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Article

Efecto de la sequía en la distribución y densidad de *Dendroctonus mexicanus* Hopkins, 1905 en bosques templados

Drought effect over the distribution and density of *Dendroctonus mexicanus* Hopkins, 1905 in temperate forest

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Resumen:

Los bosques templados de Nuevo León son susceptibles al ataque de insectos descortezadores del género *Dendroctonus*, los cuales son considerados como los más destructivos en bosques de pino en México; donde tienen un papel importante, ya que a densidades altas pueden alterar los procesos ecológicos. En este estudio se caracterizaron las infestaciones por *Dendroctonus mexicanus* con base en la altitud a la que se presentan y la superficie infestada; así como, los cambios temporales de estas variables de 2008 a 2012; además, se analizó la relación entre el número de hectáreas afectadas y el índice de precipitación estandarizada. Se contabilizaron 1 435.13 ha dañadas de 2008 a 2012. Las infestaciones se registraron desde los 1 176 hasta 3 010 msnm, que cubren, prácticamente, toda la distribución del género *Pinus* en la zona. En el periodo estudiado no se observó evidencia de un incremento en la altitud a la que se localizaron los insectos; pero sí, un aumento en el intervalo altitudinal. La alta mortalidad causada por *D. mexicanus* en hospederos del género *Pinus*, independientemente de la altitud a la que se ubiquen, es un indicador de la expansión del intervalo altitudinal regional de *D. mexicanus* después de un año seco.

Palabras clave: Cambio climático, *Dendroctonus mexicanus* Hopkins, 1905, dinámica poblacional, insectos descortezadores, intervalo altitudinal, plaga forestal.

Abstract:

The temperate forests of *Nuevo León* are susceptible to the attack of *Dendroctonus* bark beetles, which are considered the most destructive insects in Mexican pine forests. These insects play an important role in forests; however at high densities they can alter some ecological processes. In this study, the infestations of *Dendroctonus mexicanus* are described according to the altitude at which the outbreaks occur, to the infested area, and to the temporary changes of these variables from 2008 to 2012. In addition, the relationship between the number of infested hectares and the standardized precipitation index is analyzed. From 2008 to 2012, 1 435.13 hectares were found to be infested. The infestations were located at an altitude between 1 176 and 3 010 masl, covering practically the entire distribution of the genus *Pinus* in the area. In the study period there was no evidence of an increase in the altitude at which the infestations occurred; however, an increase in the altitudinal range is observed. The high mortality caused by *D. mexicanus* to *Pinus*, regardless of the altitude at which they are found, is an indicator of the expansion of the regional altitudinal range of *D. mexicanus* after a dry year.

Key words: Climate change, *Dendroctonus mexicanus* Hopkins, 1905, population dynamics, bark beetles, altitudinal range, forest pest.

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Introduction

The temperate forests of northeastern Mexico are located in the mountain systems of the *Sierra Madre Oriental*. In the state of *Nuevo León*, 451 300 ha are covered with pine or pine-oak forests (Palacio–Prieto *et al.,* 2000). These are susceptible to attack by bark beetles of the *Curculionidae* family, specifically to those of the genera *Dendroctonus*, *Ips* and *Pseudips*, which are considered the most destructive in the pine forests of Mexico (Cibrián *et al.*, 1995) and of the United States of America (Wood, 1963; Paine *et al.,* 1997).

The genera *Dendroctonus* and *Pinus* are related to each other in terms of evolution (Zúñiga *et al.*, 2006). Therefore, at low densities, they are necessary for the functioning of the ecosystems (Wood, 1982); however, at high densities they can alter the ecological processes, as well as the makeup, structure or environmental services of the conifer forests (Malmström and Raffa, 2000; Hawkes *et al.*, 2003; Kurz *et al.*, 2008; McFarlane and Witson, 2008; Jenkins *et al.*, 2008).

