DOI:https://doi.org/10.29298/rmcf.v12i67.1079

Article

Análisis temporal de la distribución de *Dendroctonus mexicanus* Hopkins (1905) en México (2009-2018)

Temporal analysis of the distribution of *Dendroctonus mexicanus* Hopkins (1905) in Mexico (2009-2018)

Ramiro Perez-Miranda[1], Antonio González-Hernández[1], Efraín Velasco-Bautista[1], Martín Enrique Romero-Sánchez[1]*, Víctor Javier Arriola-Padilla[1] Miguel Acosta-Mireles[2]y Fernando Carrillo Anzures[2]

Resumen

En México, uno de los principales agentes de degradación forestal son los insectos descortezadores; entre ellos, *Dendroctonus mexicanus* es considerado uno de los más agresivos, ya que cada año afecta a varias especies de pino en México. El presente estudio tuvo como objetivo analizar la distribución temporal y espacial de esta especie, a partir de las bases de datos de las notificaciones forestales oficiales, entregadas a la Secretaría de Recursos Naturales (Semarnat) de 2009 a 2018. Las bases de datos se revisaron, analizaron y depuraron. Se correlacionó la variable área ecológica (norte, centro y sur) en la superficie afectada mediante un modelo de efectos fijos. Durante el intervalo de años en estudio, el escarabajo de la corteza se distribuyó en 25 estados de la república mexicana, principalmente en la Sierra Madre Occidental, Sierra Madre Oriental y Eje Neovolcánico Transversal. Los años con mayor número de registros fueron de 2012 a 2014, con presencia en bosques de pino-encino y encino-pino. Nuevo León, Chihuahua, Durango, Zacatecas y Michoacán tuvieron la mayor superficie afectada por D. *mexicanus*. Michoacán, Oaxaca, Durango, Estado de México, Nuevo León y Chihuahua fueron las entidades que presentaron una mayor cantidad de madera afectada por la plaga. El valor de la prueba global de $F_{2,14}$ (efectos fijos) fue de 17.99, y el valor *p* fue de 0.0001. Entre las tres zonas analizadas existen diferencias altamente significativas en cuanto a la variable de respuesta.

Palabras clave: Base de datos, bosques de pino, correlación, descortezador, fluctuación poblacional, insecto plaga.

Abstract

Bark beetles are one of the main agents of forest degradation in Mexico. Within this group, *Dendroctonus mexicanus* is considered the most aggressive because it affects several pine species every year. This study aimed to analyze the temporal and spatial distribution of this species based on databases from official forest notifications by the Ministry of Natural Resources (Semarnat) in Mexico from 2009 to 2018. The databases were reviewed, analyzed and debugged. The ecological zone (North, Center, and South) on the affected area variable was correlated by using a fixed effects model. During the interval of the years under study, the bark beetle was distributed in 25 Mexican states, mainly in the Western *Sierra Madre,* the Eastern *Sierra Madre* and the Transversal Neovolcanic Axis. The years with the highest number of records were from 2012 to 2014, when the beetle was present mainly in mixed pine-oak and oak-pine forests. *Nuevo León, Chihuahua, Durango, Zacatecas* and *Michoacán* are the states with *had* the largest surface areas affected by the beetle. *Michoacán, Oaxaca, Durango,* the State of *Mexico, Nuevo León* and *Chihuahua* had the largest volume of timber affected by the pest. The overall test value of $F_{2,14}$ (fixed effects) was 17.99, and the *p*-value was 0.0001. There are highly significant differences among the three zones analyzed, in regard to the response variable.

Key words: Data bases, pine forest, correlation, bark beetle, population fluctuation, insect pest.

Fecha de recepción/Reception date: 17 de febrero de 2021
Fecha de aceptación/Acceptance date: 7 de junio de 2021

[1]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Centro Nacional de Investigación Disciplinaria en Conservación y Mejoramiento de Ecosistemas Forestales. México.
[2]Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Valle de México. México.
Autor para correspondencia; correo-e: romero.martin@inifap.gob.mx

Introduction

Forests are an important livelihood for human populations, providing a variety of environmental goods and services (FAO, 2018). Mexico has a little more than 66 million hectares of temperate and tropical forest ecosystems; which amount to 33 % of the national territory (INEGI, 2016), of which 16 million hectares correspond to coniferous species (FAO, 2014). Historically, insect pests have caused damage to forest ecosystems, as responsible agents of growth reduction, deformation, weakening or death of the host individuals, which result in several ecological, economic and social impacts (FAO, 1993; Arguedas, 2006).

There are more than 70 species of insects in Mexico harmful to forest ecosystems (Semarnat, 2016a). Some natural factors that favor attacks by pests are meteorological phenomena, such as droughts, hurricanes and snowfalls, as well as fires and anthropogenic activities (Semarnat, 2008). The Ministry of Environment and Natural Resources (Semarnat, 2016a) recorded 50 483 ha affected by pests and diseases between 1990 and 2014, most of them by bark beetles (39 %), followed by mistletoes (32 %), defoliators (19 %), and borers (6 %).

In the last decades, pest outbreaks have increased, damaging thousands of trees, with the consequent economic losses of great magnitude for the producers (Díaz *et al*., 2006; del-Val and Sáenz-Romero, 2017). The most common debarking insects in North American pine forests belong to the following genera: *Dendroctonus* Erichson, *Ips* De Geer, *Scolytus* Geoffroy, *Hypothenemus* Ferrari, and *Tomicus* Latreille (Coleoptera: Curculionidae: Scolytinae) (Raffa *et al*., 2008; Smith *et al.,* 2013).

