Ants (Hymenoptera: Formicidae) in a temperate ecosystem from La Malinche National Park, Mexico

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Abstract

The formicofauna of temperate Mexican ecosystems have been studied poorly. The objective of this study was to document the number of ant species in the protected natural area of La Malinche National Park, which features a temperate ecosystem in central Mexico. Furthermore, this study serves to update the list of species for Tlaxcala State in this area of the country. During 2015 to 2016, samples were collected along six 400 m linear transects in oak forest and agricultural land (2,700, 2,800, and 2,900 masl), using pitfall traps, baits with either protein or sugar, and hand collection from plants (where ants were foraging for floral nectar, extrafloral nectar, or honeydew). Twenty-three ant species belonging to 14 genera, 11 tribes, and 4 subfamilies were collected in La Malinche National Park. One genus (Brachymyrmex Mayr [Hymenoptera: Formicidae]), 7 species in the park, and 5 species in Tlaxcala State were new collection records. In pitfall traps, 23 species were recorded, where Dorymyrmex insanus Buckley, Formica densiventris Viereck, Lasius mexicanus Wheeler, and Brachymyrmex musculus Forel (all Hymenoptera: Formicidae) were collected exclusively from agricultural land. Temnothorax brevispinosus MacKay and Stenamma huachucanum Smith (both Hymenoptera: Formicidae) were collected exclusively in the oak forest, whereas 17 species were recovered from both habitats. Nine species were recorded from either protein or sugar baits; Formica propatula Francoeur and Temnothorax texanus Wheeler (both Hymenoptera: Formicidae) were recorded only in tuna baits, and with the remainder of the species collected with tuna and honey. Seven ant species were recorded from hand collections on plants. We have increased the number of ant species in Tlaxcala State from 53 to 58 (28 of which are present in La Malinche National Park). This faunal survey demonstrated that there is a great diversity of ant species in this temperate ecosystem. It is urgent to document the diversity of formicofauna in these types of ecosystems because they may possibly be the first to be negatively affected by climate change.

Key Words: Tlaxcala State; Formicinae; Myrmicinae; oak forest; agricultural land; protected natural area

Resumen

La formicofauna de los ecosistemas templados ha sido pobremente estudiada. El objetivo de este estudio fue documentar el número de especies de hormigas en el área natural protegida del Parque Nacional La Malinche, que cuenta con un ecosistema templado en el centro de México. Además, este estudio actualiza la lista de especies de hormigas para el Estado de Tlaxcala en esta área del país. Durante 2015 y 2016, las muestras fueron colectadas a lo largo de seis transesects lineales de 400 m en bosque de encino y campo de cultivo (2,700, 2,800, y 2,900 m sobre el nivel del mar), usando trampas pitfall, cebos con proteína o azúcar, y colecta manual sobre plantas (donde las hormigas estaban forrajando néctar floral, néctar extrafloral, o honeydew). Veintitrés especies de hormigas pertenecientes a 14 géneros, 11 tribus, y 4 subfamilias fueron colectadas en el Parque Nacional La Malinche. Un género (Brachymyrmex Mayr [Hymenoptera: Formicidae]), 7 especies en el parque Nacional La Malinche, y 5 especies en el estado de Tlaxcala fueron nuevos registros. En trampas pitfall, 23 especies fueron colectadas, de éstas, Dorymyrmex insanus Buckley, Formica densiventris Viereck, Lasius mexicanus Wheeler, y B. musculus Forel (todas Hymenoptera: Formicidae) fueron exclusivamente colectadas del campo de cultivo. Temnothorax brevispinosus MacKay y Stenamma huachucanum Smith (ambas Hymenoptera: Formicidae) fueron exclusivamente colectadas en el bosque de encino, mientras que 17 especies se registraron en ambos hábitats. Nueve especies fueron colectadas con cebos de proteína o azúcar; Formica propatula Francoeur y Temnothorax texanus Wheeler (ambas Hymenoptera: Formicidae) fueron registradas solo en cebos de atún, y el resto de las especies fueron registradas en cebos de atún y miel. Siete especies fueron registradas a partir de la colecta manual sobre las plantas. Hemos incrementado el número de especies de hormigas conocidas en el estado de Tlaxcala de 53 a 58 (28 de las cuales están presentes en el Parque Nacional La Malinche). Este estudio de fauna demostró que hay una gran diversidad de especies de hormigas en este ecosistema templado. Es urgente documentar la diversidad de formicofauna en estos tipos de ecosistemas porque ésta puede ser posiblemente la primera en ser afectada negativamente por el cambio climático.

