DOI: https://doi.org/10.29298/rmcf.v13i69.1161

Article

Efecto de las variables climáticas en *Dendroctonus mexicanus* Hopkins (Coleoptera: Curculionidae) en bosques de Hidalgo
Effect of climatic variables on *Dendroctonus mexicanus* Hopkins (Curculionidae) from the *Hidalgo* forests

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Resumen
La temperatura en latitudes septentrionales en el hemisferio norte es el factor más importante que determina la abundancia de los descortezadores. En los bosques de pino del centro-norte de México existen otras variables climáticas que influyen en este suceso. Se consideró como hipótesis que existe una relación entre las variables climáticas con la abundancia de *Dendroctonus mexicanus* y se planteó como objetivo describir la abundancia de *D. mexicanus* ocurrida durante los años 2015 y 2016, en relación con las variables climáticas: temperatura, precipitación, índice de aridez e índice de precipitación estandarizado en el bosque de pino de Hidalgo, mediante el monitoreo de la abundancia de los escarabajos descortezadores con trampas tipo *Lindgren*. Se observó una correlación entre la abundancia de *D. mexicanus* y las variables climáticas, de ellas destacaron la precipitación (r^2=0.59, p=0.0035) y el índice de precipitación estandarizado (r^2=0.85, p=0.0082). La mayor abundancia de *D. mexicanus* se presentó en un ambiente de ligero a moderadamente húmedo. El aumento en la abundancia del insecto descortezador en los bosques de pino del estado de Hidalgo está correlacionado con los regímenes de variables climáticas como la temperatura, el índice de aridez y en especial con la precipitación e índice de precipitación estandarizado.

Palabras clave: Abundacia, escarabajos descortezadores, estaciones del año, índice de precipitación estandarizado, precipitación, temperatura.

Abstract
The temperature in northern hemisphere latitudes in the north seems to be the most important factor that determines the greater abundance of bark beetles, in the pine forests of north-central Mexico there are other climatic variables that influence this event. There is a relationship between the changes in the climatic variables that influence the changes in the abundance of *D. mexicanus*, such as temperature, precipitation, aridity index and standardized precipitation index in the pine forest of *Hidalgo*. This study consisted of monitoring the abundance of bark beetles using Lindgren-type traps. Observing in the results, a relationship is apparent between the abundance of *D. mexicanus* and climatic variables, among which the precipitation (r^2 = 0.59) and the standardized precipitation index (r^2 = 0.85) stand out. The increase in the abundance of *D. mexicanus* in pine forests in *Hidalgo* is related to changes in the regimes of climatic variables such as temperature, aridity index and especially with precipitation and standardized precipitation index.

Key words: Abundance, bark beetles, seasons, standardized precipitation index, precipitation, temperature.

Fecha de recepción/Reception date: 16 de mayo de 2021
Fecha de aceptación/Acceptance date: 30 de noviembre de 2021

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Introduction

The survival of bark beetles in more northern latitudes decreases in winter because they are poikilothermic organisms; thus, the increase in environmental temperature regulates the number of individuals (Faccoli, 2002; Safranyik *et al*., 2010). In addition, the number of generations per year increases because their metabolic rate accelerates and the diapause time decreases (Amat-García *et al*., 2005; Aukema *et al*., 2016) —as in the case of *Dendroctonus frontalis* Zimmerman and *D. ponderosae* Hopkins—, and, hence, they become pests (Trần *et al*., 2007; Safranyik *et al*., 2010; Six and Bracewell, 2015). For this reason, temperature variation is considered an important factor in increasing the abundance and population dynamics of bark beetles throughout the year (Chapman *et al*., 2012; Gaylord *et al*., 2013; Hart *et al*., 2014).

There are studies that relate precipitation and extreme temperature events to a higher abundance of bark beetles (Chapman *et al*., 2012; Cervantes-Martínez *et al*., 2019). In contrast to extreme weather events, such as unseasonal cold snaps, which reduce bark beetle populations during winter (Sambaraju *et al*., 2012; Weed *et al*., 2015; Rosenberger *et al*., 2017). This is because the insects are unable to colonize the host trees in the presence of a cold and humid climate.

Temperature and precipitation are two determining variables in the life cycle of insects (Bentz and Jönsson, 2015; Six and Bracewell, 2015), as has been acknowledged for *D. mexicanus* Hopkins and *D. adjunctus* Blandford (Salinas-Moreno *et al*., 2010; Six and Bracewell, 2015; Soto-Correa *et al*., 2019). In Mexico, the number of *D. frontalis* beetles has been observed to increase as precipitation augments; however, such increase has not been observed in relation to the temperature when it tends to average approximately 19 °C (Soto-Correa *et al*., 2019).

Since 1836, outbreaks of insect pests of the genus *Dendroctonus* Erichson in the pine forests of *Hidalgo*, Mexico, have become more frequent and are the cause of high mortality of trees of the genus *Pinus* (Servicios Forestales de Hidalgo, 2017). In this respect, the death of individuals of the species *Pinus patula* Schltdl. & Cham (Fonseca-Gonzáles *et al.,* 2014), *Pinus teocote* Shiede ex Schltdl *et* Cham and *Pinus leiophylla* Shiede ex Schltdl *et* Cham (Sánchez-Martínez, 2004) has been documented in large forested areas.