Under normal conditions, the effects of the *Dendroctonus* genus are minor and only kill a few isolated trees or small groups of trees; however, under certain circumstances, local populations can explode in epidemics that last several years and kill thousands of individuals over larger areas.

In Mexico, *Dendroctonus frontalis* Dietz (1890) and *Dendroctonus mexicanus* Hopkins (1905) are the most important species at medium to low altitudes at sea level, while *Dendroctonus adjunctus* Blandford (1897) has a greater impact in higher elevations (Salinas-Moreno *et al.,* 2004; Atkinson, 2017).

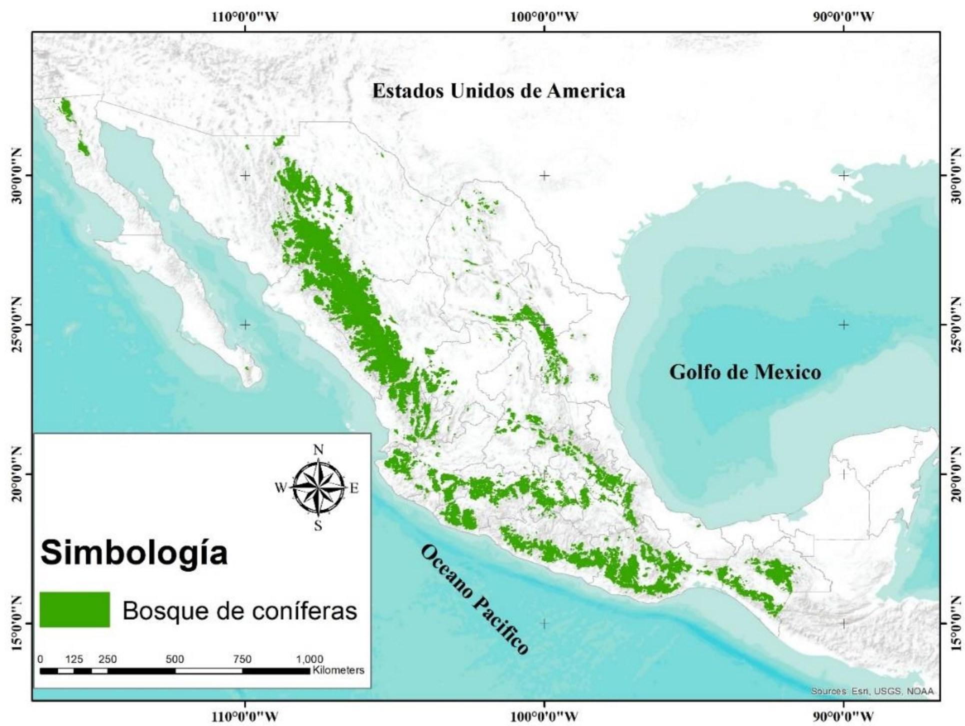
The Mexican pine beetle (*Dendroctonus mexicanus*) represents an essential factor in the degradation and loss of forest ecosystems in the country, with environmental, economic and social implications (Cibrián *et al*., 1995; Moser *et al*., 2005; Manzo-Delgado *et al*., 2014). For this reason, information must be generated for the development of protection strategies against possible outbreaks (Salinas-Moreno *et al*., 2010), as well as to determine the distribution of bark beetle taxa in order to identify forest areas at risk of infestation and prone to be affected (González-Hernández *et al*., 2020).

The presence of bark beetles can be prevented through surveillance, since timely detection and a good diagnosis increase the possibility of eradicating and managing the problematic species, as well as avoiding its dispersal to other sites (Sánchez-Martínez y Wagner 2009). The aim of this study was to analyze the temporal and spatial distribution of the Mexican pine beetle according to the databases of official forest notifications, delivered to the Ministry of Natural Resources (Semarnat) from 2009 to 2018, in order to statistically correlate the areas with the highest incidence of *D. mexicanus* through the years.

Materials and Methods

Study area

The natural distribution of pine forests in Mexico was considered as a reference (Figure 1), present in almost all of the country, except for the *Yucatán* Peninsula (Rzedowski, 2006; INEGI, 2016). Physiographically, they predominate in the Western *Sierra Madre*, the Eastern *Sierra Madre*, the Neovolcanic Axis and the Southern *Sierra* (INEGI, 2001). The climates where they grow are temperate sub-humid [C(w)], semi-warm sub-humid [(A)C], semi-arid and arid (BS), semi-cold sub-humid (Cb), warm sub-humid (Aw) (García and Conabio, 1998). The altitude at which they thrive varies from 200 to 4 200 masl (Inegi, 2018). The prevailing temperatures are 0 to 17 °C (Guevara and Arroyo, 2016; INEGI, 2016).



Source: INEGI (2016).

Figure 1. Location of coniferous forests in the Mexican republic

Data analysis

Geographic and general data on forest notifications. The geographic coordinates of the presence of the Mexican bark beetle were obtained from the databases provided by the Forest Health Analysis and Reference Department of the Forest Health and Genetic Resources Conservation Directorate of the General Directorate of Forest and Soil Management (DGGFS) of the *Subsecretaría de Gestión para la Protección Ambiental of the Secretaría de Medio Ambiente y Recursos Naturales (Semarnat)* (Undersecretariat of Management for Environmental Protection of the Ministry of the Environment and Natural Resources).

