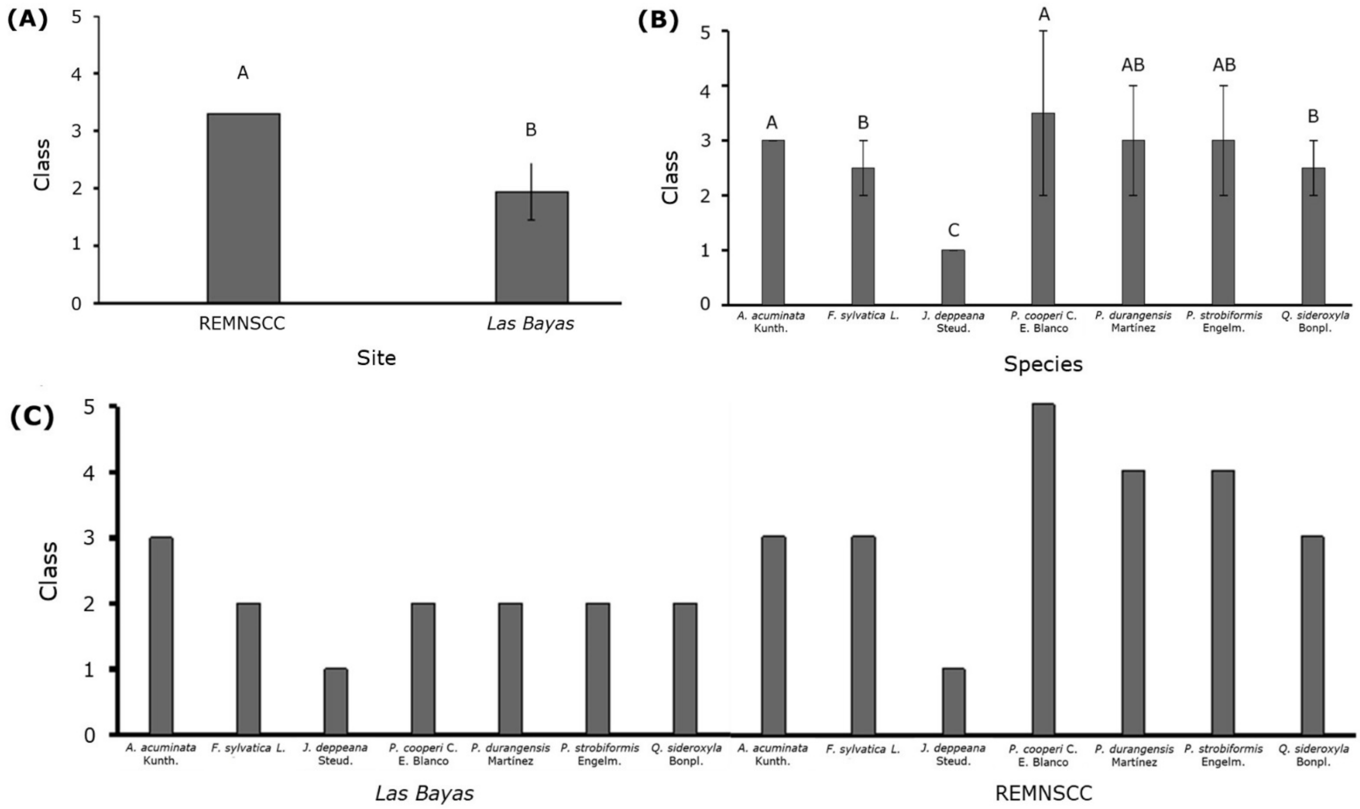
According to the Kruskal-Wallis test, the natural durability determined with the UNE-EN 350:2016 (*Asociación Española de Normalización*, 2017) European standard differed significantly between sites, species and Site/Species interaction ($p<0.05$) (Table 6).

Table 6. Kruskal-Wallis tests of the natural durability of wood of six commercially important timber species in Mexico according to the UNE-EN 350:2016 European standard.

Factor	*H*	*df*	(*p*<0.05)
Site (S)	72.25	1	<2.2e-16
Species (Sp)	90.40	6	<2.2e-16
S:Sp	194.00	13	<2.2e-16

H = Kruskal-Wallis test value; *df* = Degrees of freedom.