Palabras Clave: Tlaxcala State; Formicinae; Myrmicinae; oak forest; agricultural land; protected natural area

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in nutrient cycling, bioturbation, and pedogenesis (Arcila & Lozano-Zambrano 2003). In addition, ants interact in a variety of ways with other organisms in antagonistic or mutualistic manners. Antagonistically, they can function as plant herbivores. For example, in the case of leaf cutters, ants of the tribe Attini (Formicidae: Myrmicinae) harvest leaves not for their own consumption but as substrates to grow the fungus on which they feed. Leaf cutters are the primary consumers in terrestrial ecosystems in the New World, and their impact on vegetation is greater than any herbivore taxa (Beattie & Hughes 2009). This group can act as mutualists where they grow and feed on the fungus they are producing; although they consume part of the mycelium, the fungus relies exclusively on the ants for propagation and reproduction (Vásquez-Bolaños & Quiroz-Rocha 2013). Also, ants that defend plants against herbivores in exchange for the nectar that the plants produce from extrafloral nectarics can be considered mutualists (Beattie & Hughes 2009). Furthermore, those ants that act as seed dispersants are similarly regarded as mutualists (Rico-Gray & Oliveira 2007; Salazar-Rojas et al. 2012). For all of these reasons ants can be used as bioindicators (Arcila & Lozano-Zambrano 2003). Approximately 13,000 species of ants occur worldwide (Vázquez-Bolaños 2015). For Mexico, the most recent taxonomic review indicates that there are 927 present in the country belonging to 93 genera and 11 subfamilies, with the Myrmicinae subfamily being the most represented with 51.5% of the species (Vázquez-Bolaños 2015).

However, there are still knowledge gaps regarding the taxonomy of ants in Mexico. These knowledge gaps occur because identification to the species level often is difficult and complex; additionally, the number of taxonomic specialists is lacking (Vázquez-Bolaños 2015). Generally, there appears to be a geographic bias in the sampling of this group of insects. Ants have been more studied in the tropics than temperate or arid areas of Mexico (Hinojosa Ontiveros et al. 2015). This is partly because, like other groups of organisms, ant diversity follows a latitudinal and altitudinal pattern, with most ant species occurring at lower forest elevations and tropical latitudes (Ward 2000). Studies in temperate ecosystems have shown differential composition in ant functionality when compared with tropical ecosystems. For example, cold climate specialists are an important component of temperate ecosystems (Andersen 1997, 2000; Cuautle et al. 2016) followed by Myrmicine generalists in low land tropics (Andersen 2000). Whereas tropical climate specialists are dominated by Dolichoderinae in arboreal tropical rainforests, Myrmicine generalists and subordinate Camponotini are important dominant elements as well (Andersen 2000). It has been reported that cold climate specialists could be the first ant group negatively affected by climate change because they are associated with low temperature environments (Ellison 2012). Because of this, knowledge of ant communities in temperate ecosystems has become vitally important because changes in its abundance or richness could be the first warning of the effect of global warming, and changes in the way we manage natural resources should be implemented.

Rojas (2001) reported that Tlaxcala, Querétaro, Aguascalientes, and the state of Mexico were areas with the least ant diversity; however, it is believed that this is merely the result of having been poorly studied. Velasco Corona et al. (2007) recorded Liotometopum apiculatum Mayr (Formicidae: Dolichoderinae) from Tlaxcala while Vásquez-Bolaños (2011) reported Formica retecta Francoeur (Formicidae: Formicinae) and Pogonomyrmex barbatus Smith (Formicidae: Myrmicinae) from the same city. Vásquez-Bolaños & Quiroz-Rocha (2013) reported 14 states of Mexico, including Tlaxcala, did not have a local myrmecofauna survey. Later, Vásquez-Bolaños (2015) reported 14 species (5 subfamilies, 14 genera) for Tlaxcala State. Eleven of those reported species were state records as a result of the study by Landero-Torres et al. (2014) conducted in the Botanical Garden of Tizatlán, Tlaxcala.

In a subsequent study, Landero-Torres et al. (2015) recorded 9 more species from Tlaxcala State (6 municipalities), including Pheidole ceras Wheeler (Formicidae: Formicinae), which was the first ant species reported for the Natural Protected Area, La Malinche National Park. Subsequently, Dubovikoff & Coronado-Blanco (2017) reported 20 species for Tlaxcala State (7 municipalities) of which 8 species were collected in La Malinche National Park. Later, Castillo-Guevara et al. (2019) reported 4 new species in La Malinche National Park. Finally, Dáttilo et al. (2019) has reported 9 species in La Malinche National Park. As a result of the above studies, 53 species, 23 genera, 16 tribes, and 7 subfamilies were reported for Tlaxcala State. Despite the importance of La Malinche National Park as a protected area in a temperate ecosystem, a formicid fauna survey has been conducted in the area. The objective of this study was to update the fauna list of Formicidae species for the state of Tlaxcala, Mexico, by adding to the species inventory present in La Malinche National Park. The information, reported herein, contributes particularly to the knowledge of formicofauna of Tlaxcala and Mexico, and temperate ecosystems in general.