The causes of the growth of the bark beetle population can be explained by hypotheses related to both intrinsic (Coulson *et al.*, 1989; Williams and Liebhold, 2002; Edmonds *et al.,* 2005; Raffa *et al.*, 2008; Westfall and Ebata, 2009; Evangelista *et al.*, 2011) and extrinsic factors (Safranyik and Linton, 1998; Turchin *et al.*, 1999; Lombardero *et al.*, 2000; Turchin *et al.*, 2003; Trzcinski and Reid, 2009). Furthermore, the behavior of an infestation outbreak can be linked to the variability of the climate (Logan *et al.*, 1999), the altitude (Rubin-Aguirre *et al.,* 2015), and, indirectly, to the effects of the host trees on the climate (Bentz *et al.*, 2010).

On the other hand, the dependence of the beetles on the temperature (Raffa *et al.*, 2008) and the reduction of the precipitation and moisture are directly related to the defense capability of the trees (Wermelinger, 2004; Raffa *et al.*, 2005; Six *et al.*, 2014) and to the survival of the beetles in winter (Safranyik and Linton, 1998).

The present study analyzes the drought effect, expressed as the standardized precipitation index (SPI) on the surface area affected by *D. mexicanus* Hopkins 1905, and the changes in altitude exhibited by the population between 2008 and 2012.

The objectives were: i) to characterize the infestations with *Dendroctonus mexicanus* Hopkins, 1905, based on the altitude at which the outbreaks occur, on the infested surface area, and on the temporary changes in these variables during a five-year period; and ii) to correlate the number of infested hectares with the standardized precipitation index.

Materials and Methods

Description of the study area

This study was carried out in the temperate pine and pine-oak forests located within the *Cumbres de Monterrey* National Park (PNCM, by its Spanish acronym), in the western-central area of the state of *Nuevo León*; in the physiographic province of the *Sierra Madre Oriental*. The types of climate are: (Cw_1), temperate with summer rains, and (ACw), semiwarm subhumid with summer rains.

Field and laboratory work

The areas where bark beetles were present were identified based on the information generated from the infestation records delivered to the management of the *Cumbres de Monterrey* National Park. The data of location, host tree, insect species, and infested surface area were verified in field for each of the years from 2008 to 2012. The surface areas and the altitudes were registered with *Garmin eTrex Legend* GPS, and the insects were identified by means of taxonomy codes. The areas where the location and surface area data were positioned in a geographical information system (GIS) (*Arc Gis 10.1*), with the coordinates in WGS84 Datum format. The altitude was verified with the topographic charts of the *Instituto Nacional de Estadística y Geografía, INEGI* (National Institute of Statistics and Geography) (*Rayones*: G14C43; *Allende*: G14C36 and *San Antonio de las Alazanas*: G14C35). All the surface areas were quantified for the five study years. Figure 1 shows the analyzed localities.