Dendroctonus mexicanus is a generalist species, as it colonizes 21 of the 47 *Pinus* taxa present in Mexico (Salinas-Moreno *et al*., 2004); therefore, it is of great importance to understand the population dynamics of bark beetles in the pine forests of the state of *Hidalgo* in order to propose management strategies to prevent and control the incidence of these pests (del Val and Sáenz-Romero, 2017).

The present paper describes the relationship between climatic variables and the abundance of *D. mexicanus* in the pine forest of the state of *Hidalgo* during 2015 and 2016. The importance of this study lies in the lack of studies involving continuous collections in the spatiotemporal distribution of *D. mexicanus*. The result will be the guideline for understanding the dynamics of the abundance of bark beetles under scenarios of future changes in temperature, precipitation, and aridity.

Materials and Methods

Characterization of the study site

The study was carried out in pine forests in the state of Hidalgo, located between 21°24'22'' and 19°38'3'' N, and 99°53'43'' and 97°59'8'' W —an area that is part of the Mexican Transversal Volcanic Belt and the Sierra Madre Oriental, comprising the municipalities of *Jacala*, *Pacula*, *Metztitlán*, and *Zimapán*. The forest occurs within an altitudinal range of 1 800 to 2 600 m (Conabio, 2004). The climate is predominantly temperate, with an average annual temperature of 16 °C; an average minimum temperature of 4 °C in January (the coldest month), and an average maximum of 27 °C in April and May. Rainfall occurs in the summer, from

June to September, with an average rainfall of 800 mm, with fluctuations of 600 to 1 500 mm, and a dry season between October and May (Conabio, 1998; Conabio, 2004).

Sampling system for *D. mexicanus*

The sampling consisted of four transects, one per locality, within the pine-oak forest; the transects consisted of four to six sampling sites with an altitudinal separation interval of 100 m (Table 1). The sampling was carried out using paired traps. Two Lindgren-type traps consisting of eight funnels were set up at each sampling site —a trap with an artificial bait (*Dendroctonus* attractant Alpha-pinene + Frontalin + Endobrevicomine; Synergy Semiochemicals Corporation™) and an unbaited control trap—, separated by a distance of 50 m. In each trap, a (BioQuip™) collecting jar with a mixture of equal parts of (Prestone af ex™) antifreeze and 70 % alcohol was installed for the purpose of slaughtering and preserving the captured insects (Macías-Sámano *et al.,* 2004).

Table 1. *Dendroctonus mexicanus* Hopkins sampling sites in the pine forest in *Hidalgo*, abundances per site in both years and modeled climatic data (1961-1990).

Municipality	N Latitude	W Longitude	Altitude (m)	Abundance 2015	Abundance 2016	MAT (ºC)	MAP (mm)	DD5 (°C)	AAI
Metztitlán	20º42’40.8”	98º46’52.9”	2 222	802	---	16.1	846	4016	0.21
Metztitlán	20º40’20.3”	98º46’43.7”	2 216	969	---	16.0	844	4010	0.21
Metztitlán	20º42’36.4”	98º46’48.1”	2 163	978	---	16.1	855	4019	0.21
Metztitlán	20º42’53.3”	98º47’40.6”	2 046	1 290	---	16.0	903	4007	0.23
Zimapán	20º55’49.9”	99º13’38.4”	2 098	143	363	17.1	521	4406	0.12
Zimapán	20º56’03.7”	99º13’29.5”	1 998	436	818	17.4	502	4499	0.11
Zimapán	20º56’13.1”	99º13’19.5”	1 880	838	625	17.7	476	4602	0.10
Zimapán	20º56’14.8”	99º13’15.5”	1 812	436	318	17.9	456	4662	0.10
Zimapán	20º56’15.4”	99º13’09.8”	1 722	1 493	1386	18.0	439	4725	0.09
Zimapán	20º56’17.0”	99º13’03.8”	1 654	717	1190	18.1	432	4755	0.09
Pacula	20º55’46.8”	99º14’14.4”	2 117	1 535	2063	17.1	523	4379	0.12
Pacula	20º56’24.7”	99º13’37.2’’	2 014	311	83	17.3	506	4469	0.11
Pacula	20º56’45.7’’	99º14’42.8’’	1 938	246	183	17.6	489	4553	0.11
Pacula	20º56’46’’	99º14’20.3’’	1 880	1 993	1675	17.7	476	4602	0.10
Jacala	20º54’05.2”	99º09’21.0”	1 611	1 421	281	18.3	469	4814	0.10
Jacala	20º54’14.8”	99º09’10.6”	1 532	570	210	18.6	455	4927	0.09
Jacala	20º54’21.5”	99º09’12.3”	1 440	998	15	18.7	447	4974	0.09
Jacala	20º54’25.8”	99º09’15.0”	1 342	773	53	18.7	447	4992	0.09

MAT = Mean annual temperature; MAP = Mean annual precipitation; DD5 = Degrees day; AAI=Annual aridity index; ---= No data available.

Individuals of the genus *Dendroctonus* were collected on a fortnightly basis from February 2015 to December 2016. Subsequently, they were taken to the Faculty of Natural Sciences of the Autonomous University of Querétaro (*Universidad Autónoma de Querétaro*) and identified according to the codes proposed by Cibrián-Tovar *et al.* (1995).