**Materials and Methods**

**STUDY SITE**

The study was conducted at La Malinche National Park, Tlaxcala, Mexico, with a total area of 46,093 ha (19.233°N, 98.033°W; 2,300–4,461 masl). Approximately 17,500 ha of the protected area of the park is comprised of coniferous and oak remnant forests surrounded by a landscape of human-induced grasslands, i.e., Festuca tolucensis H.B.K., Muhlhenbergia macoura (Kunth), and Stipa ichu (Ruíz & Pav.) Kunth (all Poaceae), that usually is subjected to prescribed burning for thinning of the cultivation areas and secondary succession vegetation. The park is in the Mexican Transition Zone, a biogeographic province that was proposed by Halfflter (2008) for insects and other groups. In this transition zone, there are Neartic and Neotropical biota. Within the Mexican Transition Zone, there are a series of mountains and volcanoes that constitute the Trans-Mexican Volcanic Belt, in which La Malinche National Park is included. The Trans-Mexican Volcanic Belt is characterized as a route of dispersion for northern fauna to the mountains as a result of the many volcanic events present in this area. This situation has resulted in a high rate of change in species composition (i.e., beta diversity) in this area (Moctezuma et al. 2016). Mean annual precipitation is 800 mm; the rainy season is between Jun and Oct, and mean annual temperature is 15 °C (Lara 2006; Villers et al. 2006).

Our study was conducted in 7.68 ha of preserved transitional oak forest located within La Malinche National Park (i.e., Quercus rugosa Née, Quercus crassipes Humb. & Bonpl., Quercus laurina Bonpl., Quercus crassifolia Bonpl., and Quercus dysphylloa Benth. [all Fagaceae]) that included hedgerows, rainfed agriculture (i.e., maize crops), and agricultural land used for grazing livestock outside La Malinche National Park, with an elevation range between 2,700 to 2,900 masl. At each elevation range (2,700, 2,800, and 2,900 masl) we established 3 paired 400 m linear transects, spaced at least 500 m apart, that included a transect in an oak forest and agricultural land (i.e., 1 transect pair at each altitudinal step). The separation between paired transects from each elevation range was at least 1.5 km. Ant samples were collected in each of these transects using 3 collection methods: pitfall traps, protein or sugar baits, and hand collection from plants where ants foraged for floral or extrafloral nectar as well as honeydew sources. To avoid interference between sampling methods, collections were performed on different d of the mo.
Pitfall Traps

The pitfall traps consisted of plastic cups (Reyma®, Reyma Group, Ecatepec, Mexico State, Mexico) (10 cm high) that contained 70 mL of propylene glycol. Traps were placed during the dry season (Mar 2015 and Apr 2016) and rainy season (Jul 2015 and Sep 2016). In each transect, 20 traps were placed 20 m apart (20 traps per transect × 6 transects = 240 traps total). Trap contents were collected 96 h after placement. Captured ants were stored in 70% ethanol and transferred to the laboratory for identification.

Baits

Bait collections were conducted during Apr and Sep 2015. Bait stations were placed every 10 m along the linear transects described earlier. Each sampling point consisted of paired Petri dishes (at < 10 cm apart) with baits as attractants (placed in the center of the Petri dish). Two types of baits were used: 0.5 mL of commercial honey (Carlot®. Herdez, Mexico City, Mexico) diluted with 50% water, and 0.5 g of commercial tuna (Dolores®, Pinza Group, Mexico City, Mexico). For each transect, there were 9 sampling points with 18 Petri dishes. Each mo, 108 Petri dishes were placed (2 vegetation types × 3 transects × 9 sampling points × 2 types of bait), for a total of 648 Petri dishes. Baits were placed ad libitum in the center of each Petri dish. Weather permitting, Petri dishes were placed in the first pair of transects at 9:00 AM, the second pair of transects at 11:00 AM, and in the third at pair at 1:00 PM, and remained in place for 4 h each. The order of placement of Petri dishes in transects was alternated each mo. Ants from collections were stored in 70% ethanol and transferred to the laboratory for identification.

