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Review

An Updated Review of Dendrochronological Investigations in Mexico, a Megadiverse Country with a High Potential for Tree-Ring Sciences

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Abstract: Dendrochronology is a very useful science to reconstruct the long-term responses of trees and other woody plants forming annual rings in response to their environment. The present review considered Mexico, a megadiverse country with a high potential for tree-ring sciences given its high climatic and environmental variability. We reviewed papers considering Mexican tree species that were published from 2001 to 2016. Most of these studies examined tree species from temperate forests, mainly in the pine and fir species. The review included 31 tree species. The most intensively sampled family and species were the Pinaceae and Douglas fir (*Pseudotsuga menziessi* (Mirb.) Franco), respectively. Some threatened tree species were also studied. Dendrochronological investigations were mainly conducted in northern and central Mexico, with Durango being the most sampled state. The reviewed studies were mostly developed for hydroclimatic reconstructions, which were mainly based on the tree-ring width as a proxy for the climate. Tree-ring studies were carried out in both national and foreign institutions. Our review identified relevant research gaps for dendrochronologists such as: (i) biomes which are still scarcely studied (e.g., tropical dry forests) and (ii) approaches still rarely applied to Mexican forests as dendroecology.

Keywords: conifers; dendroecology; dendroclimatology; tree rings

1. Introduction

Dendrochronology is the science studying annual growth rings in trees and other woody plants by relating characteristics of these rings with the environmental conditions in which they were formed [1]. The features of tree rings constitute an indirect source for understanding the historical characteristics of the environment in which trees have grown [2]. Usually, sensitive tree species are chosen because they form annual growth rings with certain amount of variability, which allows for synchronizing tree-ring series of different trees growing at the same site. In this way, the targeted tree species should be able to record different types of temporal signals in their rings due to the variability of environment conditions, especially the climate [3–5].

One of the first dendrochronological investigations was carried out in America by Andrew E. Douglass, who found a clear dependence between the width of growth rings in pine species from the southwestern part of United States of America (USA) and precipitation [6]. Other early contributions to tree-ring sciences in the neotropical regions were based on quantifying the activity of the vascular cambium as related to climate [7] or in the study of specific tree species, often considering their cambium phenology [8,9]. In the southern part of America, one of the first tree-ring studies examined *Cedrela fissilis* [10]. As the species and site conditions of the earliest dendrochronological studies developed in the southwestern part of USA are similar to those encountered in many northern Mexico forests, this promoted the theory that Douglass' school, including disciples such as E. Schulman, pioneered tree-ring studies in semi-arid northern American forests [11].

This research along with others stimulated the birth and development of dendrochronology, which promoted the realization of new studies mainly applied to reconstruct climate (dendroclimatology) [12]. Some of these studies are being developed in Mexico [13].

Mexico is considered one of the main Latin-American countries with a higher potential for dendrochronological investigations, due to its high environmental and climatic heterogeneity. These conditions result in a high diversity of gymnosperm (pines, firs and cypresses) or angiosperm tree species (oaks), which often show a high longevity [14–16]. The first dendrochronological studies of Mexico were carried out in places close to El Salto (Durango) city for some species of pines [11]. In the last decades, a large number of studies have been carried out, mainly focusing on dendroclimatology [17–19].

Although these studies are becoming more numerous in Mexico, we still do not know the state of the art in this scientific field. To our knowledge, there is no report that documents the current situation in the country of dendrochronology and the perspectives offered by dendrosciences. The systematization of this collection in a database would provide an overview to identify the background, knowledge gaps and trends that research has taken depending on the tree species, scientific scope, geographical region and type of ecosystem among other specific data. This constitutes a starting point for researchers interested in further developing dendrosciences in Mexico.

The objective of this study was to analyze the dendrochronological investigations that have been performed in Mexican terrestrial ecosystems, based on an exhaustive literature review to generate a diagnosis and synthesize the dendrochronological perspectives in this megadiverse country with a great tradition in forestry and ecology. In general, we expected to find more conifers and deciduous broadleaf tree species from seasonal climate zones in these studies. This is due to their growth rings being better defined, which facilitates their synchronization or cross-dating and subsequent measurement, compared with tropical forests in which tree-ring delimitation and cross-dating are not so simple [1,20,21].

2. Materials and Methods

A bibliographic research of scientific articles developed in the subject of dendrochronology was done, using scientific Internet searcher engines (Web of Science-Thomson, Scopus, Science Direct, Google Academic, Redalyc). The research was performed considering studies published between the years of 2001 and 2016. The following English and Spanish keywords were used in: "dendrocronología", "dendrochronology", "anillos de crecimiento", "tree rings", "paleoclimatología", "paleoclimatology", "dendroclimatología", "dendroclimatology" "dendroecología" and "dendroecology". We included those publications based on studies that were developed in Mexico and excluded those that were not published in indexed journals, avoiding grey literature (thesis, memories of congresses, technical brochures, etc.).

From the research, a bibliographic database was built and analyzed, containing the following fields of information: vegetation type based on the classification of Land Use and Vegetation of the National Institute of Statistics and Geography (INEGI), studied tree species, site data (state, geographic coordinates and altitude), study objective and scope, journal where the study was published and measured variables (tree-ring width, earlywood and latewood widths, length of the series or chronologies) as well as the institution where the investigation was conducted.

3. Results

A total of 55 articles were found in indexed journals (see the complete list in the Appendix A). These studies were carried out at altitudes ranging from 1300 to 4000 m above sea level (Figure 1). More than half of the studies (53%) were carried out in forests located at more than 3000 m of elevation.

