

The diversity of ant communities (Hymenoptera: Formicidae) and their connections with other arthropods from three temperate forests of Central Mexico

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Abstract: Ants have been considered useful for bioindication because of their ecological characteristics. Nonetheless, among the characteristics of a bioindicator group, there must be a consistent and replicable response to disturbance. In this sense, divergent reactions have been found, even between taxons narrowly related. The objective of this work was to compare the diversity of the ant communities in three different temperate forests with different levels of disturbance, and to correlate their abundance and diversity of species, with that found in other arthropod communities of the same forests. The work was carried out in three municipalities in the North of the State of Mexico, where three types of different forests were identified by their degree of disturbance. These types include: 1) primary forest (PF), with typical species of a conserved forest; 2) mixed forest (MF), with species of a conserved forest and a reforestation effort; and 3) reforested forest (RF), with species used in reforestation efforts and indicative of disturbance. In each sample, an area of 2 500 m² was selected. Each area had 16 pitfalls apiece and they were placed 10 m away from each other. Samples were collected twice; one from February through March 2009 (dry season) and another from August through September 2010 (rainy season), which produced a total of 192 traps. Obtained specimens were identified at the most taxonomically specific level. All data captured was transformed to $\sqrt{n + 0.5}$ and diversity index levels of Shannon and Simpson were calculated, as well as richness of species for ants, beetles, grasshoppers, true bugs, and spiders. The values of richness, diversity, and abundance were correlated with the Pearson coefficient, and to evaluate possible causal relationships between these, a path analysis was performed. Results suggested an important influence of the site over ant communities, and values of richness, abundance and diversity were correlated with the communities of spiders, beetles, grasshoppers and true bugs, but not for all the sites studied. Responses to environmental changes are not only on the numeric proportions of abundance, richness and diversity, but also in the indirect and casual ecological interactions. Finally, the data seems to indicate that the responses of the ants to the environmental changes are not necessarily reflected on other organisms' communities, so the ants' role as bioindicators can be limited. *Rev. Biol. Trop.* 64 (2): 571-585. Epub 2016 June 01.

Key words: reforestation, bioindicators, species richness, landscape ecology, ecological function, causal analysis.

Ants have shown to be an excellent tool for bioindication in different terrestrial ecosystems (Andersen, Hoffmann, Muller, & Griffiths, 2002; Andersen, Fisher, Hoffmann, Read & Richards, 2004). This is due to characteristics such as biodiversity, dominance, biomass,

taxonomical knowledge, easy collection, sensitivity to environmental changes and ecological functionality, among others (Alonso & Agosti, 2000). Furthermore, it has been suggested that the diversity, abundance and composition of their communities is strongly influenced by a

wide spectrum of factors related to disturbance, such as the type, time, intensity and frequency of the disturbance (Guzmán-Mendoza & Zavala-Hurtado, 2005). However, regardless of their importance, ants cannot be considered an infallible tool for monitoring due to the lack of data to understand the dynamics of their communities in relation to disturbance, and even aspects of their ecology are not completely understood (Kaspari, 2003).

The efficiency of the taxonomic bioindicators is related to the consistency and repetitiveness of their reactions to disturbance. In this matter, Hodkinson and Jackson (2005) noted varied responses to the same source of disturbance in phylogenetically divergent taxa, and even in narrowly related taxa. Due to the fact that ants have different ecological roles and a wide vertical niche differentiation (Chen, Adams, Bergeron, Sabo, & Hooper-Bùi, 2014; Kristine, 2014), can they be a good bioindicators? Most of the literature where ants are suggested as bioindicators, has based the results in the identification of species, abundance and some ecological characteristics such as diversity, trophic levels and their association with modified environments (Andersen et al., 2004; Chanatásig-Vaca et al., 2011; Chen et al., 2014). In this matter, it is important to recognize how the communities of ants change according to a disturbance event, because this change can reflect modifications of other communities of invertebrates (Andersen & Majer, 2004). This problem has not been completely studied, although it is known that the ecological communities are a complex of interdependent organisms where species can affect each other through direct and indirect interactions (Wootton, 1994a). Also, it is not clear if different communities are dependent on temporary, morphological or chemical rules (Gigante et al., 2014). In this matter, the interpretations of the changes in biodiversity for disturbance events based on a single taxon are incomplete (Lawton et al., 1998).