At the *Las Bayas* site, the average natural durability of the six species was rated Class 1; at the REMNSCC site, the woods deteriorated more, so they were placed in Class 3 (Figure 3A).



A = Durability by site; B = Durability by species; C = Durability by Site/Species interaction.

Figure 3. Natural durability of wood of six commercially important species in Mexico, exposed to soil at the REMNSCC sites in *Sinaloa* and *Las Bayas* in *Durango*, evaluated according to the UNE-NE 350:2016 European standard.

The results of the non-parametric Kruskal-Wallis test showed significant statistical differences between species ($p<0.05$) (Table 6). *Juniperus deppeana* exhibited the highest durability, being rated Class 1 (very durable); this durability can be considered to be related to the species' content of extractives, which may confer a higher level of resistance to termites, fungi, and even excess moisture. In Class 2 (durable), the woods of *Q. sideroxyla* and *F. sylvatica* (control) were classified. *P.*

durangensis and *P. strobiformis* were less resistant, and *A. acuminata* and *P. cooperi* were rated Class 3 (moderately durable) (Figure 3B).

Pinus durangensis, *P. strobiformis*, *Q. sideroxyla*, and *F. sylvatica* specimens placed at *Las Bayas* site were classified as durable. These test specimens showed some signs of rot and surface attack by termites. Finally, the wood of *A. acuminata* and *P. cooperi* corresponded to Class 3 (moderately durable) (Figure 3B). While in site REMNSCC, *Juniperus deppeana* was rated Class 1; *F. sylvatica* and *Q. sideroxyla*, Class 2; *P. durangensis* and *P. strobiformis*, Class 4 (less durable), with slight rot, and; finally, *P. cooperi*, Class 5 (not durable), due to total deterioration caused jointly by fungi and termites (Figure 3C).

In a similar study, Brischke *et al.* (2013) researched the durability of various woods exposed to six types of soil over a five-year period. As in the present study, these authors obtained differences in durability between sites; their results revealed that a soil with the presence of concrete caused greater erosion than other soils such as sand, gravel, and substrates modified by human intervention that induce reactions of the chemical components of soil and wood, which result in greater deterioration, compared to woods not exposed to soils without such intervention.

Honorato *et al.* (2001) observed that woods experience more decay in soils enriched with fertilizers and with a high humus content. As previously mentioned, the higher chemical activity in these soils contributes to the greater deterioration of the wood. In the research documented here, the greatest damage was observed at the site with deciduous forest soils (REMNSCC) and is attributed to the large amount of organic matter present in the soil.

Serna-Mosquera *et al.* (2020) evaluated the durability of *Ochroma pyramidale* (Cav. *ex* Lam.) Urb. wood subjected to three different treatments, with three replicates of 30 specimens each. The authors obtained no significant differences for moisture content or mass loss and recorded an increase in moisture content of 119.32 and

90.63 % in the specimens that placed them in low resistance categories not suitable for constructions in contact with soil. This coincides with the six species studied at the *Las Bayas* and REMNSCC sites, where *Pinus cooperi* was a non-durable wood, as in both sites it exhibited a higher deterioration than the other studied species. The authors cited above agree that the deterioration of wood in contact with the soil is mainly caused by moisture; Herrera *et al.* (2006) point out that decay is more severe in sapwood than in heartwood.

Conclusions

According to the UNE-EN 252:2015 and UNE-EN 350:2016 European standards, *Juniperus deppeana* wood is the most durable one and exhibits the least deterioration after being exposed to weathering in the soil of two experimental sites; therefore, it is included in Class 1.

Quercus sideroxyla, *Alnus acuminata*, and *Pinus cooperi* are durable woods, although they show some damage, and depending on the soil to which they were exposed, they are rated Class 2 or 3. Based on both European standards (UNE-EN 252:2015 and UNE-EN 350:2016), it was determined that all the species studied at *Las Bayas*, *Durango*, exhibited greater durability, so they are considered Class 1; while those studied at the REMNSCC site are Class 3, Class 4, and 5, with non-durable woods like that of *Pinus cooperi*.