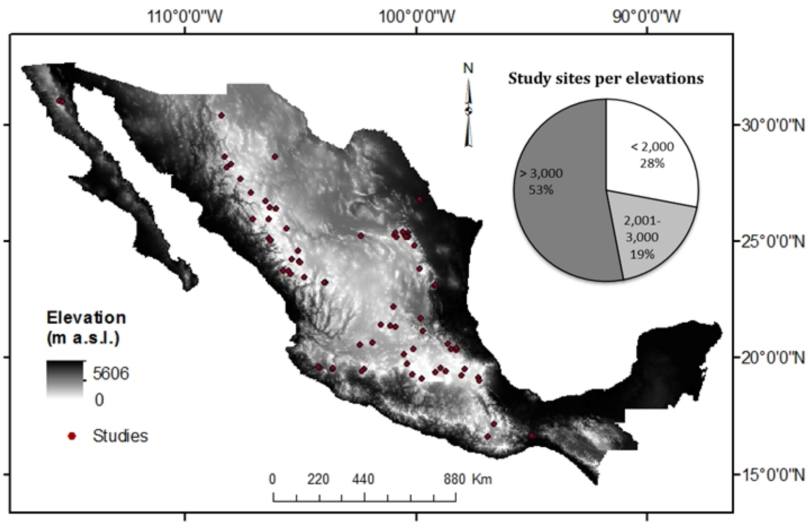

Figure 1. Sample sites of the dendrochronological studies carried out in Mexico. The upper right graph indicates the classification of sites based on their elevation.

Dendrochronological studies have been developed in seven different types of vegetation (Figure 2). Among them, 48% of the studies were developed for the pine species found within pine forests, which were the most studied type of vegetation, followed by the oyamel forest (*Abies religiosa* (Kunth) Schltdl. & Cham.) in 24% of the studies. The pine-oak forest was found in 14% of the studies and the gallery forest accounted for 8%. The types of vegetation that were less frequently studied included mountain mesophilous forest, coniferous scrubland and subtropical scrubland, with 2% of studies carried out in each one.

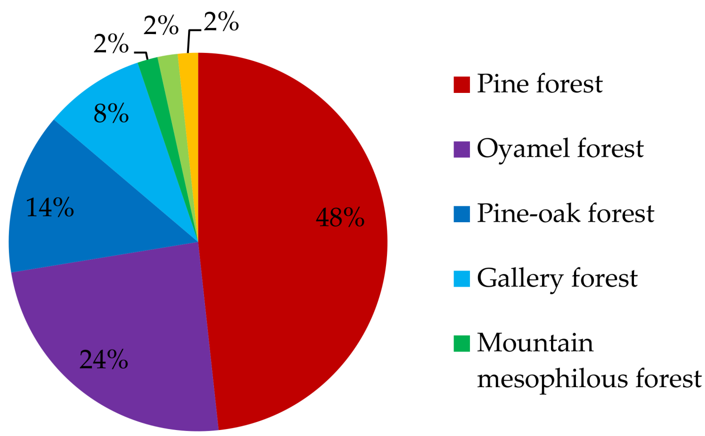

Figure 2. Percentages of studies classified according to the type of ecosystem following the classification of the National Institute of Statistics and Geography (INEGI).

Dendrochronological studies in Mexico examined 26 tree species, which were distributed in five families. The species of the Pinaceae family accounted for 82% of the studies, those of the Cupressaceae family accounted for 13%. Finally, the families Oleaceae, Fabaceae and Fagaceae were only considered in 2% of the studies for each family (Figure 3). The most studied genera were Pinus, Taxodium, Pseudotsuga and Abies. Pinus was the most intensively studied (16 species), showing concordance with the great diversity of this genus present in Mexico that represents a world center in the diversity of pines [22].

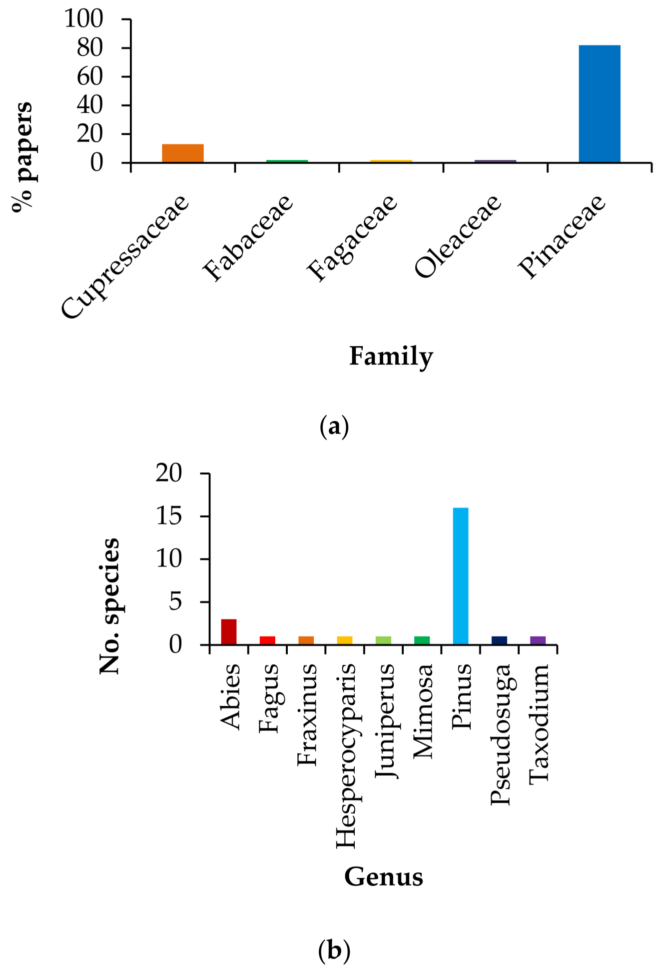

Figure 3. Dendrochronological studies performed in Mexico and grouped, according to (**a**) the taxonomic family and (**b**) the genus of the studied tree species.

The studied species and their frequency are reported in Figure 4. The tree species with a greater number of studies is *P. menziesii* (16 studies), which is considered as one of the most important species in dendrochronology due to its climate sensitivity, good cross-dating and wide geographical distribution [23]. Another tree species frequently studied was *Pinus cooperi* C.E. Blanco (11 studies), which also has remarkable dendrochronological potential [24–27]. These two species were followed by *Pinus hartwegii* Lindl. and *Taxodium mucronatum* Ten. (5 studies).

There were six species studied that fall within a category of risk such as endangered (P) or subject to special protection (Pr) according to the Official Mexican Standard 059 [28]: *Abies concolor* Lindl. (Pr), *Juniperus monticola* Martínez (Pr), *Pinus jeffreyi* Balf. (Pr), *Pinus lagunae* (Rob.-Pass.) Passini (Pr), *P. menziesii* (Pr) [29] and *Pinus pinceana* Gordon & Glend. (P) (Figure 4). This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

From the geographical point of view, dendrochronological studies in Mexico have been carried out in 20 states. Durango is the state most intensively sampled, followed by the states of Mexico, Chihuahua and Coahuila (Figure 5). These studies focused on the northern and central mountainous areas of the country, mostly in the Sierra Madre Occidental complex, which contains many temperate forests. A few studies in tropical ecosystems were found, whose research can be considered incipient in relation to other Latin-American countries [16,21,30,31].