Data from nine meteorological stations of the Mexican Institute of Water Technology (IMTA, 2019) near the sampling sites were used for the purpose of learning about climate behavior in 2015 and 2016, and the averages per day were analyzed. Since

1945, historical temperature and precipitation data were drawn from three stations (*Huichapan*, *Ixmiquilpan*, and *Zacualtipán*); since 1955, from five stations (*Actopan*, *El Salto*, *Metztitlán*, *Mixquiahuala*, and *San Cristóbal*), and since 1975, from one station (*Presa de Endho*). Daily and monthly average point data were used every ten years up to 2016; standardized precipitation index (SPI) data were also used (OMM, 2012) for the years 2015 and 2016 for the abovementioned stations.

For the modeling of the specific climatic variables of each sampling site, a thin plate spline climate model developed for Mexico was applied (Hutchinson, 2004; Crookston, 2010). The estimated variables were mean monthly temperature (MMT), mean monthly precipitation (MMP), monthly aridity index (MAI = $(DD5^{0.5})/MMP$; DD5 = degrees day >5 °C). The value of the standardized precipitation index (SPI) was estimated for *Hidalgo*, based on data from the National Weather Service (*Servicio Meteorológico Nacional* (SMN, 2019). The SPI was estimated based on the values of 24 months and these were grouped according to the seasons of the year in Mexico: winter (December, January, February), spring (March, April, May), summer (June, July, August), autumn (September, October, November). SPI is a drought indicator that represents parameters such as soil moisture and precipitation anomalies, among others (McKee *et al.,* 1993; OMM, 2012).

Data analysis was performed with the SAS® statistical package version 9.3 (SAS, 2004). A Pearson analysis of the correlation between the abundance of *D. mexicanus* and climatic variables (temperature, precipitation, aridity index, SPI) was performed, and a regression between the number of *D. mexicanus*, precipitation and the standardized precipitation index (SPI) was carried out.

Results

Dendroctonus mexicanus exhibited the highest abundance in 2015 in the months of February and October, with about 3 500 individuals per month, while the lowest abundance occurred in 2016, during the period from June to October, with abundances of less than 500 individuals; during the other months, abundance remained above 1 000 individuals (Figure 1). Regarding the annual accumulation of all traps, a higher abundance was observed in 2015, with 15 949 individuals occurring at an average annual temperature of 16 °C and 752 mm of precipitation. In 2016, the abundance was lower, as only 9 263 individuals of *D. mexicanus* were captured, with an average annual temperature of 16.4 °C and 598 mm of precipitation.

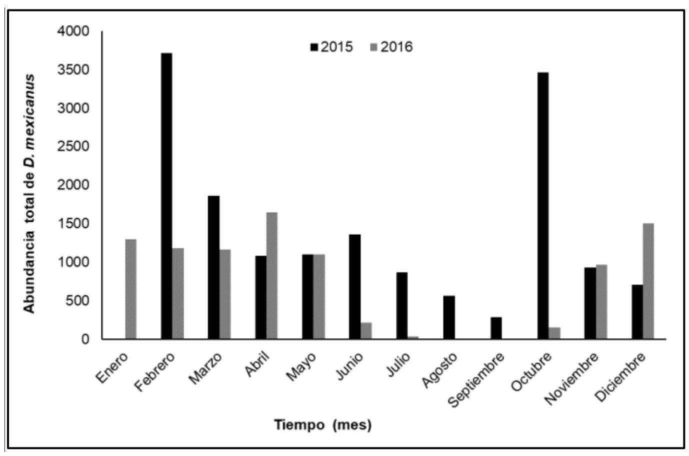

Figure 1. Total abundance of *Dendroctonus mexicanus* Hopkins by month during 2015 and 2016 in the pine forest of Hidalgo, Mexico.

The monthly mean temperature, monthly mean precipitation and monthly mean aridity index are characterized by a pattern throughout the year. Temperatures are high from March to September; precipitation occurs from June to September, and aridity, from November to May (Figure 2).

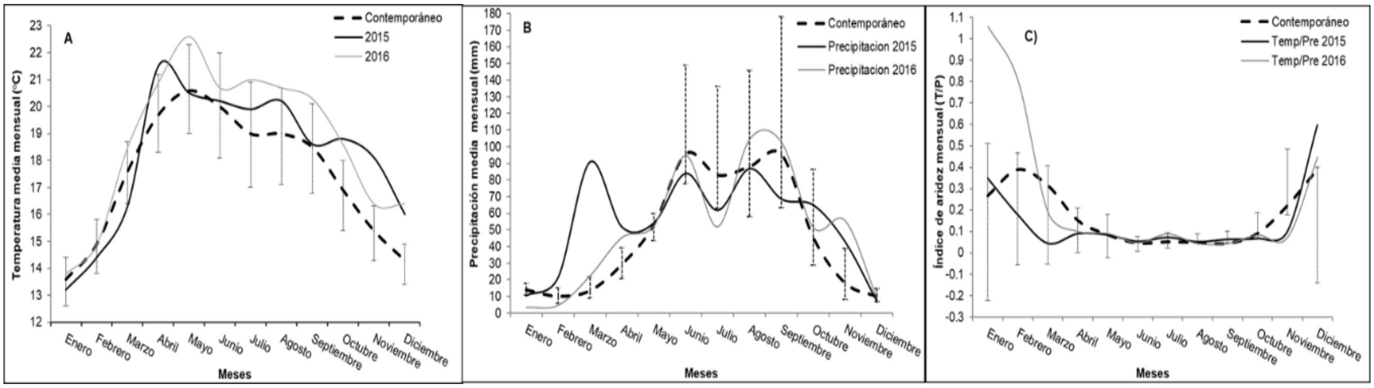

Figure 2. Monthly temperature (A); Monthly precipitation (B); Monthly aridity index (C) in 2015, 2016 and contemporary data (1963-1993) in the pine forest of the state of *Hidalgo*.