The information corresponded to the years 2009 to 2018 and comprised two types:

1) Pest information. Structured by the number of notifications of the presence of the pest, termed "Indicator", during the 2009 to 2013 and 2014 to 2018 periods.

2) Annual information. Referred to as "Indicator - geographic", from 2009 to 2018, on polygons of properties affected by *Dendroctonus mexicanus*.

The databases were first analyzed at the DGGF's Forest Health Analysis and Reference Laboratory and then debugged by specialists from the Forest Health area of the *Centro Nacional de Investigación Disciplinaria en Conservación y Mejoramiento de Ecosistemas Forestales* (Cenid Comef) (National Center for Disciplinary Research in Conservation and Improvement of Forest Ecosystems).

The criteria used for screening the information were that all notifications coincided with the natural distribution and host of the insect, as cited by different authors (Cibrián *et al*., 1995; Salinas-Moreno *et al*., 2010; Armendáriz-Toledano *et al.,* 2018). In addition, the scientific name recorded in the notifications was validated by entomologists from the Forest Health area of Cenid Comef.

For spatial data management purposes, the geographic coordinates in the notifications were converted to decimal degrees. The information was imported into the geographic information system (SIG) ArcGis™ 10.1 in order to create a layer of points in shapefile (SHP) format with the data corresponding to each record.

Subsequently, the geo-referenced data were evaluated, and the vertices of the polygons sampled for the pest were checked to ensure that they coincided with the logbook number and the indicated state. Notifications that did not meet this criterion were discarded. The analysis was performed by state of the republic in addition to screening the table of attributes of each spatial layer by logbook number, in order to avoid duplicity. Through geoprocessing in ArcGis™, information corresponding to the type of vegetation of each record was added, according to INEGI's Land Use and Vegetation Chart Series 6 (2016).

Statistical analysis

Based on the affected forest area in each state, the variable estimated in this study was generated: total affected surface area. From their geographic distribution, the state areas were grouped into one of the following zones: North, Central and South (Table 1). The zones were assigned for the purpose of data analysis and to keep the original arrangement of the data source.

Table 1. Geographic zoning.

Zones	**States***
North	*Aguascalientes (Ags), Chihuahua (Chih), Coahuila (Coah), Durango (Dgo), Nuevo León (NL), Sinaloa (Sin), Tamaulipas (Tamps), Zacatecas (Zac),*
Center	*Mexico City (CDMX), Guanajuato (Gto), Hidalgo (Hgo), Jalisco (Jal), State of Mexico (Mex), Michoacán (Mich), Morelos (Mor), Puebla (Pue), Querétaro (Qro), San Luis Potosí (SLP), Tlaxcala (Tlax), Veracruz (Ver).*
South	*Guerrero (Gro), Oaxaca (Oax), Chiapas (Chis)*

*Unique Catalog of Keys of State and Municipal Geostatistical Areas and Localities (Inegi).

The classification by large zones was due to the fact that abiotic factors, such as extended periods of drought, can trigger outbreaks of *Dendroctonus* sp.; in addition, the distribution of bark beetles is associated with altitude and latitude, among other factors (González-Hernández *et al*., 2020).

The following fixed effects model was used for statistical analysis (Montgomery, 2013):

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \,,\ \ \varepsilon_{ij} \sim N(0, \sigma^2)$$

Where:

y_{ij} = Total affected area in federal entity i of the zone j

i = 1, 2, …,17

j = 1,2,3

μ = Overall average

τ_i = Effect of zone j

ε_{ij} = Random error

Hypothesis: $H_0: \mu_j = \mu_{j'}$; $j = 1,2; j' = 2,3$; $H_1: \mu_j \neq \mu_{j'}$

Least squares mean differences were calculated as a measure of comparison between the different zones. In the case of the normality tests of the residuals, the tests of Shaphiro-Wilk, Kolmogorov-Smirnov, Cramer-von Misses, and Anderson-Darling were used.

All statistical analyses, fixed effects tests and residual analysis of the model were carried out within the statistical analysis system environment SAS® v9.3 (SAS, 2017).

Results and Discussion

General data of the notifications

A total of 4 231 records of the Mexican pine beetle were obtained for the 2009–2018 period. It must be noted that *Dendroctonus mexicanus* is sometimes confused with *D. frontalis* and *D. vitei* Wood (1974). However, both species it can be reliably differentiated by the shape of the seminal rod and the anchor; in particular, it differs from *D. vitei* by the absence of circular concavities on the anterior face of the antennal club (Cibrián *et al*., 1995; Armendáriz-Toledano *et al.,* 2018). As this differentiation is impossible to be made in the field, it was assumed that most of the records are correct after the quality control carried out by expert entomologists and indicated in the methods section.

The pest occurred in 25 of Mexico's 32 states, including *Mexico City, Sonora,* (Atkinson, 2019) and *Guanajuato*; this contrasts with the assertion by Salinas-Moreno *et al*. (2010) that the bark beetle is distributed in 23 states. *Michoacán* had the highest number of registrations, followed by the states of *Méx*, *Dgo*, *Qro*, *NL*, and *Chih*. On the other hand, *Ags*, *Sin*, *Tam*, *Ver*, followed by *Son*, *Coah*, *Col*, and *Chis* (Acronyms in Spanish), had the lowest number of records (Figure 2).