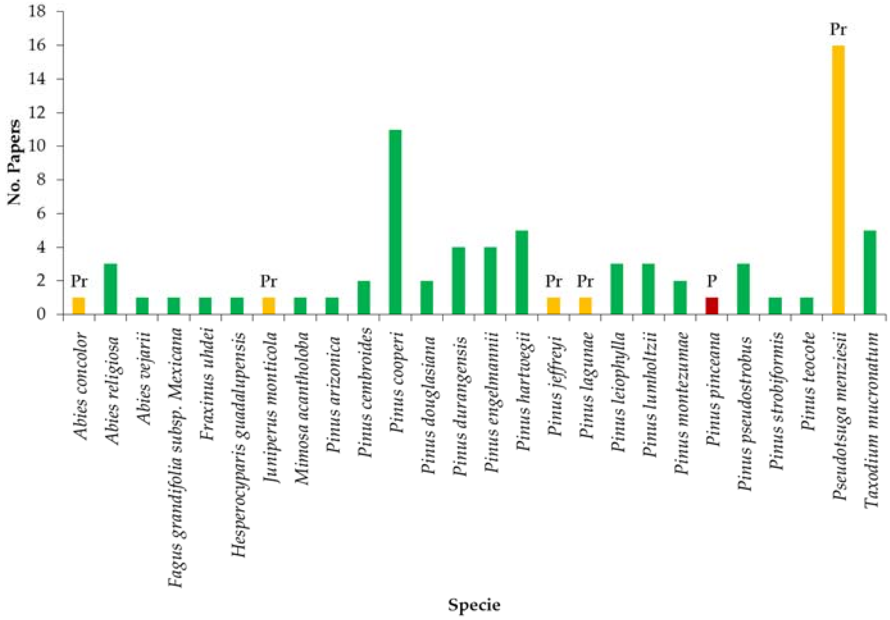

Figure 4. Number of dendrochronological studies carried out in Mexico grouped according to the sampled species and its conservation status. Yellow and red bars correspond to those trees species listed within a category in Mexican Official Standard 059 [28]. According to the Official Mexican Standard 059, "Pr" indicates those tree species subject to special protection and "P" indicates endangered tree species.

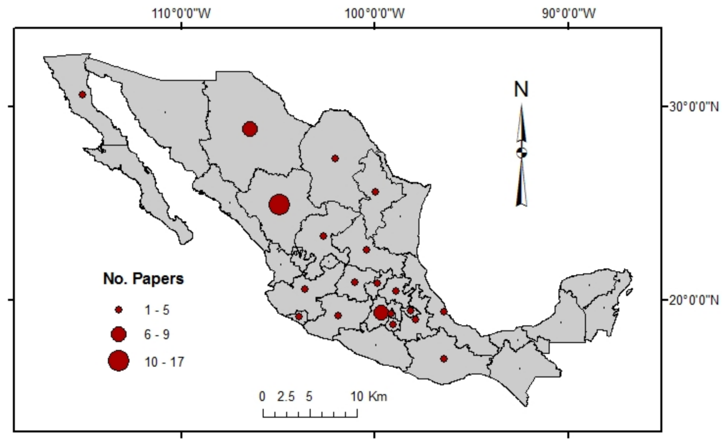

Figure 5. Dendrochronological studies performed in Mexico and grouped by states.

Regarding the temporary evolution, we observed an ascending tendency of the number of annual studies (n = 12) in the year 2016, with years 2003 and 2013 having more studies performed compared to the previous ones (n = 4 and 9 studies, respectively) (Figure 6).

In relation to the field of application, most of the studies have been developed with a climatic objective (n = 30 studies), usually for reconstructing precipitation. This is followed by those developed in the ecological (n = 23 studies) and hydrological (n = 3 studies) fields (Figure 7). A few studies were carried out in rarely explored fields, such as dendrogeomorphology or dendrochemistry (see Appendix A).

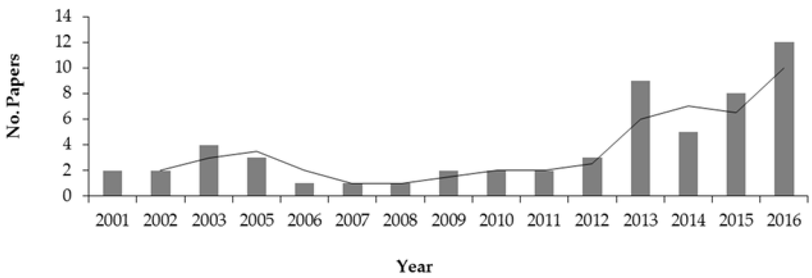

Figure 6. Dendrochronological studies realized in Mexico, grouped by year of publication.

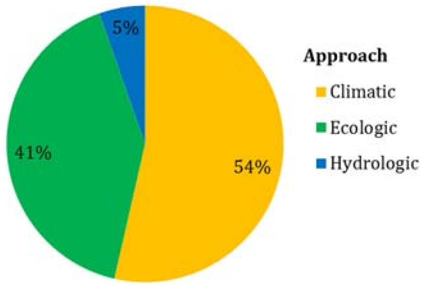

Figure 7. Dendrochronological studies performed in Mexico and grouped by its scope of application.

The journals in which the greatest numbers of Mexican dendrochronological studies have been published are mostly national journals covering 40% of the studies, such as: Madera y Bosques (n = 9 studies), Revista Chapingo-Serie Ciencias Forestales y del Ambiente (n = 5 studies), Agrociencia (n = 4 studies). This is followed by international journals, such as Dendrochronologia or Tree-Ring Research, which represent the remaining 60% of the studies (Figure 8).