Relationship between the abundance of *D. mexicanus* and climatic variables

The correlation results exhibited a low association of *D. mexicanus* abundance with the mean minimum temperature in 2015 (r = -0.51), and with the mean minimum temperature (r = -0.63), the mean minimum precipitation (r = -0.77), the aridity index (r = 0.52) and the SPI (r = 0.61 in 2016 (Table 2). On the other hand, there is a functional relationship between the monthly abundance and the mean monthly precipitation for the year 2016 (R^2 = 0.59); while, for 2015, no relationship was observed (Figure 3A, Figure 3B; Table 2).

Table 2. Pearson's correlation analysis (r) and a regression analysis (R^2) between data from climate stations near the sampling sites and modeled climate data regarding the abundance of *Dendroctonus mexicanus* Hopkins during 2015 and 2016 in the pine forest of *Hidalgo*.

Climate variable	Abundance of *D. mexicanus*			
	Pearson's coefficient (*r*)		R^2 coefficient	
	Year 2015	Year 2016	Year 2015	Year 2016
Mean temperature (Stations)	-0.47	-0.44	0.23	0.20
Mean temperature (Modeled)	-0.37	-0.41	0.14	0.17
Maximum mean temperature (Stations)	-0.34	-0.02	0.11	0.00
Maximum mean temperature (Modeled)	-0.19	0.00	0.04	0.00
Minimum mean temperature (Stations)	-0.51	-0.63	0.26	0.40
Minimum mean temperature (Modeled)	-0.44	-0.68	0.20	0.46
Mean precipitation (Stations)	-0.16	-0.77	0.03	0.59
Mean precipitation (Modeled)	-0.42	-0.86	0.18	0.74
Aridity index (Stations)	-0.11	0.52	0.01	0.27
Aridity index (Modeled)	0.37	0.77	0.13	0.60
Standardized precipitation index	-0.29	0.61	0.09	0.37
Maximum extreme temperature (Stations)	-0.24	0.42	0.06	0.18
Minimum extreme temperature (Modeled)	-0.62	-0.67	0.38	0.45

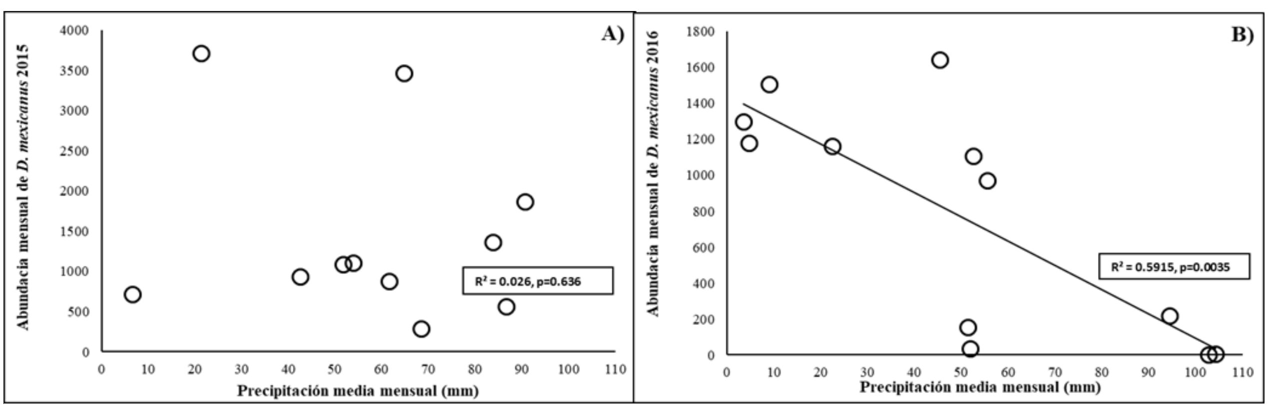

Figure 3. Regression analysis of monthly abundance of *Dendroctonus mexicanus* Hopkins with station precipitation in 2015 (A) and in 2016 (B) in the pine forest in *Hidalgo*, Mexico.

There was also a relationship between the abundance of *D. mexicanus* and the SPI organized by season, in the winter, spring, summer and fall of both years (r^2 = 0.854). The abundance of *D. mexicanus* was observed to be high in the four seasons of the year 2015; likewise, SPI presented higher values. There was a higher abundance during the winter and spring of 2016, and a lower abundance in the summer and fall (Figure 4).