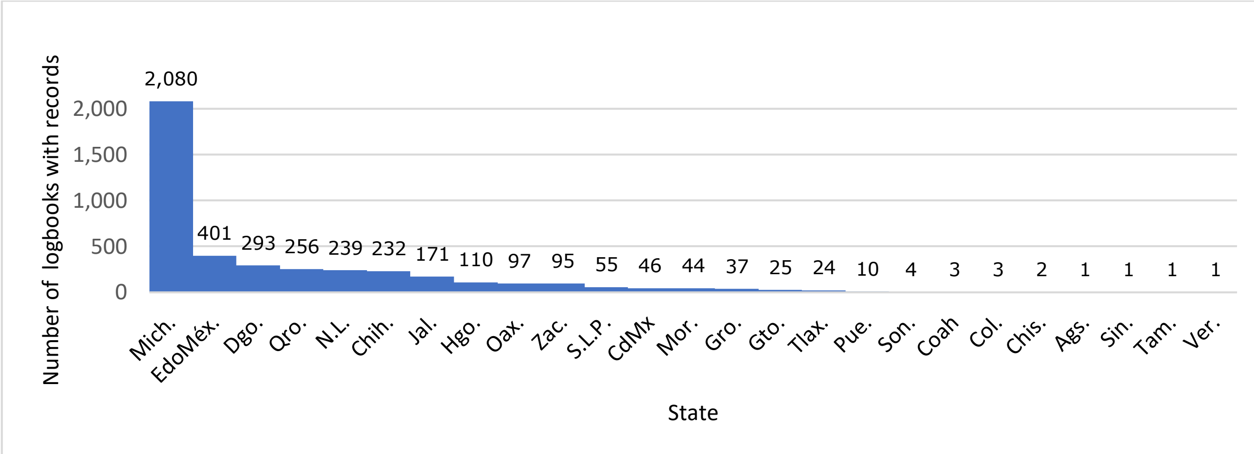
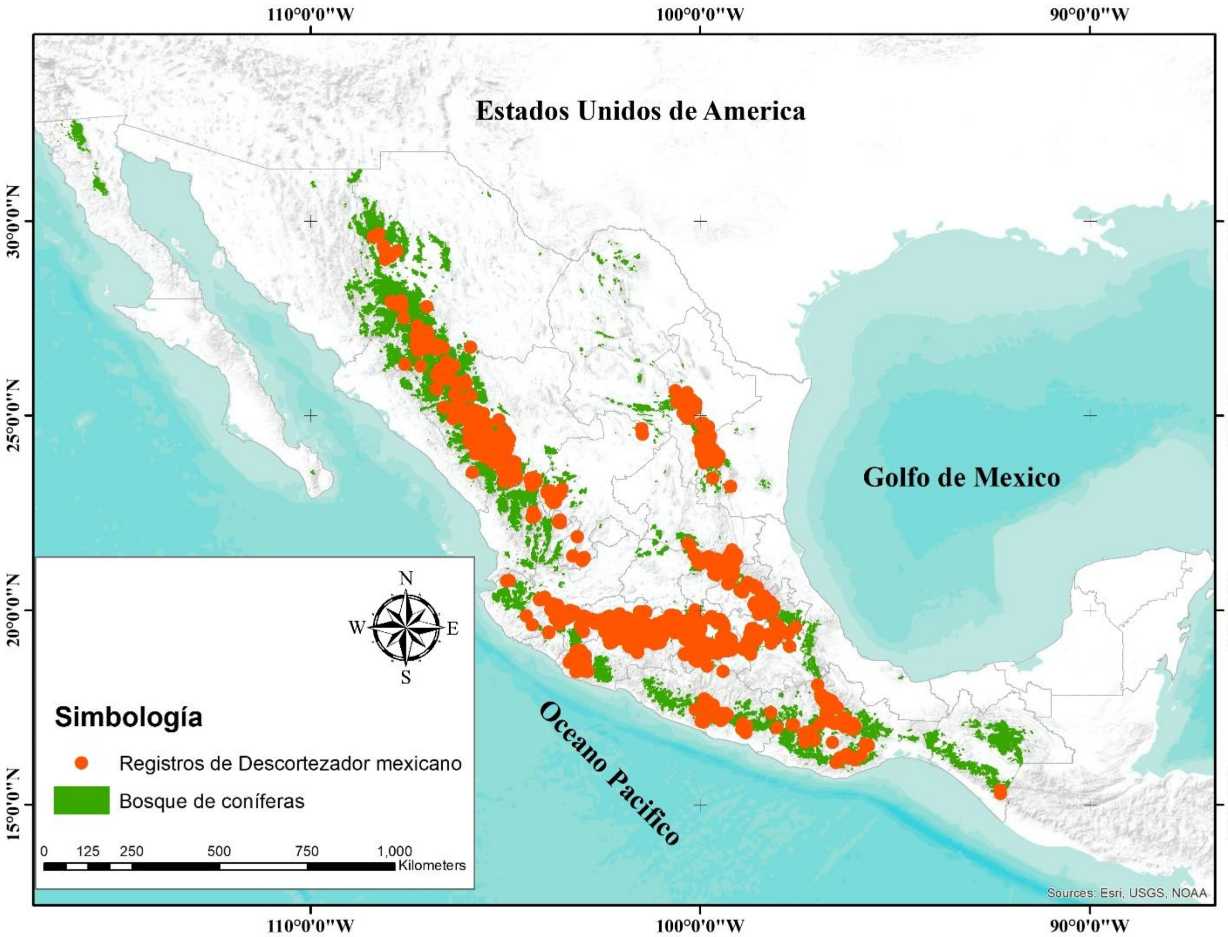


Figure 2. Logbooks with records of *Dendroctonus mexicanus* Hopkins (1905) by state (2009 to 2018).