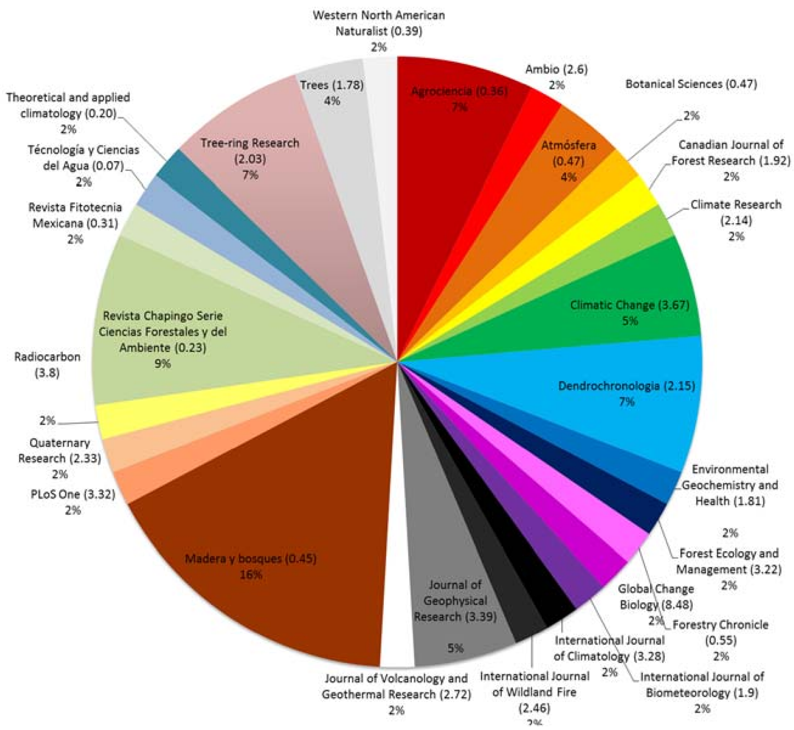

Figure 8. Dendrochronological studies on Mexican forests grouped according to the journal where they were published. The impact factor of each journal was estimated for 2015 citation data.

Dendrochronological studies have been carried out including measures of width of earlywood (EW), latewood (LW) and tree-ring width (TRW). A total of 37 studies were found for the case of TRW, while 7 studies were detected for EW. For LW, only 1 study was found. Some studies analyzed several of these variables (Figure 9). A few studies considered other variables, such as carbon and oxygen isotopes, wood density or scars due to fires or volcanic activity (see Appendix A).

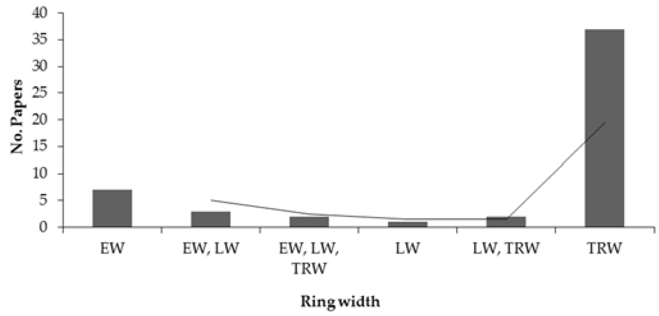

Figure 9. Dendrochronological studies performed in Mexico considering measurements of the width of earlywood (EW), latewood (LW) and total ring width (TRW).

The studies considered chronologies or mean series of tree-ring variables of different lengths or amplitudes, ranging from 49 to 607 years. Most studies are concentrated in an amplitude of 100 to 300 years (Figure 10). This is because some trees have sufficient longevity to contribute to the reconstruction of climatic events over a wide period of time. This is the case for the earlywood chronologies of up to 554 years of the extension of *P. menziesii* developed by Villanueva-Díaz et al. for temperate forests located in northern Mexico [24].

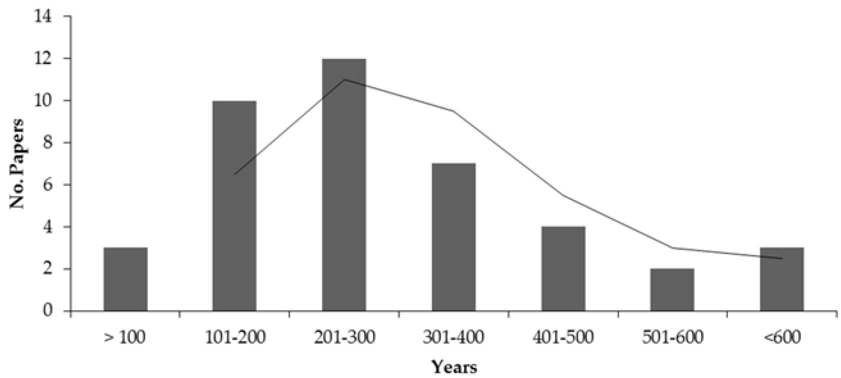

Figure 10. Dendrochronological studies performed in Mexico and grouped according to the amplitude or length of the chronologies.

The species that present a greater climatic sensitivity, quantified as correlations between climatic variables and tree-ring width, were *P. menziesii*, *T. mucronatum* and *P. cooperi*.

A total of 69% of the dendrochronological research was generated in Mexican institutions (Figure 11), with almost 60% concentrated in two of the nine national centers where the research was carried out, namely the National Institute of Forest, Agriculture and Livestock Research (INIFAP) located in Gómez Palacio (Durango) and the Juarez University of Durango State [32,33]. Of the national institutions, 71% correspond to educational centers and 31% to research centers. In Mexico, INIFAP is one of the few laboratories with a long tradition in dendrochronology. In other studies, such as Díaz et al. [34], Sheppard et al. [35] or González-Cásares et al. [36], some parts were conducted in overseas laboratories located mainly in United States of America (USA) and Europe. In USA, the universities of Northern Arizona, Arizona and Arkansas were the institutions in which a greater number of studies were carried out. The University of Arizona is considered as a pioneering center in conducting studies of this type in Mexico [8], although it has a smaller number of published studies compared to the University of Arkansas [37,38].