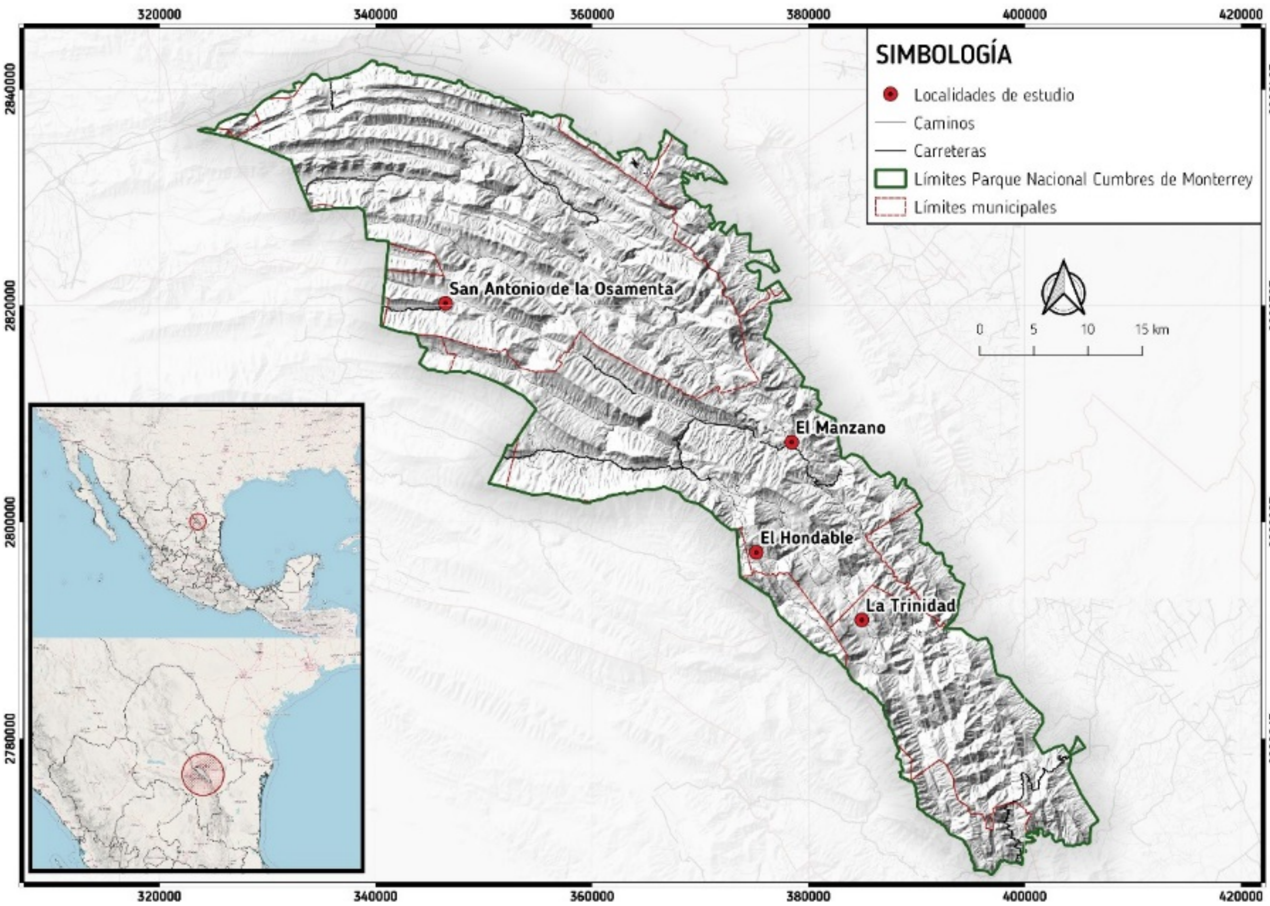

Figure 1. Map indicating the location of the studied localities.

The precipitation and temperature data utilized to estimate the SPI corresponded to stations 19069, 19048 and 19002 of the *Comisión Nacional del Agua, Conagua* (National Water Commission). This index made it possible to quantify the precipitation deficit in the year, which reflects the impact of the drought on the ecosystem. Its values range between 2 and -2; they are representative of the variability of the precipitation in terms of its history. The negative values (≤-1) are associated with periods of drought, while the positive values indicate a surplus (McKee *et al.,* 1993). The period of drought ended when the SPI reached positive values that correspond to precipitations above the median (Conagua, 2015).

Results and Discussion

The four selected localities were: *Hondable, Manzano, (Santiago, N.L.) Trinidad (Montemorelos, N.L.) and San Antonio (Santa Catarina, N.L.).* The host species were: *Pinus pseudostrobus* Lindl. and *P. teocote* Schiede ex Schltdl. & Cham. at Hondable, *Manzano* and *Trinidad*; *P. teocote, P. greggii* Engelm. ex Parl. and *P. cembroides* Zucc. at *San Antonio*, which coincide with those cited by Salinas-Moreno (2010) for *D. mexicanus*.