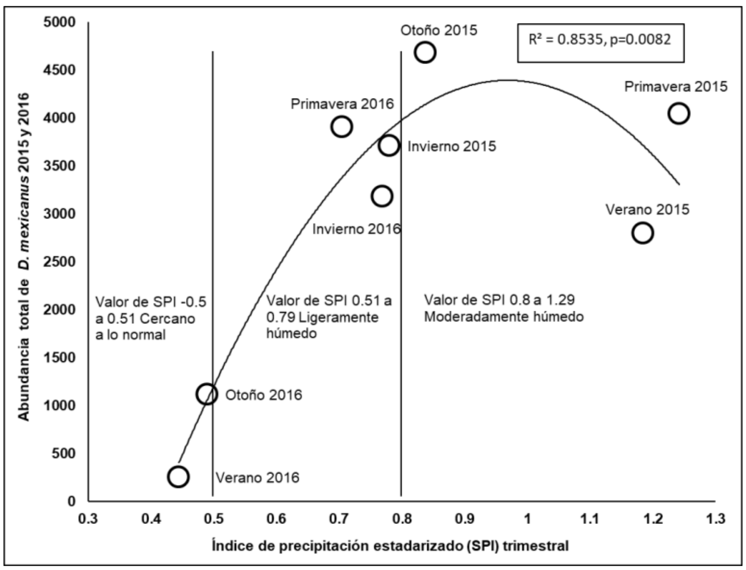

Figure 4. Relationship between the abundance of *Dendroctonus mexicanus* Hopkins and the standardized precipitation indices during 2015 and 2016 in the pine forest of Hidalgo, Mexico, and SPI intervals indicating moisture.

Discussion

The pattern of climatic variables, such as MMT, MMP and MAI partially explain the occurrence of a higher or lower abundance of *D. mexicanus* throughout 2015 and 2016. For example, the temperature range in the study area shows a pattern in the

MMT throughout the year, in which it is observed to decrease from November to January by 14 °C (-/+1 °C); then, the temperature increases gradually from February onwards, reaching 20 °C (-/+2 °C) in April and May; from June to September, the average temperature decreases to 19 °C (-/+2 °C), and the rainy season begins; the temperature decreases from September onwards, reaching 14 °C (-/+1) in December (Figure 2A).

During 2015, the MMT was higher than the historical levels in the months of February, March and April. This change may have led to an increase in the number of bark beetles during this period (Figure 2A). In other studies, the change in the regimes of climatic variables caused an increase in the abundance and changes in the population dynamics of bark beetles (Chapman *et al*., 2012; Gaylord *et al*., 2013; Hart *et al.,* 2014; Bentz and Jönsson, 2015; Six and Bracewell, 2015; Soto-Correa *et al.,* 2019).

In the forests of *Hidalgo*, the rainy season and the dry season are very different (Conabio, 1998), and the changes in climatic variables are responsible for the increase in the abundance of bark beetles. For example, throughout 2015 there were changes in the temperature and precipitation patterns; the average minimum temperature in January was 4 °C, and, therefore, the populations of bark beetles did not decrease (Sambaraju *et al.,* 2012; Weed *et al.,* 2015; Rosenberger *et al.,* 2017). Temperatures close to 0 °C are a limiting factor for the abundance of this species (Hicke *et al.,* 2006; Aukema *et al.,* 2016), while the ideal average temperature for the presence of bark beetles ranges between 5 and 11 °C (Hicke *et al.,* 2006).

Moreover, an increase of in the minimum winter temperature by 3.3 °C results in epidemic outbreaks (Trần *et al.,* 2007; Bentz *et al.,* 2016). Increased ambient temperature reduces insect mortality in the winter (Faccoli, 2002; Safranyik *et al.,* 2010). In addition, there was an oscillatory pattern of precipitation in 2015, when precipitation was out of phase with respect to the historical precipitation. In that year, there were three important peaks: the first, in March, with 90 mm (an atypical event), and the second, in June, with 90 mm; in July, it decreased to 50 mm, while the third peak occurred in August and September.

In 2016, the precipitation was more similar to the historical average (Figure 2B). The presence of rainfall in February led to a lower aridity index during that season, compared to the historical level. In February 2016, climatic conditions (temperature, precipitation, and aridity) were similar to the historical conditions, and there was a lower abundance of *D. mexicanus*. Precipitation occurred usually during the months of June-September, with no fluctuations throughout the year. The lack of rainfall in February of that year may have led to a higher aridity index, resulting in insect mortality due to lack of moisture (Amat-García *et al.,* 2005).

The average temperature suitable for a higher abundance of *D. mexicanus* has been estimated to be 18 °C (between 13 and 25 °C) (Méndez-Encina *et al.,* 2020); likewise, another study determined an optimum average of 16.6 to 18 °C (Morales-Rangel *et al.,* 2018). However, a high average temperature also affects abundance; such was the case of *D. frontalis*, which registered a lower abundance with an MMT of 19 °C (Soto-Correa *et al.,* 2019). In this study, the mean annual temperature was 19 °C (with a range of 14 to 21 °C). Throughout the year, the average temperatures were adequate for the existence of a higher abundance of bark beetles; however, it was observed that average maximum temperatures can act as a limiting factor of abundance, as was estimated for *D. frontalis*, which exhibited a relationship between maximum temperatures above 30 °C and a lower abundance (Soto-Correa *et al*., 2019). This can be attributed to the fact that certain growth states in the life cycle of the beetles are very sensitive to desiccation (Amat-García *et al.,* 2005).