Hand Collection from Plants

For each transect, hand collection of ants from plants was conducted every mo from Jun 2015 to Jul 2016 on d with mild weather conditions. Walking counts were performed from 8:00 AM to 1:00 PM beginning from a different transect and different vegetation type each time to avoid sample location bias. Observers recorded individual ants showing some type of interaction with any plant at a parallel distance no more than 10 m from the center line of the transect. Each observed specimen was collected with an entomological aspirator or forceps and preserved individually in capped 1.5 mL Eppendorf® Safe-Lock™ Axygen® microcentrifuge tubes (Corning Inc., Corning, New York, USA) containing 70% alcohol.

Ants were identified using the taxonomic keys of Mackay & Mackay (1989) following the classification proposed by Vásquez-Bolaños (2019). Identification was also aided by myrmecology specialists from the Entomology Laboratory of the Institute of Ecology AC (J. E. Valenzuela-González), University of Quebec, in Chicoutimi; the Department of Fundamental Sciences (A. Francoeur); and the University Autonoma of Guadalajara (M. Vásquez-Bolaños). A reference collection of ants collected in the study was created and later integrated into the Entomology Collection (Formicidae) of the Institute of Ecology AC, Xalapa, Veracruz, Mexico (IEA; Reg. SEMARNAT: Ver. IN.048.0198), and the Entomology Laboratory of the University of Las Americas Puebla, San Andrés Cholula, Puebla, Mexico.

Results

In La Malinche National Park, a total of 11,064 ants were collected that included workers, soldiers, and queens from pitfall traps; 3,498 ants collected from protein or sugar baits, and 1,053 ants collected from plants. Twenty-three ant species belonging to 14 genera, 11 tribes, and 4 subfamilies were recorded (Table 1). One genera (Brachymyrmex), 7 species (in La Malinche National Park: Doromyrmex insanus [Buckley], Camponotus pudorosus Emery, Formica pacifica Francoeur, Formica propatula [Francoeur], Lasius mexicanus Wheeler, Brachymyrmex musculus Forel, and Crematogaster lineolata [Say] [all Hymenoptera: Formicidae]) (Table 1) and 5 species (in Tlaxcala: D. insanus, F. pacifica, L. mexicanus, B. musculus, and C. lineolata) (Table 2) were new records. Formicinae and Myrmicinae were the subfamilies most represented with 11 and 10 species, respectively, while Dorylinae and Dolichoderinae were represented by only 1 species each. According to the sampling method used, all species were recorded in pitfall traps, 9 species were collected on baits, and 7 species were hand collected from plants.

All species were present in both environments in pitfall traps, except for D. insanus, Formica densiventris Viereck (Hymenoptera: Formicidae), L. mexicanus, and B. musculus, which were recorded only from agricultural land, while Temnothorax brevispinosus Mackay and Stenamma huachucanum Smith (both Hymenoptera: Formicidae) were recorded only in oak forest (Table 1). Formica propatula and Temnothorax texanus Wheeler (Hymenoptera: Formicidae) were collected from the tuna bait, whereas 6 species were recorded from both types of baits, with only 3 unidentified Camponotus specimens collected exclusively with honey (Table 1).

We found representatives of the following functional groups (based on the criteria of Andersen 2000): cold-climate specialists (Lasius latipes Walsh, L. mexicanus, L. niger (L.), T. brevispinosus, Temnothorax punctithorax Mackay, T. texanus, and S. huachucanum), opportunists (D. insanus, F. densiventris, F. pacifica, F. propatula, F. retecta, and Myrmica mexicana Wheeler), generalized Myrmicinae (Pheidole chalca Wheeler, Pheidole soritis Wheeler, C. lineolata, and Monomorium minimum [Buckley]), tropical climate specialists (Neivamyrmex pilosus Smith, B. musculus, and Solenopsis picea Emery), subordinate Camponotini (Camponotus picipes pilosulus Emery and Camponotus pudorosus Emery), and hot-climate specialists (Myrmecocystus melpomene Wheeler) (all Hymenoptera: Formicidae).

Discussion

Tlaxcala is a small state in central Mexico (4,016 m²), and ant collections have been carried out in only 12 of the 60 municipalities that comprise it: Tlaxco, Tizatlán, Huamantla, Nanacamilpa, Tepetitla, Tlaxala, Xaloztoc, Zacatelco, Tzompantepec, Teacalco, Apizaco, and Tetlanohcan. Of the representative vegetation types present in Tlaxcala, the oak forest and agricultural land ants had not been sampled until recent studies by Castillo-Guevara et al. (2019) and Dáttilo et al. (2019) in the La Malinche National Park. Prior to these studies, Landero-Torres et al. (2019) reported 4 species new to La Malinche National Park. More recently, Dáttilo et al. (2019) reported 9 species for La Malinche National Park: P. soritis Wheeler, P. chalca Wheeler, M. melanoticus, L. niger, L. latipes Walsh, S. picea, Neivamyrmex...
Table 1. Inventory of ant species collected in La Malinche National Park in Tlaxcala, Mexico, by Vásquez-Bolaños (2011); Landero-Torres et al. (2015); Vásquez-Bolaños (2015); Dubovikoff & Coronado-Blanco (2017); Castillo-Guevara et al. (2019); Dáttolo et al. (2019). Abbreviations: OF = oak forest, AL = agricultural land, P = pitfall trap, B = bait, HB = honey bait, TB = tuna bait, HCP = hand collection from plants. Mexico distribution ant species (Vásquez-Bolaños 2015). *Camponotus pudorosus and Formica propatula had been reported for Tlaxcala State, but not specifically in La Malinche National Park.