If ants are a good bioindicator, their communities will be affected in same way that other communities of invertebrates such as beetles

(Didham, Hammond, Lawton, Eggleton, & Stork, 1998), spiders (Buchholz, 2010), grasshoppers (Saha, Sarkar, & Haldar, 2011) and true bugs, that are also important components in terrestrial ecosystems and that will sensibly respond to the modifications of the habitat. This relationship, among invertebrate communities, must be observed through the analysis of the causal effects that allow the partition of the coefficients of correlation in the direct and indirect effects of various characteristics, to a dependable variable (Togay, Togay, Yildirim, & Dogan, 2008). This is possible through a Path Analysis, a promising statistical technique to evaluate the covariance between species in the research of the structure of communities (Wootton, 1994a). The objective of this study was to compare the diversity of the ant communities and their relation to other arthropod communities in three temperate forests from central Mexico.

MATERIALS AND METHODS

Sampling areas: This work was done in the North State of Mexico in the municipalities of San José Del Rincón, Jocotitlán and El Oro. According to García (1996), the weather in the area of study is classified as Cw_2 , which means sub-humid temperate (18 to 20°C) with showers in summer (200 to 1 800 mm) and temperate forest. The studied zones were clearly located in three categories of disturbance, including: Primary Forest (PF), with relatively little disturbance; Mixed Forest (MF); and Reforested Forest (RF). This allowed identification of forest under different environmental conditions. Vegetation of PF, (19°45' N - 99°59'20" W, 2 908 masl) consisted of the arborous stratus of species of *Quercus* (*Q. rugosa* Née, *Q. laurina* Humb. & Bonpl., *Q. crassipes* Humb. & Bonpl.), *Arbutus xalapensis* Kunth, *Alnus* sp., and *Pinus* sp. and in herbaceous-arborous stratus by *Arctostaphylos pungens* Kunth, *Pinguicula moranensis* Kunth and *Geranium lilacinum* R. Knuth. In MF, (19°43'N - 100°05'38" W, 2 738 masl) there were species characteristically found in primary forest (*Q. crassipes*,

Q. rugosa, *Arbutus* sp., *Pinus* sp.), but the presence of *Cupressus lindleyi* Klotzsch ex. Endl. showed evidence of disturbance by reforestation. In contrast, species such as *Echeandia nana* (Baker) Cruden, *Begonia gracilis* Kunth and *Lepidium virginicum* (Greene) Thell. in the herbaceous-arboreal stratus suggested a conserved forest, because these are found reported in the nucleus zone of the Reserve of the Biosphere of the Monarch Butterfly (Cornejo-Tenorio, Casas, Farfán, Villaseñor, & Ibarra-Manríquez, 2003). In RF (19°40' N - 100°05'51" W, 2 679 masl), a monospecific forest was found of *C. lindleyi*, and in the stratus herbaceous-arboreal species such as *Aldama dentata* La Llave, *Zinnia haageana* Regel and *Buddleja sessiliflora* Kunth are considered indicators of disturbance (Espinoza-García & Sarukhan, 1997; Calderón de Rzedowski & Rzedowski, 2004).

Ant sampling: To estimate the abundance, diversity and composition of the community of ants, a study area of 2 500 m² was selected in each zone, and 16 pit fall traps were placed with 10 m of separation between them (Whitmore, Slotow, Crouch, & Dippenaar-Schoeman, 2002; Sanders, Moss, & Wagner, 2003; Sarmiento, 2003). Previous studies of macrofauna in soils have suggested plots of 40 x 5 m (Swift & Bignell, 2001), because with the selected scale, the effect of pseudo replication is minimized (Bignell, 2009). The collections were carried out from February to March 2009 (dry season) and one more August through September 2010 (rainy season), which produced a total of 192 traps. The traps consisted of 0.5 L plastic containers that were 11 cm in diameter and 13 cm in height. These containers were covered with a plastic dish that held a vial with a lure made from a mixture of oats and honey. Although studies have shown that using traps with lures does not show better results for ground ants (Wang, Strazanac, & Butler, 2001), the lure was used because other arthropods were collected, and the lure can promote the growth of fungi that can attract other organisms such as larvae (Gange, 2005). At the same time,

the lure can be a potential target for many predatory ants and other arthropods (Yamaguchi & Hasegawa, 1996), and it can be used to aggregate rare species (Woodcock, 2005). The traps were buried at ground level covering the height of the containers, and before being opened for 72 h, they were kept closed for a week to minimize possible disturbance effects (Bestelmeyer & Wiens, 2001). Once opened, the containers were partially filled with ethylene glycol, a preservation substance that limits evaporation, and a few drops of powdered detergent to break superficial tension (Bestelmeyer et al., 2000; Castro-Delgado, Vergara-Cobian, & Arellano-Ugarte, 2008). The content of the traps was emptied in a filtering cloth over a thin layer of water, allowing the separation through flotation of detritus and organisms smaller than 0.3 cm in diameter. This technique has been used to separate seeds (Pake & Venable, 1996). The ants obtained in this process were placed in vials containing 70 % ethanol to be identified in a laboratory. The determination of genus level was performed with the keys of Mackay and Mackay (2005), while for species, different keys were used according to the group. To obtain keys and comparison of specimens, AntWeb (2002) was consulted.