Regarding the number and distribution of records of the Mexican bark beetle, the largest number coincided with the states with the highest timber production, while the lowest number corresponded to states with an intermediate to low level of timber production (Semarnat, 2016b).

As for its spatial distribution, a predominant tendency was observed in the Transverse Neovolcanic Axis, followed by the Western *Sierra Madre*, the Eastern *Sierra Madre* and the Southern *Sierra Madre* (Figure 3).



Simbología = Symbology; *Registros de descortezador mexicano* = Records of Mexican bark beetle; *Bosque de coníferas* = Coniferous forest.

Figure 3. Distribution in Mexico of the *Dendroctonus mexicanus* Hopkins (1905) records in coniferous vegetation.

Pest records showed a decline in the 2009-2011period, and an increase from 2012 to 2014, from which it declined to its lowest point (203 cases) in 2016, and then ascended (Figure 4).

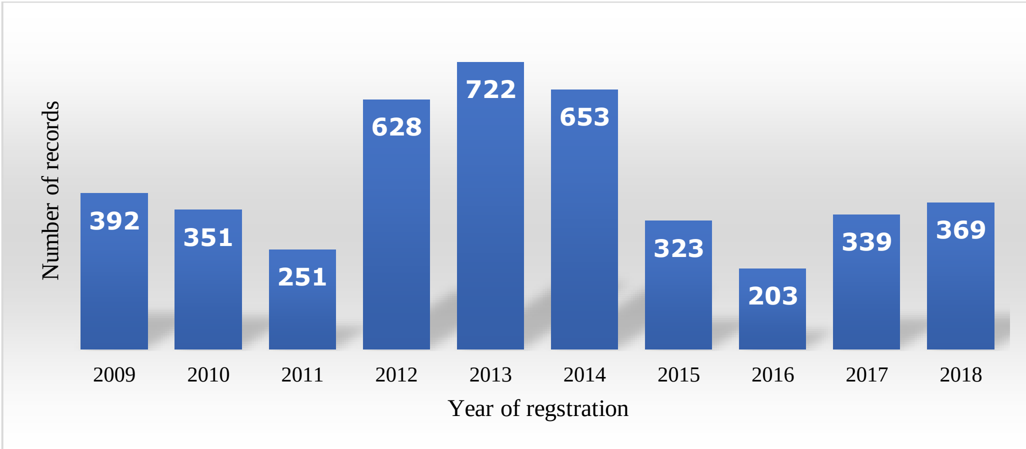


Figure 4. Number of *Dendroctonus mexicanus* Hopkins (1905) records from 2009 to 2018.

In general, the percentages of bark beetle records by vegetation type are described as follows: 72.66 % are found in natural coniferous forests, 47.2 % in mixed (pine-oak) forests, and 27.3 %, in disturbed (secondary) vegetation, according to the current nomenclature of the *Instituto Nacional de Estadística y Geografía, Inegi* (National Institute of Statistics and Geography). The data indicated that the pest was predominant mainly in primary forests (72.66 %).

The states with the highest presence of *D. mexicanus* in the period under analysis were, *Nuevo León, Chihuahua, Durango* and *Zacatecas*, adding up to 59.6 % of the total in the country. These states accounted for 39 895.7 ha of damaged pine forest (Table 2).

Table 2. Surface area with recorded infestation by the Mexican bark beetle by state during the 2009-2018 period (in hectares).

Num.	State	Affected area	%
1	*NL*	15 480.9	23.1
2	*Chih*	10 381.1	15.5
3	*Dgo*	8 936.4	13.3
4	*Zac*	5 097.3	7.6
5	*Mich*	3 806.3	5.7
6	*Gro*	3 796.3	5.7
7	*SLP*	3 725.0	5.6
8	*Mex*	3 399.3	5.1
9	*Oaxaca*	2 500.3	3.7
10	*Hgo*	2 148.1	3.2
11	*Gto*	1 880.1	2.8
12	*Jal*	1 771.2	2.6
13	*Qro*	1 321.3	2.0
14	*Mor*	1 246.90	1.9
15	*Son*	523	0.8
16	*Tlax*	328.3	0.5
17	*Chis*	216.5	0.3
18	*Pue*	155.2	0.2
19	*CDMX*	107.6	0.2
20	*Coah*	96.4	0.1
21	*Col*	12	0.0
22	*Ags*	11.6	0.0
23	*Son*	6.3	0.0
24	*Tam*	1.5	0.0
25	*Ver*	0.2	0.0
	Total	66 949.0	100.0

Durango, with 25 % of its forests, and *Chihuahua*, with 18 %, were the states with the largest forest area and timber production affected by bark beetles. Those with the lowest percentages were *Puebla* (0.2 %), Mexico City and *Coahuila* (0.2 %), and *Aguascalientes, Colima, Sonora, Tamaulipas* and *Veracruz*, which together totaled 0.05 %. 12 635 ha (equivalent to 19 % of the total surface area) of the states located in the central part of the country —*Jalisco, Michoacán*, State of México, *Morelos*, Mexico City, *Hidalgo, Puebla* and *Veracruz*—were affected, this being a region in which, according to certain authors, *Dendroctonus mexicanus* is commonly found (Salinas-Moreno *et al*., 2010; González-Hernández *et al.,* 2020). In the southern zone —*Guerrero, Chiapas* and *Oaxaca*— a total infested area of 6 513.1 ha (9.72 %) was recorded. It should be noted that the surface area affected by the Mexican bark beetle in *Oaxaca* has increased in the last decade (Conafor, 2020).