| Formicidae | Vegetation types | Collecting techniques | Distribution |
|------------|------------------|-----------------------|--------------|
| Dolichoderinae Forel, 1878 | AL | P | BC, BCS, CHIH, DGO, HGO, NAY, NL, PUE, QRO, QR, SIN, SON, TAMPS, VER, YUC |
| Leptomyrmecini Emery, 1913 | AL, OF | P | |
| Dorymyrmex Mayr, 1866 | AL | P | |
| Dorymyrmex insanus (Buckley, 1866) | AL | P | |
| Neivamyrmex Borgmeier, 1940 | AL, OF | P | |
| Neivamyrmex pilosus Smith, 1858* | AL, OF | P | |
| Formicinae Forel, 1878 | AL, OF | P | |
| Camponotinae Forel, 1878 | AL, OF | P | |
| Camponotus Mayr, 1861 | AL, OF | P | |
| Camponotus picipes pilosulus Emery, 1925** | AL, OF | P | |
| Camponotus pudorosus Emery, 1925* | AL, OF | P | |
| Formicini, Forel, 1878 | AL, OF | P | |
| Camponotus Mayr, 1861 | AL, OF | P | |
| Camponotus picipes pilosulus Emery, 1925** | AL, OF | P | |
| Formica Linnaeus, 1758 | AL, OF | P | |
| Formica browni Francoeur, 1973* | AL, OF | P | |
| Formica densiventris Viereck, 1903* | AL, OF | P | |
| Formica moki Wheeler, 1906* | AL, OF | P | |
| Formica pacifica Francoeur, 1973 | AL, OF | P, HB, TB, HCP | VER |
| Formica propatula Francoeur, 1973** | AL, OF | P, TB, HCP | |
| Formica retecta Francoeur, 1973** | AL, OF | P | |
| Lasius Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Formicidae | Vegetation types | Collecting techniques | Distribution |
| Dolichoderinae Forel, 1878 | OF | P | |
| Leptomyrmecini Emery, 1913 | OF | P | |
| Dorymyrmex Mayr, 1866 | OF | P | |
| Dorymyrmex insanus (Buckley, 1866) | OF | P | |
| Neivamyrmex Borgmeier, 1940 | OF | P | |
| Neivamyrmex pilosus Smith, 1858* | AL, OF | P | |
| Formicinae Forel, 1878 | AL, OF | P | |
| Camponotinae Forel, 1878 | AL, OF | P | |
| Camponotus Mayr, 1861 | AL, OF | P | |
| Camponotus picipes pilosulus Emery, 1925** | AL, OF | P | |
| Camponotus pudorosus Emery, 1925* | AL, OF | P | |
| Formicini, Forel, 1878 | AL, OF | P | |
| Camponotus Mayr, 1861 | AL, OF | P | |
| Camponotus picipes pilosulus Emery, 1925** | AL, OF | P | |
| Formica Linnaeus, 1758 | AL, OF | P | |
| Formica browni Francoeur, 1973* | AL, OF | P | |
| Formica densiventris Viereck, 1903* | AL, OF | P | |
| Formica moki Wheeler, 1906* | AL, OF | P | |
| Formica pacifica Francoeur, 1973 | AL, OF | P, HB, TB, HCP | VER |
| Formica propatula Francoeur, 1973** | AL, OF | P, TB, HCP | |
| Formica retecta Francoeur, 1973** | AL, OF | P | |
| Lasius Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |
| Lasius Fabricius, 1804 | AL, OK | P, HB, TB | |
| Lasius mexicanus Wheeler, 1917 | AL | P | |
| Lasius niger Linnaeus, 1758* | AL, OF | P | |
| Myrmecocystus Wesmael, 1838 | AL, OF | P | |
| Myrmecocystus melanoticus Wheeler, 1914* | AL, OF | P | |
| Plagiolepidini Ashmead, 1905 | AL, OF | P | |