In north-central Mexico, *D. mexicanus* lives in forests where there is an association between the anticipated increase in temperature at the end of the winter and an explosion in the population of bark beetles (Hernández-Muñoz *et al.,* 2017). Changes in the rainfall pattern are another factor that promotes a greater abundance of *D. mexicanus* in places where most of the year the temperature is appropriate for the development of this species, as a result of the presence of humidity in the environment due to precipitation (López-Gómez *et al.,* 2017; Cervantes-Martínez *et al*., 2019). This relationship has been observed in 15 Mexican states (Cervantes-Martínez *et al.,* 2019).

The life cycles of the beetles are in accordance and in harmony with the seasonality of the annual cycle of the region where they live (Amat-García *et al.,* 2005). Climate change modifies annual seasonality and leads to favorable conditions for bark beetles (del-Val and Sáenz-Romero*,* 2017). In a study conducted in *Hidalgo*, outbreaks of *Dendroctonus* coinciding with lower rainfall in the rainy season were registered in 1940, 2011, and 2013 (Cervantes-Martínez *et al.,* 2019).

Another characteristic to consider is the average minimum temperatures below 5 °C, or average maximum temperatures above 32 °C, which limit the abundance of bark beetles. However, if rainfall occurs, the right conditions are generated for a greater abundance, as is the case for various types of beetles in tropical areas with the temperature required to fulfill vital functions and the necessary humidity to prevent dessication (Amat-García *et al.,* 2005).

On the other hand, the relationship between the abundance of *D. mexicanus* and the standardized precipitation index (SPI) reinforces the importance of the presence of humidity in the environment in increasing the abundance; it also coincides with higher SPI values within the analyzed interval, while lower abundance corresponds to lower SPI values. The SPI must be slightly to moderately moist in order for a higher abundance to exist (OMM, 2012).

The present study is a contribution that provides information on the abundance of *D. mexicanus* associated with climatic variables. However, knowledge of temperature- and precipitation-dependent physiological processes is still limited for most of the bark beetle species both in the southwestern United States and in Mexico (Bentz *et al.,* 2016).

Conclusions

Knowledge of the relationship between the greater or lesser abundance of *D. mexicanus* in pine forests in Hidalgo and the patterns of temperature, precipitation, aridity index, and, especially, the standardized precipitation index is very important because it allows us to have an approximation of where the right conditions for the existence of an outbreak of *D. mexicanus* are present. This study generates evidence of the increase in the abundance of *D. mexicanus* in the forests of Hidalgo and its relationship with the humidity of the environment, which should be characterized as slightly (SPI = 0.51-0.79) to moderately humid (SPI = 0.8-1.29). Having data for only two years may not be sufficient to know the dynamics of the abundance of *D. mexicanus*, as it will depend on the particular conditions of each site.

Acknowledgments

The authors are grateful to the *Conafor-Conacyt* fund C01-234547 for the support provided to carry out the project.

Conflict of interests

The authors of this article had no conflict of interest in the conduct of the study, the drafting of the manuscript, or the evaluation of the article.

Contribution by autor

José Carmen Soto-Correa: participated in data analysis, experiment planning and writing of the manuscript; Guillermo Hernández-Muñoz: identification of individuals, data analysis, and drafting of the manuscript; Víctor Hugo Cambrón-Sandoval: conduct of the experiment and drafting of the paper.

References

Amat-García, G. Gasca H. J. y G. Amat E. 2005. Guía para cría de escarabajos. Fundación Natura-Universidad Nacional de Colombia. Banco ideas Impresores. Bogotá, Colombia*.* 80 p.

Aukema, B. H., F. R. McKee, D. L. Wytrykush and A. L. Caroll. 2016. Population dynamics and epidemiology of four species of *Dendroctonus* (Coleoptera: Curculionidae): 100 years since J. M. Swaine. Canadian Entomologist 148: S82-S110. Doi:https://doi.org/10.4039/tce.2016.5.

Bentz, B. J. and A. Jönsson. 2015. Modeling bark beetle responses to climate change. *In*: Vega, F. and R. Hofstetter (eds). Bark Beetles: Biology of native and invasive species, Elservier Academic Press. Logan, UT, USA. pp. 533-553. Doi:https://doi.org/10.1016/B978-0-12-417156-5.00013-7.

Bentz, B., J Duncan and J. A. Powell. 2016. Elevational shifts in thermal suitability for mountain pine beetle population growth in a changing climate. Forestry 89(3): 271-283. Doi:https://doi.org/10.1093/forestry/cpv054.

Cervantes-Martínez, R., J. Cerano-Paredes, G. Sánchez-Martínez, J. Villanueva-Díaz, G. Esquivel-Arriaga, V. H. Cambrón-Sandoval, J. Méndez-Gonzáles and L. U. Castruita-Esparza. 2019. Historical back beetle outbreaks in México, Guatemala and Honduras (1895-2015) and their relationship with droughts. Revista Chapingo Series Ciencias Forestales y del Ambiente 25(2): 269-290. Doi:http://dx.doi.org/10.5154/r.rchscfa.2019.01.006.