The least damage for all wood species is observed at a puncture height of 250 mm. This indicates that there is less deterioration and greater durability at ground level (greater aeration) than at a height of 10 mm (base of the specimen, less aerated and with greater exposure to organic matter).

To more precisely establish the influence of site on the durability of wood species, future studies could explore a wider variety of taxa as well as environmental settings. Moreover, long-term research is needed to better understand how the deterioration evolves over time. It would also be relevant to evaluate the effectiveness of protective treatments in reducing deterioration and analyze the interaction between the measurement height and additional environmental factors such as rainfall, temperature, etc., in order to determine the effectiveness of these treatments.

Acknowledgements

To the National Council of Humanities, Science and Technology (Conahcyt, by its acronym in Spanish) for the support of the first author's doctoral scholarship. To the Institutional Doctorate Program in Agricultural and Forestry Sciences from the *Juárez* University of the State of *Durango*.

Conflict of interest

The authors declare that they have no conflict of interest in this research work.

Contributions by author

Yolanda Ontiveros-Moreno, Serafín Colín-Urieta and Artemio Carrillo-Parra: organization of research, field measurements, and drafting of the manuscript; Edgar Benjamín López-Camacho: data collection; José Javier Corral-Rivas, José Ciro Hernández-Díaz and José Ángel Prieto-Ruiz: data analysis, literature review, and drafting of the manuscript. The document was reviewed by all the authors.

References

Ali, A. C., E. Uetimane J., U. Råberg and N. Terziev. 2011. Comparative natural durability of five wood species from Mozambique. International Biodeterioration & Biodegradation 65(6):768-776. Doi: 10.1016/j.ibiod.2011.03.010.

Asociación Española de Normalización. 2015. UNE-EN 252:2015 Ensayo de campo para determinar la eficacia protectora relativa de un protector de madera en contacto con el suelo. Asociación Española de Normalización. Madrid, MD, España. 25 p.

Asociación Española de Normalización. 2017. UNE-EN 350:2016 Durabilidad de la madera y de los productos derivados de la madera. Ensayos y clasificación de la resistencia a los agentes biológicos de la madera y de los productos derivados de la madera. Asociación Española de Normalización. Madrid, MD, España. 60 p.

Brischke, C., L. Meyer, G. Alfredsen, M. Humar, … and P. Larsson-Brelid. 2013. Natural durability of timber exposed above ground a survery. Drvna Industrija 64(2):113-129. Doi: 10.5552/drind.2013.1221.

Colín-Urieta, S., A. Carrillo-Parra, J. G. Rutiaga-Quiñones, P. López-Albarrán, R. Gabriel-Parra and M. Ngangyo-Heya. 2018. Natural durability of seven tropical timber species in ground contact at three sites in Mexico. Journal of Tropical Forest Science 30(1):75-81. Doi: 10.26525/jtfs2018.30.1.7581.

De la Cruz C., R., A. Carrillo P., J. A. Nájera L., F. Cruz C., F. J. Hernández y J. Méndez G. 2018. Durabilidad natural de la madera de siete especies forestales de El Salto, Durango. Revista Mexicana de Ciencias Forestales 9(46):103-129. Doi: 10.29298/rmcf.v9i46.144.

Elgueta, P., R. Campos, G. Hernández, C. Reyes, … y P. Mardones. 2019. Durabilidad natural de la madera de pino Oregon (*Pseudotsuga menziesii* (Mirb.) Franco). Instituto Forestal, Área Tecnología y Productos de Madera. Concepción, CCP, Chile. 11 p.

Hermoso, E., J. Fernández-Golfín, M. Conde, M. T. Troya, … y M. Conde. 2015. Caracterización de la madera aserrada de *Pinus radiata* modificada térmicamente. Maderas, Ciencia y Tecnología 17(3):493-504. Doi: 10.4067/S0718-221X2015005000044.

Herrera B., J. F., A. M. Arango M. y J. Cano C. 2006. Metodología para el establecimiento de áreas cementerio de maderas en la región de Cotové (Antioquiotia, Colombia). Revista Facultad Nacional de Agronomía-Medellín 59(1):3271-3280. http://www.redalyc.org/articulo.oa?id=179914074012. (7 de febrero de 2021).