Mexico state abbreviations: BC = Baja California, BCS = Baja California Sur, CHIH = Chihuahua, DGO = Durango, HGO = Hidalgo, MEX = Estado de México, MOR = Morelia, NAY = Nayarit, NL = Nuevo León, PUE = Puebla, QRO = Querétaro, QR = Quintana Roo, SIN = Sinaloa, SON = Sonora, TAMPS = Tamaulipas, VER = Veracruz, YUC = Yucatán.
Table 2. Inventory of ant species in Tlaxcala State, Mexico. Ant species marked with an asterisk (*) were collected in La Malinche National Park during the current study.

| FORMICIDAE Latreille, 1809 | References |
|-----------------------------|-------------|
| **DOLICHODERINAE** Forel, 1878 | | |
| Leptomyrmecini Emery, 1913 | | |
| *Dorymyrmex Mayr, 1866* | | |
| *Dorymyrmex insanus* (Buckley, 1866) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015; Dubovikoff & Coronado-Blanco 2017 |
| *Dorymyrmex bicolor* Wheeler, 1906 | Dubovikoff & Coronado-Blanco 2017 |
| *Dorymyrmex smithi* Cole, 1936 | | |
| Linepithema Mayr, 1886 | | |
| *Linepithema disperatum* (Forel, 1885) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| Tapinonmini Emery, 1913 | | |
| Limetopum Mayr, 1861 | | |
| *Limetopum apiculatum* (Forel, 1885) | Velasco Corona et al. 2007; Vásquez-Bolaños 2011, 2015; Dubovikoff & Coronado-Blanco 2017 |
| **Dorylinae** Leach, 1815 | | |
| **Tapinomini** Emery, 1913 | | |
| **Liometopum** Mayr, 1861 | | |
| *Liometopum apiculatum* Mayr, 1870 | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| **Tapinoma** Foerster, 1850 | | |
| **Linepithema** Mayr, 1866 | | |
| *Linepithema dispertitum* (Forel, 1885) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| **Tapinoma melanocephalum** (Fabricius, 1793) | | |
| **Dorylini** Ashmead, 1905 | | |
| **Labidus** Jurine, 1807 | | |
| *Labidus coecus* (Latreille, 1802) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| *Neivamyrmex* Borgmeier, 1940 | | |
| *Neivamyrmex pilosus* Smith, 1858* | Dáttilo et al. 2019 |
| **Ectatomminae** Emery, 1895 | | |
| **Gnamptogenys** Roger, 1863 | | |
| *Gnamptogenys strigata* (Norton, 1868) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| **Formicini** Latreille, 1809 | | |
| **Camponotini** Forel, 1878 | | |
| *Camponotus* Mayr, 1861 | | |
| *Camponotus atriceps* (Smith, 1858) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| *Camponotus picipes pilosulus* Emery, 1925* | Castillo-Guevara et al. 2019; Dáttilo et al. 2019 |
| *Camponotus planatus* Roger, 1863 | Landero-Torres et al. 2015 |
| *Camponotus pudorosus* Emery, 1925* | Dubovikoff & Coronado-Blanco 2017 |
| **Formicinae** Latreille, 1809 | | |
| **Formicinae** Latreille, 1809 | | |
| **Formica** Linnaeus, 1758 | | |
| *Formica browni* Francoeur, 1973 | Dubovikoff & Coronado-Blanco 2017 |
| *Formica densiventris* Viereck, 1903* | Dubovikoff & Coronado-Blanco 2017 |
| *Formica moki* Francoeur, 1973 | Dubovikoff & Coronado-Blanco 2017 |
| *Formica propatula* Francoeur, 1973* | Landero-Torres et al. 2015; Dubovikoff & Coronado-Blanco 2017 |
| *Formica pulla* Francoeur, 1973* | Dubovikoff & Coronado-Blanco 2017 |
| *Formica retecta* Francoeur, 1973* | Vásquez-Bolaños 2011, 2015; Dubovikoff & Coronado-Blanco 2017; Castillo-Guevara et al. 2019; Dáttilo et al. 2019 |
| *Formica xerophila* Smith, 1939 | Dubovikoff & Coronado-Blanco 2017 |
| **Lasius** Fabricius, 1804 | | |
| *Lasius latipes* Walsh, 1863* | Dubovikoff & Coronado-Blanco 2017; Dáttilo et al. 2019 |
| *Lasius mexicanus* Wheeler, 1917* | Dáttilo et al. 2019 |
| *Lasius niger* Linneaus, 1758* | Dubovikoff & Coronado-Blanco 2017 |
| *Lasius sitiens* Wilson, 1955 | Dáttilo et al. 2019 |
| **Myrmecocystus** Wesmael, 1838 | | |
| *Myrmecocystus melanoticus* Wheeler, 1914* | | |
| **Plagiolepidini** Ashmead, 1905 | | |
| *Brachymyrmex* Mayr, 1868 | | |
| *Brachymyrmex musculus* Forel, 1899* | | |
| **Paratrechina** Motschoulsky, 1863 | | |
| *Paratrechina longicornis* (Latreille, 1802) | | |
| **Myrmicinae** Lepeletier, 1835 | | |
| *Attini* Smith, 1858 | | |
| *Atta* Fabricius, 1818 | | |
| *Atta mexicana* (Smith, 1858) | | |
| **Pheidole** Westwood, 1839 | | |
| *Pheidole azteca* Wilson, 2003 | Landero-Torres et al. 2015 |
Our study is the first taxonomic faunal survey conducted exclusively at La Malinche National Park using 3 collection methods over a period of 2 yr. This fact makes it the most recent complete study conducted in the area. Ant species recorded in La Malinche National Park and Tlaxcala State belonged to the following functional groups: cold-climate specialists (7 species), opportunists (6 species), generalized Myrmicinae (4 species), tropical climate specialists (3 species), subordinate Camponotini (2 species), and hot-climate specialists (1 species). As expected, cold-climate specialists were the best represented group in this temperate high-altitude ecosystem. Opportunist species were the second functional group in terms of number of species. This is interesting given that this functional group is associated with sites with high levels of disturbance and stress; although some of these species are found only on agricultural land (D. insanus and F. densiventeris), the majority were found in both vegetation types. The generalized Myrmicinae, which are associated with warm, open environments, were found in both vegetation types, although numerically they were better represented in agriculture land (Castillo-Guevara et al. 2019). Of the 23 species of ants recorded in our study, 2 cold-climate specialist species were exclusively present in the oak forest, whereas 4 species that were opportunists, cold-climate specialists, and tropical climate specialists were collected exclusively from agricultural land (Table 1). Cold-climate