During the study period, 1 435.13 hectares were found to be infested with *Dendroctonus mexicanus* (Table 1). The number of hectares was estimated based on a variance analysis. The year 2012 had the largest number of affected hectares, with differences in relation to all the previous years (2008-2011: F=0.003, d.f. =3; 2009-2012: F=0.05 d.f.=3; 2010-2012: F= 0.05, d.f.= 3; 2011-2012: F=0.004, d.f.= 3). Although the year 2010 seemingly had more affected hectares than 2008, 2009 and 2011, there were no statistical differences (F= 2.35, d.f.= 15).

Table 1. Surface area infested with *Dendroctonus mexicanus* Hopkins, 1905 in the four studied localities (2008 through 2012).

Locality	**Surface area infested with *D. mexicanus* (ha)**					
	2008	**2009**	**2010**	**2011**	**2012**	**Total**
Hondable	53	103.05	99.73	60.78	117.8	434.35
Manzano	4.96	7.54	66.47	65.12	15.96	160.5
Trinidad	17.38	5.18	210.29	25.62	448.38	706.85
San Antonio	26.76	0	0	29.33	77.79	133.88
Total	102.1	115.77	376.49	180.84	659.93	1435.13

The genus *Pinus* is host to *D. mexicanus*, whose preferred altitude interval is 2 100 to 2 500 m, with variations of 800 to 3 400 m (Salinas-Moreno, 2004). In the study area, the host trees are distributed at altitudes ranging between 1 100 and 3 200 masl. The lowest altitude at which infestations with *D. mexicanus* occurred was that of *Trinidad*, at 1 176 masl, in the year 2012, and the highest, that of *San Antonio*, at 3 010 masl, in 2011.

In general, no increase was observed in the altitude at which the infestations occurred; however, the altitude interval broadened in three localities (*Hondable*, *Trinidad* and *San Antonio*) in the years 2011 and 2012. Likewise, the number of outbreaks increased in the same period (Table 2).

Table 2. Altitude interval and number of outbreaks of infestation with *Dendroctonus mexicanus* Hopkins, 1905 in the four studied localities (2008 through 2012).

Locality	Year	Number of outbreaks year^{-1}	Altitude interval (m)
	2008	1	200
	2009	2	381
Hondable	2010	6	281
	2011	1	561*
	2012	18	684*
	2008	1	140
Manzano	2009	1	50
	2010	5	319*

	2011	10	186
	2012	6	149
Trinidad	2008	3	730
	2009	2	78
	2010	3	162
	2011	1	461
	2012	22	1139*
San Antonio	2008	2	260
	2009	0	0
	2010	0	0
	2011	6	891*
	2012	12	778*

* = Years in which the altitude interval increased.

A general increase in the mortality of the genus *Pinus* was observed, regardless of the altitude; this may be an indicator of the expansion of its regional distribution. In *P. ponderosa* forests in the southern United States of America, various species of Scolytidae were observed to exhibit high mortality rates at sites located at lower altitudes and with higher degrees of drought (Negrón and Popp, 2004; Negrón *et al.*, 2009). The same tendency was documented in forests of Michoacán, with a great abundance of Scolytidae in low altitude areas (Rubin-Aguirre *et al*., 2015).

In all localities, the driest year was 2011 (Table 3), this may have led to hydric stress and weakening of the trees (Allen *et al.*, 2010; Allen *et al.*, 2015); furthermore, it led to an increase in the population density of bark beetles (Bentz *et al.*, 1991; Safranyk and Linton, 1998; Ungerer *et al.*, 1999; Raffa *et al.*, 2008).

Table 3. Standardized precipitation index (SPI) and the infected area per in template forests in the four studied localities.

Locality	Year	Surface Area	SPI	Correlation coefficient
Hondable	2008	53	-1.62*	0.97
	2009	103.05	-1.55*	
	2010	99.73	1.84**	
	2011	60.77	-1.82*	
	2012	117.8	1.95**	
Manzano	2008	4.96	0.138**	0.60
	2009	7.54	-1.55*	
	2010	66.47	1.84**	
	2011	65.12	-2.00*	
	2012	16.15	1.95**	
Trinidad	2008	17.38	-1.16***	0.77
	2009	5.18	-1.33***	
	2010	210.29	1.86**	
	2011	25.62	-1.33***	
	2012	448.38	-1.22***	
San Antonio	2008	26.76	0.95**	0.93
	2009	0	0.68**	
	2010	0	0.73**	
	2011	29.33	-2.00*	
	2012	77.79	-1.50*	

* = Extremely dry year; ** = Humid year, Normal year; *** =Moderately dry year.