Honorato S., J. A., L. Vázquez S. y F. J. Zamudios S. 2001. Durabilidad natural de la madera de cinco especies de *Quercus* del estado de Puebla. Polibotánica (12):85-100. https://polibotanica.mx/index.php/polibotanica/article/view/666. (14 de febrero de 2021).

Ibáñez, C., C. Mantero, M. Rabinovich, R. Escudero y J. Franco. 2016. Ensayo de preservación de madera tratada con Zn y Mn: efectividad de tratamiento antilixiviantes con bórax luego de cinco años de contacto con el suelo. Madera, Ciencia y Tecnología 18(2):305-316. Doi: 10.4067/S0718-221X2016005000028.

Larsson-Brelid, P., C. Brischke, A. O. Rapp, M. Hansson, … and A. Pilgård. 2011. Methods of field data evaluation-time versus reliability. *In*: The International Research Group on Wood Protection (Edit.). The 42nd Annual Meeting of IRG, Proceedings IRG Annual Meeting. The International Research Group on Wood Protection. Stockholm, STO, Sweden. pp. 1-23. https://www.irg-wp.com/irgdocs/details.php?ccd7c744-6ed0-2960-71cc-24ee50947277. (29 de agosto de 2021).

Meyer, L., C. Brischke and A. Pilgård. 2012. Moisture performance based wood durability testing. *In*: The International Research Group on Wood Protection (Edit.). Proceedings IRG Annual Meeting. The International Research Group on Wood Protection. Kuala Lumpur, KL, Malaysia. pp. 1-26. https://www.irg-wp.com/irgdocs/details.php?fda7b0a3-fe62-1432-6761-05b0dc7e8bfa. (13 de mayo de 2021).

Moreno, K. G., E. M. Spavento y S. E. Monteoliva. 2022. Evolución del color y de la aparición de defectos en la madera de *Eucalyptus globulus* expuesta a intemperismo natural. Maderas, Ciencia y Tecnología 24(1):1-12. Doi: 10.4067/s0718-221x2022000100426.

Raymundo, T., M. Contreras, S. Bautista-Hernández, R. Díaz-Moreno y R. Valenzuela. 2012. Hongos tremeloides del bosque de las Bayas, municipio de Pueblo Nuevo, Durango, México. Polibotánica (33):85-103. https://www.scielo.org.mx/pdf/polib/n33/n33a6.pdf. (5 de junio de 2021).

RStudio Team. 2020. RStudio: Integrated Development for R (3.6.3). Boston, MA, United States of America. RStudio. http://www.rstudio.com/. (7 de marzo de 2020).

Rubio, Y., A. Beltrán y H. Bárcenas. 2010. El Mineral de Nuestra Señora, Cosalá, Sinaloa. *In*: Ceballos, G., L. Martínez, A. García, E. Espinoza, J. Bezaury C. y R. Dirzo (Edits.). Diversidad, amenazas y áreas prioritarias para la conservación de las selvas secas del Pacífico de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). Tlalpan, D. F., México. pp. 410-415.

Sandberg, D., A. Kutnar, O. Karlsson and D. Jones. 2021. Wood modification technologies: Principles, sustainability, and the need for innovation. CRC Press. Boca Raton, Fl, Unites States of America. 442 p.

Serna-Mosquera, Y. B., J. J. Torres-Torres y Y. Y. Asprilla-Palacios. 2020. Durabilidad natural de la madera de *Ochroma pyramidale* Urb. en el municipio de Atrato Colombia. Entramado 16(1):192-202. Doi: 10.18041/1900-3803/entramado.1.6105.

Taraborelli, C., M. M. Refort, E. Spavento, L. Maly, … y G. Keil. 2020. Evaluación de tratamientos superficiales en madera expuesta a condiciones de intemperismo natural. Revista de la Facultad de Agronomía, La Plata 119(1):1-9. Doi: 10.24215/16699513e039.

Ypushima P., A. L. 2015. Caracterización biológica y química de la madera de teca (*Tectona grandis*) en dos condiciones edafoclimáticas y su relación con el crecimiento. Tesis de Doctorado. Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara. Zapopan, Jal., México. 115 p. http://repositorio.cucba.udg.mx:8080/xmlui/handle/123456789/5885. (16 de junio de 2021).