Table 2. (Continued) Inventory of ant species in Tlaxcala State, Mexico. Ant species marked with an asterisk (*) were collected in La Malinche National Park during the current study.

| Formicidae Latreille, 1809 | References |
|---------------------------|------------|
| Pheidole calens Forel, 1901 | Dubovikoff & Coronado-Blanco 2017 |
| Pheidole ceres Wheeler, 1904 | Landero-Torres et al. 2015; Vásquez-Bolaños 2015 |
| Pheidole chalca Wheeler, 1914* | Dáttilo et al. 2019 |
| Pheidole deceptrix Forel, 1899 | Landero-Torres et al. 2015 |
| Pheidole hirtula Forel, 1899 | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| Pheidole hyatti Emery, 1895 | Dubovikoff & Coronado-Blanco 2017 |
| Pheidole nitidicollis Emery, 1896 | Landero-Torres et al. 2015 |
| Pheidole polymorpha Wilson, 2003 | Dubovikoff & Coronado-Blanco 2017 |
| Pheidole tepicana Pergande, 1896 | Landero-Torres et al. 2015 |
| Pheidole sortis Wheeler, 1908* | Dáttilo et al. 2019 |
| Crematogastri Forel, 1893 | |
| Crematogaster Lund, 1831 | |
| Crematogaster lineolata Say, 1836* | Dubovikoff & Coronado-Blanco 2017 |
| Crematogaster opaca Mayr, 1870 | |
| Temnothorax Mayr, 1861 | |
| Temnothorax brevispinosus Mackay, 2000* | Dubovikoff & Coronado-Blanco 2017 |
| Temnothorax manni (Wheeler, 1914) | Dubovikoff & Coronado-Blanco 2017; Dáttilo et al. 2019 |
| Temnothorax punctithorax Mackay, 2000* | |
| Temnothorax texanus Wheeler, 1903* | Dáttilo et al. 2019 |
| Myrmicini Lepeleter de Saint-Fargeau, 1835 | |
| Myrmica Latreille, 1804 | |
| Myrmica mexicana Wheeler, 1914* | Dubovikoff & Coronado-Blanco 2017; Castillo-Guevara et al. 2019; Dáttilo et al. 2019 |
| Myrmica striolaster Cole, 1953 | Dubovikoff & Coronado-Blanco 2017 |
| Ponogomyrmecini Ward, Brady, Fisher & Schultz, 2014 | |
| Ponogomyrmex Mayr, 1868 | Vásquez-Bolaños 2011, 2015 |
| Solenopsisidini Forel, 1893 | |
| SolenOPSIS Mayr, 1855 | |
| Monomorium ebrium Forel, 1891 | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| Monomorium minimum (Buckley, 1867)* | Castillo-Guevara et al. 2019; Dáttilo et al. 2019 |
| Solenopsis Westwood, 1840 | |
| Solenopsis geminata (Fabricius, 1804) | Landero-Torres et al. 2014; Vásquez-Bolaños 2015 |
| Solenopsis picea Emery, 1896* | Dáttilo et al. 2019 |
| Stenammin Ashmead, 1905 | |
| Stenamma Westwood, 1839 | |
| Stenamma huachucanum Smith, 1957* | Dáttilo et al. 2019 |
| Stenamma ignotum Branstetter, 2013 | Dubovikoff & Coronado-Blanco 2017 |
| PONERINAE Lepeletier, 1835 | |
| Ponerini Lepeletier, 1835 | |
| Odontomachus Latreille, 1804 | |
| Odontomachus leticeps Roger, 1952 | Landero-Torres et al. 2015 |
| Pseudomyrmecinae Smith, 1952 | |
| Pseudomyrmecini Smith, 1952 | |
| Pseudomyrmex Lund, 1831 | |
| Pseudomyrmex pallidus (Smith, 1855) | Landero-Torres et al. 2015 |