Chapman, B. T., T. T. Veblen and T. Schoennagel. 2012. Spatiotemporal patterns of mountain pine beetle activity in the southern Rocky Mountains. Ecology 93: 2175-2185. Doi:https://doi.org/10.1890/11-1055.1.

Cibrián-Tovar, D. Méndez-Montiel, J. T. Campos-Bolans, R. Yates-Ho III y Flores-Lara, J. 1995. Insectos forestales de México/ Forest Insects of Mexico. Universidad Autónoma Chapingo. Subsecretaría Forestal y de Fauna Silvestre, SARH, México, Forest Service, USDA, USA. Natural Resources Canada, Comisión Forestal de América del Norte, FAO. Texcoco, Edo. de Méx., México. 453 p.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 1998. 'Climas' (clasificación de Köppen, modificado por García). Escala 1:1000000. México, D.F., México. s/p.

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 2004. Ordenamiento Ecológico Territorial de la región de "Los Mármoles" Hgo. http://www.conabio.gob.mx/institucion/proyectos/resultados/InfDQ006_3a_parte.pdf (1 de julio de 2019).

Crookston, N. 2010. Research on forest climate change: Potential effects of global warming on forests and plant climate relationships in western north America and Mexico. http://charcoal.cnre.vt.edu/climate (4 de julio de 2019).

del-Val, E. y C. Sáenz-Romero. 2017. Insectos descortezadores (Coleoptera; Curculionidae) y cambio climático: problemática actual y perspectivas en los bosques templados. TIP Revista Especializada en Ciencias Químico-Biológicas 20(2): 53-60. Doi:https://doi.org/10.1016/j.recqb.2017.04.006.

Faccoli, M. 2002. Winter mortality in sub-corticolous populations of *Ips typographus* (Coleoptera, Scolytidae) and its parasitoids in the south-eastern Alps. Journal of Pest Science 75: 62-68. Doi:https://doi.org/10.1034/j.1399-5448.2002.02017.x.

Fonseca-Gonzáles, J., H. De los Santos-Posadas, A. Rodríguez-Ortega y R. Rodríguez-Laguna. 2014. Efecto del daño por el fuego y descortezadores sobre la mortalidad de *Pinus patula* Schl. et Cham en Hidalgo, México. Agrociencia 48: 103-113. http://www.scielo.org.mx/pdf/agro/v48n1/v48n1a7.pdf (16 de marzo de 2021).

Gaylord, M. L., T. E. Kolb, W. T. Pockman, J. A. Plaut, E. A. Yepez, A. K. Macalady, R. E. Pangle and N. G. McDowell. 2013. Drought predisposes piñon-juniper woodlands to insect attacks and mortality. New Phytologist 198: 567-578. Doi:https://doi: 10.1890/13-0230.1.

Hart, S. J., T. T. Veblen, K. S. Eisenhart, D. Jarvis and D. Kulakowski. 2014. Drought induces spruce beetle (*Dendroctonus rufipennis*) outbreaks northwestern Colorado. Ecology 95: 930-939. Doi:https://doi.org/10.1111/nph.12174.

Hernández-Muñoz, G., J. C. Soto-Correa, V. H. Cambrón-Sandoval y I. Avilés-Carrillo. 2017. Explosión de la abundancia de descortezadores, un acontecimiento adelantado a la primavera en el bosque de pino en Hidalgo. Entomología Forestal 525-530. http://www.entomologia.socmexent.org/revista/2017/EF/EM1912017_525-530.pdf (4 de diciembre de 2020).

Hicke, J. A., J. A, Logan, J. Powell and D. S. Ojima. 2006. Changing temperaturas influence suitability form modeled mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in the western United States. Journal of Geophysical Research Biogeociences 111:2-12. Doi:https://doi.org/10.1029/2005JG000101.

Hutchinson, M. F. 2004. Anusplin (computer program) version 4.3. The Australian National University. Centre for Resource and Environmental Studies. Canberra, Australia. n/p.

Instituto Mexicano de Tecnología del Agua (IMTA). 2019. Extractor Rápido de Información Climatológica III (ERIC), Software. Semarnat. México. https://www.imta.gob.mx/es/productos/software/eric-iii-version-3-2-extractorrapido-de-informacion-climatolo-detail (20 de agosto de 2018).

López-Gómez, V., B. Torre-Huerta, J. F. Reséndiz-Martínez, G. Sánchez-Martínez and A. R. Gijón-Hernández. 2017. Influence of climatic parameters on the population fluctuations of the complex *Dendroctonus frontalis* Zimmerman, 1869 and *Dendroctonus mexicanus* Hopkins, 1909. Revista Mexicana de Ciencias Forestales 8:7-29. Doi:https://doi.org/10.29298/rmcf.v11i59.668.

Macías-Sámano, J. E., A. Niño-Domínguez, J. Cruz-López, R. Altúzar-Mérida y O. Maldonado. 2004. Monitoreo de descortezadores y sus depredadores mediante el uso de semioquímicos: Manual operativo 2ª ed. El Colegio de la Frontera Sur, Ecosur Conafor. CONANP-USDA Forest Service. Tapachula, Chis, México. 11 p.