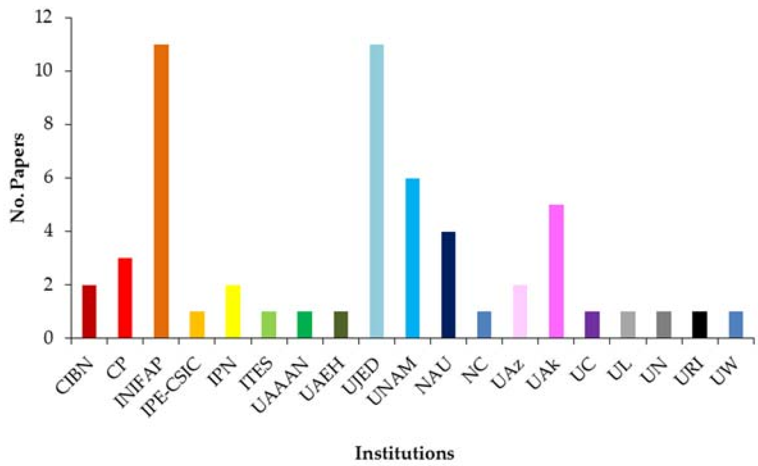

Figure 11. Research centers in which work is carried out around dendrochronological issues in Mexico estimated according to the first author of the study). The abbreviations are: National Center of Biological Research of the Northwest (CIBN), College of Postgraduates (CP), National Institute of Forestry, Agriculture and Livestock Research (INIFAP), Pyrenean Institute of Ecology (IPE-CSIC), National Politecnich Institute (IPN), Technological Institute of El Salto (ITES), Antonio Narro Autonomous Agrarian University (UAAAN), Autonomous University of Hidalgo State (UAEH), Juarez University of Durango State (UJED), National Autonomous University of Mexico (UNAM), Northern Arizona University (NAU), The Nature Conservancy (NC), University of Arizona (UAz), University of Arkansas (UAk), University of California (UC), University of Leeds (UL), University of Nevada (UN), University of Rhode Island (URI) and University of Washington (UW).

4. Conclusions

This is the first systematic review conducted for dendrochronological investigations carried out in Mexico that were published from 2001 until 2016 in indexed journals. Conifers are the most intensively sampled tree species because of their longevity and sensitivity to climate variability. Regarding the measured variables, most studies were based on the measurement of tree-ring width, although measuring earlywood and latewood features may also contribute to improving the reach of some studies. A lack of studies on tropical dry forests has been detected, which is an area of opportunity for the development of projects given the high richness of tree species found in this biome and because these forests experience seasonal droughts. There is a marked tendency in carrying out tree-ring studies focusing on climatic reconstructions, which suggests that it may be beneficial to broaden tree-ring sciences to encompass other research fields, such as ecology (dendroecology) or geomorphology (dendrogeomorphology). Dendrochronological studies are mostly published in international journals. Collaboration with national and international researchers is a great opportunity to promote the future development of dendrochronology in Mexico.

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Author Contributions: M.P.-G. and J.J.C. conceived and designed the review; A.C.A.-H. performed the review; all authors analyzed the data and wrote the paper.

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

Appendix A

Table A1. List of articles consulted on dendrochronology by species or Mexican forests published in indexed scientific journals.

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
1	2001	Ambio	Biondi, F.	A 400-year tree-ring chronology from the tropical treeline of North America.	Pinaceae	*Pinus hartwegii* Lindl.	Pine forest	Colima	Dendroclimatology	TRW
2	2001	International Journal of Climatology	Díaz, S.C.; Touchan, R.; Swetnam, T.	A tree-ring reconstruction of past precipitation for Baja California Sur, Mexico.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Pine-oak forest	Baja California	Dendroclimatology	TRW
3	2002	Climate Research	Díaz, S.C.; Therrell, M.; Stahle, D.; Cleaveland, M.	Chihuahua (Mexico) winter-spring precipitation reconstructed from tree-rings, 1647–1992.	Pinaceae	*Pinus lagunae* (Rob.-Pass.) Passini	Oyamel forest	Chihuahua and Durango	Dendroclimatology	EW
4	2002	Journal of Geophysical Research	Therrell, M.; Stahle, D.; Cleaveland, M.; Villanueva-Díaz, J.	Warm season tree growth and precipitation over Mexico.	Pinaceae, Cupressaceae	*Pseudotsuga menziesii* (Mirb.) Franco, *Pinus montezumae* Lamb., *Taxodium mucronatum* Ten.	Pine forest and Gallery forest	-	Dendroclimatology	LW and TRW
5	2003	Tree-ring Research	Pohl, K.; Therrell, M.; Blay, J.; Ayotte, A.; Cabrera, J.; Díaz, S.; Cornejo, E.; Elvir, J.; González, M.; Opland, D.; Park, J.; Pederson, G.; Bernal, S.; Vázquez, L.; Villanueva-Díaz, J.; Stahle, D.	A cool season precipitation reconstruction for Saltillo, Mexico.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Coahuila	Dendroclimatology	EW
6	2003	Climatic Change	Cleaveland, M.; Stahle, D.; Therrell, M.; Villanueva-Diaz, J.; Burns, B.	Tree-Ring Reconstructed Winter Precipitation and Tropical Teleconnections in Durango, Mexico.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Durango	Dendroclimatology	EW
7	2003	Canadian Journal of Forest Research	Stephens, S.; Skinner, C.; Gill, S.	Dendrochronology-based fire history of Jeffrey pine—mixed conifer forests in the Sierra San Pedro Martir, Mexico.	Pinaceae	*Pinus jeffreyi* Balf.	Pine forest	Baja California	Dendroecology	Fire scars