mex pilosus Smith, T. texanus, and S. huachucanum (all Hymenoptera: Formicidae).

Our study is the first taxonomic faunal survey conducted exclusively at La Malinche National Park using 3 collection methods over a period of 2 yr. This fact makes it the most recent complete study conducted in the area. Ant species recorded in La Malinche National Park and Tlaxcala State belonged to the following functional groups: cold-climate specialists (7 species), opportunists (6 species), generalized Myrmicinae (4 species), tropical climate specialists (3 species), subordinate Camponotini (2 species), and hot-climate specialists (1 species). As expected, cold-climate specialists were the best represented group in this temperate high-altitude ecosystem. Opportunist species were
specialists that were found only in the oak forest, such as T. brevispinosus and S. huachucanum, could be used as positive bioindicators for monitoring this protected natural area. The functional groups that were present in both vegetation types were cold-climate specialists, generalized Myrmicinae opportunists (with 4 species in each group), subordinate Camponotini, tropical climate specialists (with 2 species in each group), and hot-climate specialists (with 1 species). Whereas the Formica genus is represented by a great diversity of species, our survey reported only 4 species. We also collected representatives from the Fusca group, which are considered opportunist species (F. densiventris, F. pacifica, F. propatula, F. retecta) from both vegetation types.

Our study updates and lists new records in La Malinche National Park for 7 species belonging to 6 genera. Overall, we recorded 28 ant species of 14 genera, 11 tribes, and 5 subfamilies for the La Malinche National Park (Table 1). It is necessary to carry out systematic sampling in other vegetation types in La Malinche National Park. This work increases the number of known species of Tlaxcala State (Table 2), in addition to the 53 species previously reported by Landero-Torres et al. (2015), Vásquez-Bolaños (2015), Dubovikoff & Coronado-Blanco (2017), Castillo-Guevara et al. (2019), and Dättilo et al. (2019). Studies on ants in Tlaxcala State have begun only fairly recently. The first report of 1 ant species, Liometopum apiculatum Mayr (Hymenoptera: Formicidae) (Velasco Corona et al. 2007), was published in 2007; Vásquez-Bolaños (2011) reported Pogonomyrmex barbatus Smith and F. retecta. Later, Landero-Torres et al. (2014) further reported 11 ant species, and Vásquez-Bolaños (2015) recently published 14 ant species. That same year, Landero-Torres et al. (2015) reported 9 new ant species for Tlaxcala State, and Dubovikoff & Coronado-Blanco (2017) reported 20 new ant species. Castillo-Guevara et al. (2019) reported 2 new species; more recently Dättilo et al. (2019) reported 8 new ant species in Tlaxcala State. The updated number of species for Tlaxcala State now increases to 58 species, belonging to 24 genera, 16 tribes, and 7 subfamilies.

After the present study, Tlaxcala State can now be compared, with respect to the number of reported ant species, with the states of Durango (60 species) and Puebla (61 species). Ant diversity in Tlaxcala State now is superior to 10 Mexican states: Estado de México (16), Guanajuato (16), Querétaro (17), Distrito Federal (18), Zacatecas (21), Aguascalientes (36), Campeche (37), Colima (40), Sinaloa (48), and Coahuila (60) species. Castillo-Guevara et al. (2019) reported 2 new species; more recently Dättilo et al. (2019) reported 8 new ant species in Tlaxcala State. These data suggest that there is still a large gap to cover with respect to ant diversity in such a megadiverse country as Mexico.

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