In regard to the seasonality of bark beetle damage during the period under study, the area with damage was variable. However, it was observed that in 2014, the highest percentage was 34.2 % of the total for the period, while in 2013 it represented 18.6 %, and 16.2 % in 2015, corresponding to 69.1 % of the total of the evaluated years.

The volume of damaged wood by *Dendroctonus mexicanus* was higher in *Michoacán, Oaxaca, Durango* and State of Mexico, which together totaled 1,014 455.6 m^3, equivalent to 71.1 % of the country's total. In contrast, those with the least damage were *Veracruz, Tamaulipas, Aguascalientes, Coahuila, Colima, Sonora* and *Sinaloa*, which accounted for 0.22 % of the total (Table 3). It is important to note that these entities do not have a considerable extension of conifers (INEGI, 2016), except for *Sinaloa*, where, we assume, due to its small forest area, there were fewer records than in the other states.

Table 3 Volume of timber affected by state in the 2009–2018 period in Mexico.

Num.	**State**	**Affected timber (m^3)**
1	*Mich*	438 198.6
2	*Oax*	306 006.5
3	*Dgo*	154 829.8
4	*Méx.*	115 420.7
5	*NL*	80 766.8
6	*Chih*	80 282.9
7	*Gro*	70 151.6
8	*Qro*	45 001.3
9	*Jal*	32 029.7
10	*Hgo*	27 707.9
11	*Zac*	19 871.6
12	*SLP*	15 842.4
13	*CDMX*	10 482.0
14	*Mor*	8 064.5
15	*Gto*	6 425.9
16	*Chis*	5 631.5
17	*Tlax*	4 954.9
18	*Pue*	1 735.9
19	*Sin*	1 400.0
20	*Son*	1 027.4
21	*Col*	219.0
22	*Coah*	198.8
23	*Ags*	140.2
24	*Tam*	112.5
25	*Ver*	7.6
	Total	1 426 510.1

It must be noted that the volume of affected timber fluctuated during the period under study; however, the trend was upward. In particular, from 2012 to 2014 there was a cumulative damage to timber of almost 50 % (Figure 5).

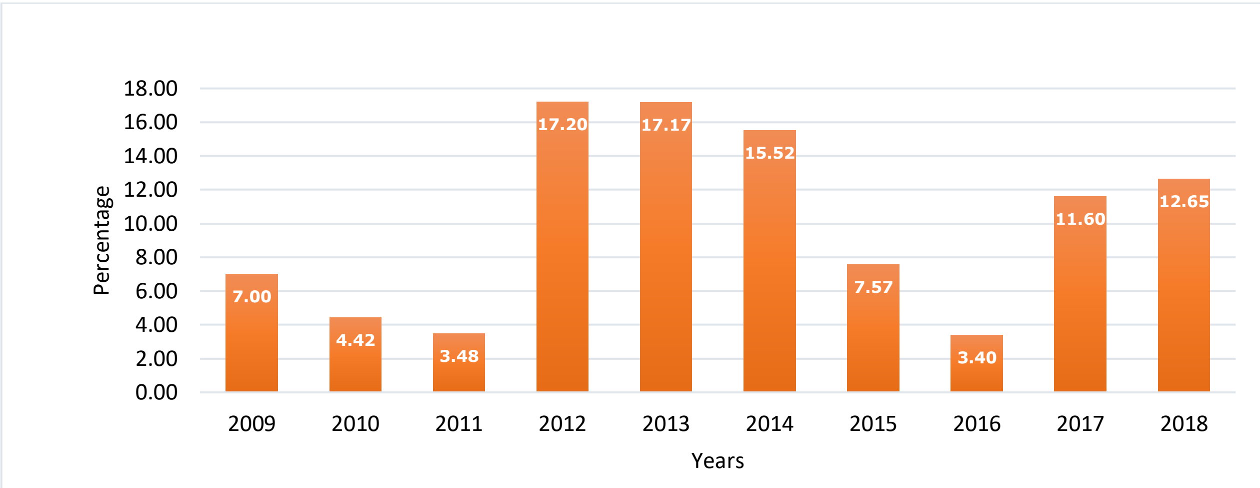


Figure 5. Percentage of damaged wood volume by *Dendroctonus mexicanus* Hopkins (1905) during the 2009–2018 period.

According to Safranyik *et al.* (2010) and Rubín-Aguirre *et al.* (2015), the growth of the population of bark beetles is limited by environmental variables such as temperature and humidity, which would explain the annual behavior for each particular area. For example, in 2012, the months in which most of the records were concentrated were August to December, January to May in 2013, and February to July in 2014 (Figure 6); for this reason, they must be analyzed according to the climatic conditions of each state.