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
8	2003	Quaternary Research	Biondi, F.; Galindo I.; Gavilanes, J.; Elizalde, A.	Tree growth response to the 1913 eruption of Volcán de Fuego de Colima, Mexico.	Pinaceae	*Pinus hartwegii* Lindl.	Pine forest	Colima	Dendroecology	TRW
9	2005	Forest Ecology and Management	González-Elizondo, M.; Jurado, E.; Návar, J.; González-Elizondo, M.S.; Villanueva, J.; Aguirre, O.; Jiménez, J.	Tree-rings and climate relationships for Douglas-fir chronologies from the Sierra Madre Occidental, Mexico: A 1681–2001 rain reconstruction.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Durango and Zacatecas	Dendroclimatology	TRW
10	2005	Dendrochronologia	Therrell, M.	Tree rings and "El año del hambre" in Mexico.	Pinaceae		Oyamel forest	Durango and Zacatecas	Dendroclimatology	
11	2005	Dendrochronologia	Villanueva, J.; Luckman, B.; Stahle, D.; Therrell, M.; Cleaveland, M.; Cerano-Paredes, J.; Gutierrez-Garcia, G.; Estrada-Avalos, J.; Jasso-Ibarra, R.	Hydroclimatic variability of the upper Nazas basin: water management implications for the irrigated area of the Comarca Lagunera.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco, *Pinus durangensis* Martínez	Pine forest	Durango and Zacatecas	Dendrohydrology	EW
12	2006	Climatic Change	Therrell, M.; Stahle, D.; Villanueva-Díaz, J.; Cornejo-Oviedo, E.; Cleaveland, M.	Tree-ring reconstructed maize yield in central Mexico: 1474–2001.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Puebla	Dendroecology	LW
13	2007	Climatic Change	Villanueva-Diaz, J.; Stahle, D.; Luckman, B.; Cerano-Paredes, J.; Therrell, M.; Cleaveland, M.; Cornejo-Oviedo, E.	Winter-spring precipitation reconstructions from tree rings for northeast México.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Coahuila, Nuevo León and Tamaulipas	Dendroclimatology	EW
14	2008	Tree-ring Research	Sheppard, P.; Ort, M.; Anderson, K.; Elson, M.; Vazquez-Salem, L.; Clemens, A.; Little, N.; Speakman, R.	Multiple dendrochronological signals indicate the eruption of Paricutín volcano, Michoacán, México.	Pinaceae	*Pinus leiophylla* Schiede ex Schltdl. & Cham., *Pinus pseudostrobus* Lindl., *Pinus montezumae* Lamb., *Pinus teocote* Schltdl. & Cham.	Pine forest	Michoacan	Dendroecology	LW and TRW
15	2009	Madera y bosques	Villanueva Díaz, J.; Cerano Paredes, J.; Constante-García, V.; Fulé, P.; Cornejo, E.	Variabilidad hidroclimática histórica de la sierra de Zapalinamé y disponibilidad de recursos hídricos para Saltillo, Coahuila.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco, *Pinus cembroides* Gordon	Pine forest	Coahuila and Nuevo León	Dendroclimatology and dendrohydrology	EW, LW and TRW

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
16	2009	Madera y bosques	Cerano, J.; Villanueva, J.; Fulé, P.; Arreola, J.; Sánchez, I.; Valdez, R.	Reconstrucción de 350 años de precipitación para el suroeste de Chihuahua, México.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Chihuahua	Dendroclimatology	EW, LW and TRW
17	2010	Madera y bosques	Arreola-Ortiz, M.; González–Elizondo, M.; Návar–Cháidez, J.	Dendrocronología de *Pseudotsuga menziesii* (Mirb.) Franco de la Sierra Madre Oriental en Nuevo León, México.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Nuevo León	Dendroclimatology	TRW
18	2010	Madera y bosques	Santillán–Hernández, M.; Cornejo–Oviedo, E.; Villanueva–Díaz, J.; Cerano–Paredes, J.; Valencia–Manzo, S.; Capó–Arteaga, M.	Potencial dendroclimático de *Pinus pinceana* Gordon en la Sierra Madre Oriental	Pinaceae	*Pinus pinceana* Gordon & Glend.	Pine forest	Hidalgo, Queretaro, Zacatecas, San Luis Potosi and Coahuila	Dendroclimatology	TRW
19	2011	Western North American Naturalist	Bickford, I.; Fulé, P.; Kolb, T.	Growth Sensitivity to Drought of Co-Occurring Pinus spp. along an Elevation Gradient in Northern Mexico.	Pinaceae	*Pinus engelmannii* Carrière, *Pinus lumholtzii* B.L. Rob. & Fernald	Pine forest	Chihuahua	Dendroecology	TRW
20	2011	Revista Chapingo Serie Ciencias Forestales y del Ambiente	Cerano-Paredes, J.; Villanueva-Díaz, J.; Valdez-Cepeda, R.; Arreola-Ávila, J.; Constante-García, V.	El Niño Oscilación del Sur y sus efectos en la precipitación en la parte alta de la cuenca del río Nazas.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Durango	Dendrohydrology	TRW
21	2012	Técnología y Ciencias del Agua	Villanueva-Díaz, J.; Cerano-Paredes, J.; Estrada-Ávalos, J.; Constante-García, V.; Cortés-Barrera, E.	Variabilidad hidroclimática reconstruida con anillos de árboles para la cuenca Lerma Chapala en Guanajuato, México.	Pinaceae, Cupressaceae	*Taxodium mucronatum* Ten., *Pinus cembroides* Gordon	Pine forest and Gallery forest	Guanajuato, Jalisco and Queretaro	Dendroclimatology	TRW
22	2012	Revista Chapingo Serie Ciencias Forestales y del Ambiente	Villanueva Díaz, J.; Fulé, P.; Cerano Paredes, J.; Estrada Avalos, J.; Sánchez Cohen, I.	Reconstrucción de precipitación estacional para el barlovento de la Sierra Madre Occidental.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Oyamel forest	Durango	Dendroclimatology	EW
23	2012	Forestry Chronicle	Cassell, B.; Alvarado, E.	Reconstruction of fire history in Mexican tropical pines using tree rings.	Pinaceae	*Pinus douglasiana* Martínez	Pine forest	Jalisco	Dendroecology	TRW, fire scars