In the present study, only the locality *Hondable* registered a high correlation between the affected surface area and the standardized precipitation index for the same year (R^2=-0.72). *Manzano* (R^2= 0.08), *Trinidad* (R^2= 0.05) and *San Antonio* (R^2= -0.16) exhibited no correlations. The result for *Hondable* may be due to the fact that three out of the five years of the study had SPIs with extreme drought. However, their effects on the populations of bark beetles cannot not always be observed in the same year but become evident in a later year.

In Oregon, infestations with *D. ponderosa* were correlated with the precipitation of the year in which the population growth was registered, as well as with that of the previous year (Preisler *et al.*, 2012).

In the four studied localities, a high negative correlation was determined between the standardized precipitation index and the surface area infested in the following year (*Hondable*: R^2=-0.97; *Manzano*: R^2=-0.60; *Trinidad*: R^2=-0.77; *San Antonio*: R^2=-0.93); the data are shown in Table 3. This correlation can be accounted for by the fact that some extreme climate events bring abundant resources for certain species of bark beetles (Gandhi and Herms, 2010).

Larger infested surface areas and broader altitude intervals (1 176-2 936 masl) were registered in the year 2012; furthermore, the SPI was moderate to extremely dry in 2011 and 2012; both situations may represent an accumulated drought effect in the trees, particularly in the locality of *Trinidad*, where 2008 and 2009 were dry years, and the infested surface area increased significantly in 2010. The years 2011 and 2012 were also dry in the same locality, and the infested surface area increased in 2012.

Some research shows an expansion in the distribution of the insects because the increase in temperature creates new niches for this growth (Nealis and Peter, 2009). Although the response of the bark beetles to climate change does not appear to be linear but rather more complex, there already are direct effects on their population and on their hosts, which renders the analysis difficult (Bentz *et al.*, 2010). For various species of Scolytidae, increases in the altitude interval of the infestations have been shown to be related to dry summers (Marini *et al.*, 2012). Therefore, the climate is regarded as a more important limiting factor than the availability of hosts (Bentz *et al.*, 2010). Likewise, according to other studies, warmer temperatures are associated to the reproduction and survival of Scolytidae species (Bentz *et al.*, 1991; Tykarski, 2006).

There is no evidence of an increase in the altitude at which infestations occurred between 2008 and 2012; however, an increase in the altitude interval can be observed. In 2008, the infestations appeared between 1 471 and 2 300 m (interval of 829 m) while in 2012 they were between 1 176 and 2 936 m (range of 1 760 m).

Conclusions

1 435.13 ha were found to be infested with *D. mexicanus* in the 2008-2012 period, and an increase was observed in 2012.

Infestations with *D. mexicanus* occurred at an altitude between 1 176 and 3 010 masl, almost equal to the entire altitude interval at which its hosts are distributed: 1 100 to 3 200 m.

The high mortality caused by *D. mexicanus* in the genus *Pinus*, regardless of the altitude at which these trees are distributed, is an indicator of the expansion of the regional altitude interval of *D. mexicanus* after a dry year.

The standardized precipitation index is negatively correlated with the surface affected by *D. mexicanus* in the year following that in which the drought occurred, or as an accumulated effect of two years of drought; thus, negative SPI values result in an increase of the affected surface area.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Diana Pinzón Moncada: field data collection and statistical analysis; Gerardo Cuéllar Rodríguez: data analysis, literature search and writing of the manuscript; Enrique Jurado: foundation, writing and editing of the manuscript; Marco Aurelio González-Tagle: drafting and editing of the manuscript.

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