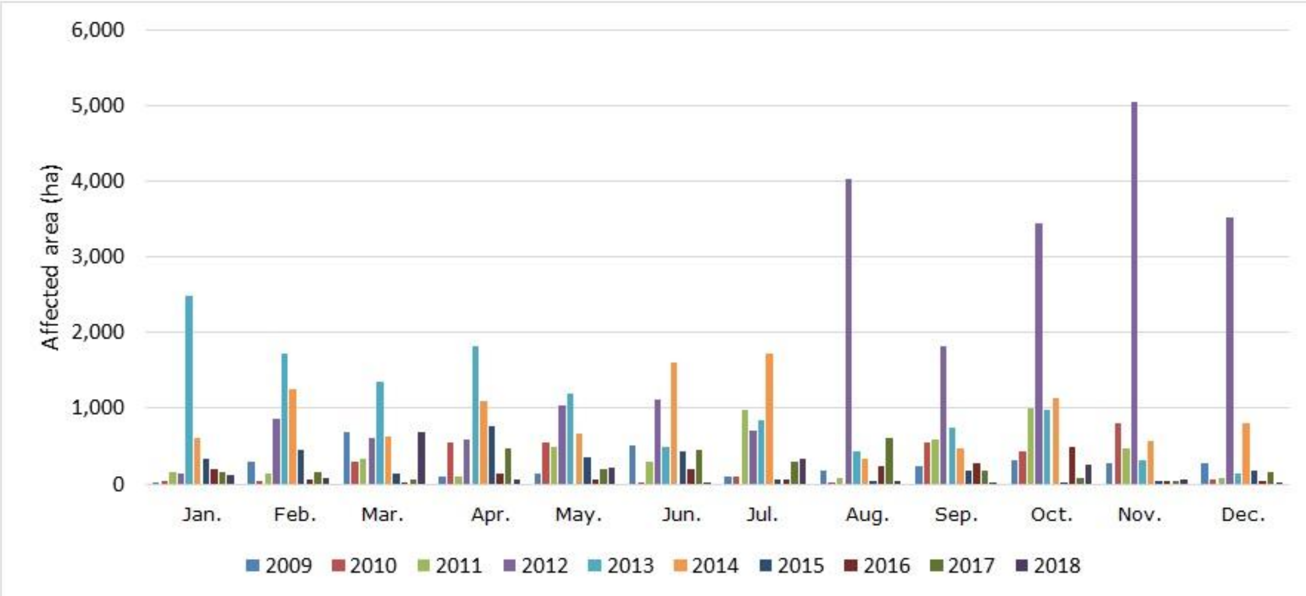


Figure 6. Area affected (ha) by month in Mexico by *Dendroctonus mexicanus* Hopkins (1905) in the 2009–2018 period.

Two main flight peaks were detected: from April to June and from September to December, depending on the geographical region of the country (Vázquez-Collazo *et al*., 2007; Avilés-Carrillo *et al*., 2016; Morales-Rangel *et al*., 2016; del-Val and Sáenz-Romero, 2017) (Figure 6).

Bark beetles are part of the forest dynamics, but lately, as the climate changes, especially with the anomalous temperatures (usually high), conditions are more favorable for the development of these insects as a pest of Mexican temperate coniferous forests (IPCC, 2014). *Dendroctonus mexicanus* has shown a preferential distribution towards temperate, humid and sub-humid environments, with a mean annual temperature ranging between 12 °C and 18 °C (Cuéllar *et al.,* 2012; González-Hernández *et al.*, 2020). In terms of precipitation, *D. mexicanus* has been observed in areas with 600 to 1 200 mm of rainfall (Armendáriz-Toledano *et al.,* 2018); however, previous modeling has indicated its potential distribution in an optimal range of approximately 800 mm (González-Hernández *et al.*, 2020).

The rate of development of certain species of bark beetles of the genus *Dendroctonus*, including *Dendroctonus mexicanus*, depends mainly on temperature (Mitton and Sturgeon 1982). Therefore, the monthly behavior would be associated with the particular temperature conditions for each year and state evaluated. Although there is a lack of data, it has been shown that the lack of rainfall is related to the increase in the number of bark beetle reports (Esparza, 2014); which would explain a sudden increase in the number of pest records from 2009 to 2011 in northern Mexico.

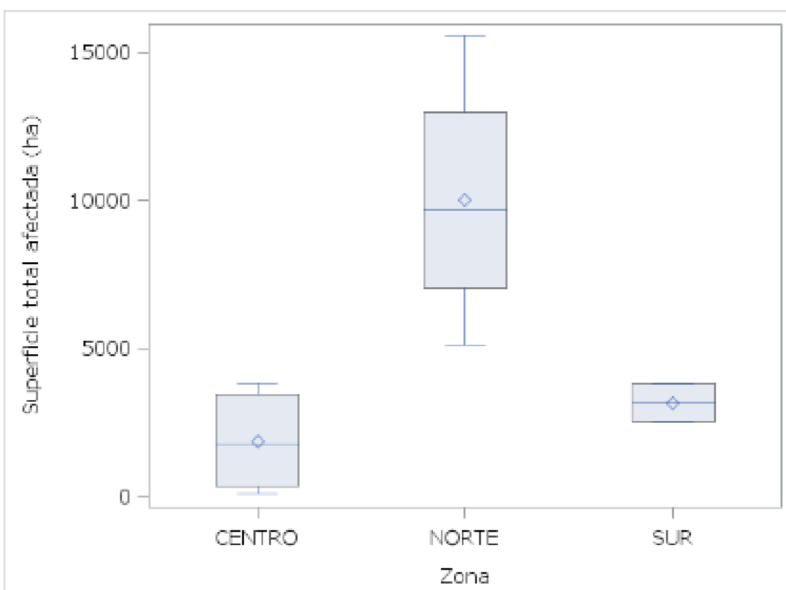
Correlation of the effect of geographic area on total affected area