Méndez-Encina, F. M., J. Méndez-Gonzáles y J. Cerano-Paredes. 2020. Distribución actual y potencial de *Dendroctonus mexicanus* Hopkins bajo dos escenarios de cambio climático. Madera y Bosques 26(2): 1-14. Doi: 10.21829/myb.2020.2622002.

McKee, T. B., N. J. Doesken and J. Kleist. 1993. The relationship of drought frequency and duration of time scales. *In:* Eighth Conference on Applied Climatology, American Meteorological Society. January 17-22. Anaheim CA, USA. pp. 179-186.

Morales-Rangel, A., V. H. Cambrón-Sandoval, J. C. Soto-Correa, R. W. Jones y J. A. Obregón-Zuñiga. 2018. Efecto de la temperatura en poblaciones de *Dendroctonus frontalis* Zimmerman y *Dendroctonus mexicanus* Hopkins (Coleoptera: Curculionidae: Scolytinae) bajo un escenario de cambio climático en la Sierra Gorda. Acta Zoológica Mexicana (nueva serie) 34: 1-8. Doi:http://dx.doi.org/10.21829/azm.2018.3412141.

Organización Meteorológica Mundial (OMM). 2012. Índice normalizado de precipitación, Guía del usuario. No. 1090. Ginebra, Suiza 15 p.

Rosenberger, W. D., B. H. Aukema and R. C. Venette. 2017. Cold tolerance of mountain pine beetle among novel Eastern pines: A potential for trade-offs in an invaded range? Forest Ecology and Management 400: 28-37. Doi:https://doi.org/10.1016/j.foreco.2017.05.031.

Safranyik, L., A. L. Carrol, J. Régniére, D. W. Langor, W. G. Riel, T. L. Shore, B. Peter, B. J. Cooke, V. G. Nealis and S. W.Taylor. 2010. Potential for range expansion of mountain pine beetle into the boreal forest of North America. The Canadian Entomologist 142(5): 415-442. Doi:https://doi.org/10.4039/n08-CPA01.

Salinas-Moreno, Y., A. Ager, C. F. Vargas, J. L. Hayes and G. Zúñiga. 2010. Determining the vulnerability of Mexican pine forests to bark beetles of the genus *Dendroctonus* Erichson (Coleoptera: Curculionidae: Scolytinae). Forest Ecology and Management 260: 52-61. Doi: https://doi.org/10.1016/j.foreco.2010.03.029.

Salinas-Moreno, Y., M. G. Mendoza, A. Barrios, R. Cisneros, J. Macías-Sámano and G. Zúñiga. 2004. Areography of the genus *Dendroctonus* (Coleoptera: Curculionidae: Scolytinae) in Mexico. Journal of Biogeography 31: 1163-1177. Doi:https://doi.org/10.1111/j.1365-2699.2004.01110.x.

Sambaraju, R. K., A. L. Carroll, J. Zhu, K. Stahl, R. Dan Moore and B. H. Aukema. 2012. Climate change could alter the distribution on mountain pines beetle outbreaks in western Canada. Ecography 35: 211-223.Doi:https://doi.org/10.1111/j.1600-0587.2011.06847.x.

Sánchez-Martínez, G. 2004. Diagnóstico fitosanitario de los bosques de pino, pino-encino y encino-pino en la sierra Fría, Aguascalientes. INIFAP. Campo Experimental de Pabellón de Arteaga. Folleto Técnico. Pabellón de Arteaga, Ags, México. 30 p.

Statisctical Analysis System (SAS). 2004. SAS / STAT 9.3 User's Guide. SAS Institute Inc. Cary, NA, Carolina, USA. 4975 p.

Servicios Forestales de Hidalgo. 2017. Información climatológica, Hidalgo. https://smn.cna.gob.mx/es/informacion-climatologica-por-estado?estado=hgo (2 de julio de 2019).

Servicio Meteorológico Nacional (SMN). 2019. Información climática del estado de Hidalgo. https://smn.cna.gob.mx/es/informacion-climatologica-por-estado?estado=hgo (5 de julio de 2019).

Six, D. L. and R. R. Bracewell. 2015. Chapter 8. *Dendroctonus*. *In*: Vega F., E. and R. W. Hofstetter (eds.). Bark beetles: Biology and Ecology of Native and Invasive Species. Academic Press. San Diego, CA, USA. pp. 305-350.

Soto-Correa, J. C., I. Avilés-Carrillo, D. Girón-Gutíerrez y V. H. Cambrón-Sandoval. 2019. Abundancia altitudinal de *Dendroctonus frontalis* (Coleoptera: Curculionidae) en relación a variables climáticas en Hidalgo, México. Revista de Biología Tropical 67: 370-379. Doi:http://dx.doi.org/10.15517/rbt.v67i3.34436.

Trần, J. K., T. Ylioja, R. F. Billings, J. Régniére and M. Ayres. 2007. Impact of minimum winter temperatures on the population dynamics of *Dendroctonus frontalis*. Ecological Applications 17: 882-899. Doi: https://doi.org/10.1890/06-0512.

Weed, S. A., B. Bentz, M. P. Ayres and T. P Holmes. 2015. Geographycally variables response of *Dendroctonus ponderosae* to winter warming in the western United States. Landscape Ecology 30: 1075-1093. Doi: https://doi.org/10.1007/s10980-015-0170-z.