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
24	2013	Revista Chapingo Serie Ciencias Forestales y del Ambiente	Cerano-Paredes, J.; Méndez-González, J.; Amaro-Sánchez, A.; Villanueva-Díaz, J.; Cervantes-Martínez, R.; Rubio-Camacho, E.	Reconstrucción de precipitación invierno-primavera con anillos anuales de *Pinus douglasiana* en la Reserva de la Biosfera Sierra de Manantlán, Jalisco.	Pinaceae	*Pinus douglasiana* Martínez	Pine forest	Jalisco	Dendroclimatology	TRW
25	2013	Dendrochronologia	Pompa-García, M.; Cerano-Paredes, J.; Fulé, P.	Variation in radial growth of *Pinus cooperi* in response to climatic signals across an elevational gradient.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	TRW
26	2013	Agrociencia	Pompa-García, M.; Rodríguez-Flores, F.; Aguirre-Salado, C.; Miranda-Aragón, L.	Influencia de la evaporación en el crecimiento forestal.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	TRW
27	2013	Madera y bosques	Irby, C.; Fulé, P.; Yocom, L.; Villanueva, J.	Dendrochronological reconstruction of long-term precipitation patterns in Basaseachi National Park, Chihuahua, Mexico.	Pinaceae	*Pinus durangensis* Martínez, *Pinus lumholtzii* B.L. Rob. & Fernald, *Pinus engelmannii* Carrière	Pine forest	Chihuahua	Dendroclimatology	TRW
28	2013	Journal of Volcanology and Geothermal Research	Franco-Ramos, O.; Stoffel, M.; Vázquez-Selem, L.; Capra, L.	Spatio-temporal reconstruction of lahars on the southern slopes of Colima volcano, Mexico—A dendrogeomorphic approach.	Pinaceae	*Pinus leiophylla* Schiede ex Schltdl. & Cham.	Pine forest	Colima	Dendroecology	TRW, sacrs
29	2013	Radiocarbon	Beramendi-Orosco, L.; Hernandez-Morales, S.; Gonzalez-Hernandez, G.; Constante-Garcia, V.; Villanueva-Diaz, J.	Dendrochronological potential of *Fraxinus uhdei* and its use as bioindicator of fossil CO2 emissions deduced from radiocarbon concentrations in tree rings.	Oleaceae	*Fraxinus uhdei* (Wenz.) Lingelsh.	Subtropical scrubland	San Luis Potosi	Dendroecology	TRW
30	2013	Global Change Biology	Gómez-Guerrero, A.; Silva, L.; Barrera-Reyes, M.; Kishchuk, B.; Velázquez-Martínez, A.; Martínez-Trinidad, T.; Plascencia-Escalante, F.; Horwath, W.	Growth decline and divergent tree ring isotopic composition ($\delta^{13}C$ and $\delta^{18}O$) contradict predictions of CO_2 stimulation in high altitudinal forests.	Pinaceae	*Abies religiosa* (Kunth) Schltdl. & Cham., *Pinus hartwegii* Lindl.	Pine forest, Oyamel forest	Colima, Michoacan, Estado de México, Tlaxcala and Veracruz	Dendroecology	TRW, carbon and oxygen isotopes

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
31	2013	Journal of Geophysical Research	Brienen, R.; Hietz, P.; Wanek, W.; Gloor, M.	Oxygen isotopes in tree rings record variation in precipitation $\delta^{18}O$ and amount effects in the south of Mexico.	Fabaceae	*Mimosa acantholoba* (Humb. & Bonpl. ex Willd.) Poir.		Oaxaca	Dendroclimatology	TRW, oxygen isotopoes
32	2013	Journal of Geophysical Research	Meko, D.; Touchan, R.; Villanueva, J.; Griffin, D.; Woodhouse, C.; Castro, C.; Carillo, C.; Leavitt, S.	Sierra San Pedro Mártir, Baja California, cool-season precipitation reconstructed from earlywood width of *Abies concolor* tree rings.	Pinaceae	*Abies concolor* Lindl.	Oyamel forest	Baja California	Dendroclimatology	EW
33	2014	Theoretical and Applied Climatology	Pompa-García, M.; Jurado, E.	Seasonal precipitation reconstruction and teleconnections with ENSO based on tree ring analysis of *Pinus cooperi*.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroclimatology	TRW
34	2014	Agrociencia	Villanueva-Díaz, J.; Cerano-Paredes, J.; Gómez-Guerrero, A.; Correa-Díaz, A.; Castruita-Esparza, L.; Cervantes-Martínez, R.; Stahle, D.; Martínez-Sifuentes, A.	Cinco siglos de historia dendrocronológica de los ahuehuetes (*Taxodium mucronatum* Ten.) del Parque el Contador, San Salvador Atenco, Estado de México.	Cupressaceae	*Taxodium mucronatum* Ten.	Gallery forest	Estado de Mexico	Dendroclimatology	TRW
35	2014	Agrociencia	Correa-Díaz, A.; Gómez-Guerrero, A.; Villanueva-Díaz, J.; Castruita-Esparza, L.; Martínez-Trinidad, T.; Cervantes-Martínez, R.	Análisis dendroclimático de Ahuehuete (*Taxodium mucronatum* Ten.) en el centro de México.	Cupressaceae	*Taxodium mucronatum* Ten.	Gallery forest	Estado de México, Querétaro, Hidalgo and Morelos	Dendroclimatology	TRW
36	2014	Madera y bosques	Pompa-García, M.; Dávalos-Sotelo, R.; Rodríguez-Téllez, E.; Aguirre-Calderón, O.; Treviño-Garza, E.	Sensibilidad climática de tres versiones dendrocronológicas para una conífera mexicana.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine-oak forest	Durango	Dendroclimatology	TRW
37	2014	International Journal of Wildland Fire	Yocom, L.; Fulé, P.; Falk, D.; García-Domínguez, C.; Cornejo-Oviedo, E.; Brown, P.; Villanueva-Díaz, J.; Cerano, J.; Montaño, C.	Fine-scale factors influence fire regimes in mixed-conifer forests on three high mountains in Mexico.	Pinaceae	*Pinus hartwegii* Lindl., *Pinus strobiformis* Engelm., *Pseudotsuga menziesii* (Mirb.) Franco, *Abies vejarii* (Martínez)	Pine-oak forest	Coahuila and Nuevo León	Dendroecology	TRW, fire scars