The value of the overall test of $F_{2,14}$ —fixed effects— was 17.99, and its corresponding *p*-value was 0.0001. Therefore, there is sufficient evidence to conclude that there are highly significant differences between the three zones under study (North, Center and South) with respect to the response variable: total area affected by bark beetles. However, the least squares means were different from zero for the Central and North zones, with a significance level of 0.05; whereas, the South zone had a level of 0.10 (Table 4).

Table 4. Least squares means.

Zone	Estimate	Standard error	Degrees of freedom	*T* value	*P* value
Center	1 846.13	704.65	14	2.62	0.0202
North	10 003.00	1 168.52	14	8.56	<0.0001
South	3 156.66	1 652.54	14	1.91	0.0768

The estimated average for the North zone (near to 10,000 ha) was more than five times higher than the average for the Central zone, and three times higher than the mean for the South zone; likewise, the highest variability was characteristic of the North zone, while in the South zone the values were more similar (Figure 7).



Superficie total afectada = Total area affected; *Centro* = Center; *Norte = North; Sur= South.*

Figure 7. Mean values and variability of the total area affected by bark beetles by zone.

It was observed in particular, that the differences between the Central and North zones, as well as North and South were highly significant for the variable total area affected by bark beetles. This behavior was not detected in the Central or South zones (Table 5).

Table 5. Difference of least squares means.

Zone *i*	**Zone *i´***	**Estimate**	**Standard error**	**Degrees of freedom**	***T* value**	***P* value**
Center	North	-8 156.38	1 364.54	14	-5.98	<0.0001
Center	South	-1 310.52	1 796.50	14	-0.73	0.4777
North	South	6 845.86	2 023.94	14	3.38	0.0045

Normality tests indicated that the normal distribution of the studentized residuals was normal. The four statistical tests applied had p-values above 0.05 (Table 6), which is congruent with the symmetrical distribution of the residuals, whose extremes are lower than 3.0. In any case, any potential violation of other model assumptions is not critical, given that the p-values corresponding to the overall fixed effects test and the differences in means are robust, i.e., they are far from the benchmark value of 0.05.

Table 6. Normality of residuals.

Test	**Statistic**	***P* value**
Shapiro-Wilk (W)	0.9175	0.1342
Kolmogorov-Smirnov (D)	0.1718	>0.1500
Cramer-von Mises (W-Sq)	0.0794	0.2047
Anderson-Darling (A-Sq)	0.5741	0.1193

Differences between geographic areas could be due to the levels of forest fragmentation in each region (Moreno-Sanchez *et al.*, 2012), regional anomalies of climatic variables (Romero-Sanchez *et al.*, 2018), and, possibly, the institutional response of forest health agencies in the states. Finally, high-density populations of Mexican bark beetles have been responsible for economic, environmental and social losses in forest ecosystems (Moser *et al*. 2005; Manzo-Delgado *et al*., 2014). Therefore, it is important to identify the areas with the highest historical incidence of this pest in order to make appropriate decisions for both forest management and the management of this particular debarking pest.

Conclusions

In the 2009–2018 period, the temporal and spatial distribution of *Dendroctonus mexicanus* has been constant in pine forests, with presence in 25 of the Mexican states. The largest areas and volumes affected are located in the northern and central states of the country, according to the records of the evaluated period.

The analyses suggest the existence of significant differences between the North, Central and South zones, in regard to the variable total area affected by bark beetles; this is explained, in part, by the bias in the calculated means, since the estimated mean of the variable total area affected by bark beetles in the North zone is higher, and exceeds, by more than five times, the average in the Central zone, and is three times higher than the mean in the South zone. It is necessary to assess other state factors —control and management strategies, preventive practices, and the budget allocated— in order to carry out a more detailed analysis of the conditions that influence the temporal behavior of the Mexican bark beetle.

Acknowledgments

The authors wish to express their gratitude to the Forest Health Analysis and Reference Laboratory of the *Secretaría de Medio Ambiente y Recursos Naturales, Semarnat* (Ministry of Environment and Natural Resources) under the direction of Oscar Trejo Ramírez, Eng.; they also thank and acknowledge the three anonymous reviewers for their valuable comments and suggestions for the substantial improvement of this manuscript.

Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Ramiro Pérez-Miranda, Antonio González-Hernández and Martin Enrique Romero-Sánchez: conceptualized the study and wrote most of the paper; Efraín Velasco Bautista: performed the statistical analyses; Víctor Javier Arriola-Padilla: analyzed and refined the databases of bark beetles; Miguel Acosta Mireles and Fernando Carrillo Anzures: provided technical support during the data analysis and drafting of the manuscript. All authors reviewed and contributed equally to the drafting and review of the final document.

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