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
38	2015	Revista Chapingo Serie Ciencias Forestales y del Ambiente	Chacón-de la Cruz, J.; Pompa-García, M.	Response of tree radial growth to evaporation, as indicated by early and latewood.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	EW and LW
39	2015	Atmósfera	Pompa-García, M.; Némiga, X.	ENSO index teleconnection with seasonal precipitation in a temperate ecosystem of northern Mexico.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine-oak forest	Durango	Dendroclimatology	TRW
40	2015	Madera y bosques	Carlón-Allende, T.; Mendoza, M.; Villanueva-Díaz, J.; Pérez-Salicrup, D.	Análisis espacial del paisaje como base para muestreos dendrocronológicos: El caso de la Reserva de la Biosfera Mariposa Monarca, México.	Pinaceae	*Abies religiosa* (Kunth) Schltdl. & Cham., *Pinus pseudostrobus* Lindl.	Pine-oak forest Oyamel forest	Michoacan and estado de Mexico	Dendroecology	TRW
41	2015	Madera y bosques	Villanueva, J.; Cerano, J.; Olivares, N.; Valles, M.; Stahle, D.; Cervantes, R.	Respuesta climática del ciprés (*Hesperocyparis guadalupensis*) en Isla Guadalupe, Baja California, México.	Cupressaceae	*Hesperocyparis guadalupensis* (S. Watson) Bartel	Pine forest	Baja California	Dendroclimatology	TRW
42	2015	Agrociencia	Pompa-García, M.; Camarero, J.	Potencial dendroclimático de la madera temprana y tardía de *Pinus cooperi* Blanco.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroclimatology	EW y LW
43	2015	International Journal of Biometeorology	Pompa-García, M.; Miranda-Aragón, L.; Aguirre-Salado, C.	Tree growth response to ENSO in Durango, Mexico.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	TRW
44	2015	Tree-ring Research	Pompa-García, M.; Camarero, J.	Reconstructing evaporation from pine tree rings in northern Mexico	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroclimatology	TRW
45	2016	Revista Fitotecnia Mexicana	Villanueva-Díaz, J.; Vázquez-Selem, L.; Gómez-Guerrero, A.; Cerano-Paredes, J.; Aguirre-González, N.; Franco-Ramos, O.	Potencial dendrocronológico de *Juniperus monticola* Martínez en el Monte Tláloc, México.	Cupressaceae	*Juniperus monticola* Martínez	Coniferous scrubland	Estado de Mexico	Dendroclimatology	TRW

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
46	2016	Madera y bosques	Díaz-Ramírez, B.; Villanueva-Díaz, J.; Cerano-Paredes, J.	Reconstrucción de la precipitación estacional con anillos de crecimiento para la región hidrológica Presidio-San Pedro.	Pinaceae	*Pinus durangensis* Martínez	Pine-oak forest	Sinaloa and Nayarit	Dendroclimatology	TRW
47	2016	PLoS One	Pompa-García, M.; Venegas-González, A.	Temporal Variation of wood Density and Carbon in Two Elevational Sites of *Pinus cooperi* in Relation to Climate Response in Northern Mexico.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	TRW, wood density
48	2016	Atmósfera	Pompa-García, M.; Hadad, M.	Sensitivity of pines in Mexico to temperature varies with age.	Pinaceae	*Pinus cooperi* C.E. Blanco	Pine forest	Durango	Dendroecology	TRW
49	2016	Trees	González-Cásares, M.; Pompa-García, M.; Camarero, J.	Differences in climate–growth relationship indicate diverse drought tolerances among five pine species coexisting in Northwestern Mexico.	Pinaceae	*Pinus lumholtzii* B.L. Rob. & Fernald, *Pinus durangensis* Martínez, *Pinus arizonica* Engelm., *Pinus engelmannii* Carrière, *Pinus leiophylla* Schiede ex Schltdl. & Cham.	Pine-oak forest	Chihuahua	Dendroecology	TRW
50	2016	Trees	Astudillo-Sánchez, C.; Villanueva-Díaz, J.; Endara-Agramont, A.; Nava-Bernal, G.; Gómez-Albores, M.	Climatic variability at the treeline of Monte Tlaloc, Mexico: a dendrochronological approach.	Pinaceae	*Pinus hartwegii* Lindl.	Pine forest	Mexico	Dendroclimatology	TRW
51	2016	Revista Chapingo Serie Ciencias Forestales y del Ambiente	Castruita-Esparza; L.; Correa-Díaz; A.; Gómez-Guerrero; A.; Villanueva-Díaz; J.; Ramírez-Guzmán, M.; Velázquez-Martínez, A.; Ángeles-Pérez, G.	Basal area increment series of dominant trees of *Pseudotsuga menziesii* (Mirb.) Franco show periodicity according to global climate patterns.	Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco	Pine-oak forest	Chihuahua	Dendroecology	TRW, basal area increment

Table A1. *Cont.*

No	Year	Journal	Authors	Title	Family	Tree Species	Ecosystem (INEGI Classification)	Region/State	Area of Application	Variable
52	2016	Botanical Sciences	Ortiz-Quijano, A.; Sánchez-González, A.; López-Mata, L.; Villanueva-Díaz, J.	Population structure of *Fagus grandifolia* subsp. *Mexicana* in the cloud forest of Hidalgo state, Mexico.	Fagaceae	*Fagus grandifolia* subsp. mexicana (Martínez) A.E. Murray	Mountain mesophilous forest	Hidalgo	Dendroecology	TRW
53	2016	Tree-ring Research	Torbenson, M.; Stahle, D.; Villanueva-Díaz, J.; Cook, E.; Griffin, D.	The relationship between earlywood and latewood ring-Growth across North America.	Pinaceae, Fagaceae, Cupressaceae	*Pseudotsuga menziesii* (Mirb.) Franco, *Pinus engelmannii* Carrière		-	Dendroecology	EW and LW
54	2016	Dendrochronologia	Carlón, T.; Mendoza, M.; Pérez-Salicrup, D.; Villanueva-Díaz, J.; Lara, A.	Climatic responses of *Pinus pseudostrobus* and *Abies religiosa* in the Monarch Butterfly Biosphere Reserve, Central Mexico.	Pinaceae	*Pinus pseudostrobus* (Lindl), *Abies religiosa* (Kunth) Schltdl. & Cham.	Pine forest	Michoacan and estado de Mexico	Dendroecology	TRW
55	2016	Environmental Geochemistry and Health	Morton-Bermea, O.; Beramendi-Orosco, L.; Martínez-Reyes, Á.; Hernández-Álvarez, E.; González-Hernández, G.	Increase in platinum group elements in Mexico City as revealed from growth rings of *Taxodium mucronatum* ten.	Cupressaceae	*Taxodium mucronatum* Ten.	Gallery forest	Cd. de Mexico DF	Dendroecology	TRW, chemical elements

Variables' abbreviations: TRW, tree-ring width; EW, earlywood width; LW, latewood width.

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