Arthropod sampling: Other arthropods were collected with pit fall traps that have been broadly used in monitoring programs to measure organisms' diversity, and mainly the diversity of arthropods (Work, Buddle, Korinus, & Spence, 2002). The traps were cleaned with tap water and the captured specimens were stored in vials with 70 % ethanol for their taxonomical determination. Due to the abundance and feasibility of morphological identification, spiders, orthopterans, coleopterans and hemipterans were identified by families and organized by morphospecies using the Kaston (1972) key for spiders; Arnett, Downie and Jaques (1980) and Navarrete-Heredia, Newton, Thayer, Ashe and Chandler (2002) for beetles; for hemipterans and orthopterans Bland and Jaques (1978) and Fontana, Buzzetti and Mariño-Pérez (2008), respectively. All

organisms captured in this study were stored at the Laboratory of Entomology at the Autonomous Metropolitan University.

The number of ants captured by trapping was transformed to $\sqrt{n} + 0.5$. This change was recommended to reduce the variability in data caused by social behaviors of ants (Andrew, Rodgerson, & York, 2000) that results in the grouped behavior of the samples (Longino, Coddington, & Colwell, 2002). With this change in the data, the quantity of ants in the traps was compared between the types of forests by traps using the non-parametric test of Kruskal-Wallis. The significant statistical differences were analyzed with Dunn's test to identify the group or groups that generated significant differences. For the analysis the SPSS ver. 12.0 for Windows (SPSS, 2003) was used.

For each zone of forest and seasons, the abundance of captured ants by traps was added so that the analysis of richness and diversity was less sensitive to the collection site and to the changes in the patterns on harvesting of ants. Furthermore, this allowed a better representation of the characteristics of the communities in the points of space (Bestelmeyer & Wiens, 2001; Sarmiento, 2003). The Shannon (H') indexes of diversity, Pielou (J') equalities and Simpson dominance ($1/\lambda$) (Ludwing & Reynolds, 1988) were calculated. The results of the Shannon index were compared between the zones of the forest with the t test of Hutcheson (Zar, 1999). In this analysis, the program Biodiversity Professional ver. 2 was used (McAleece, 1997), and PAST for the comparisons of the t test (Hammer, Harper, & Ryan, 2001). According to Sarmiento (2003), from a matrix of presence-absence a maximum potential accumulation curve of species with Chao-1 as an estimator was built. To recognize similarities between the communities of ants, the index of similitudes of Renkonen was calculated and to compare the composition of species a PCA (principal component analysis) was made (Watt, Stork, & Bolton, 2002).

To allow for the comparison between the abundance of ants with other arthropods, the data from the latter ones was also transformed

to the $\sqrt{n}+0.5$ and analyzed with the Kruskal-Wallis test. The significant differences were evaluated with Dunn's test using the SPSS ver. 12 for Windows.

For each group of arthropods, the Shannon (H') diversity index was calculated, which allowed the statistical comparison with the diversity of ants through the test of Hutcheson. Abundance, richness and diversity of selected groups of arthropods were correlated with abundance, richness and diversity of ants using Pearson's coefficient. To test possible casual relationships of significant correlations between arthropods and ants, a Path Analysis was used because it allows the evaluation of the direct and indirect effects that each variable has over the answer variable (Jennings, Krupa, Raffel, & Rohr, 2010). For these analyses, the Infostat Program was used (Di Rienzo et al., 2011). The variables were transformed to a log and regression coefficients were estimated, the significance of each path was evaluated comparing the value of the χ^2 of the complete model excluding the given path. Wootton (1994a) suggests this method to predict direct and indirect interactions between non-manipulated species in ecological communities. Although there is controversy about how the path analysis works (Greenland, 2000), its application in ecology is promising (Wootton, 1994b).

RESULTS

Richness and abundance of ant communities: A total of 4 953 ants were quantified from five subfamilies and 34 species. Myrmicinae was the most abundant with 44.9 % (Abundance= 2 226, Median \pm S. E.= 106 \pm 48.7) and the richest of species (S= 20), followed by Formicinae (35.9 %; n= 1 781 individuals, 356.2 \pm 313.8) and Dolichoderinae (17.8 %, n= 881, 884 \pm 162), both with five species. For Ecitoninae (1.1 %, n= 59, 19.6 \pm 9.5) three species were counted, and for Ponerinae a species with three individuals (Table 1).

Considering the richness of species for each community of ants, 17 and 18 species were quantified in PF and MF, respectively.

TABLE 1
Number of individuals of ant species in three forest zone with different degree of conservation

| Taxa | PF | MF | RF |
|--|------------------|----------------------|-------------------|
| Dolichoderinae <i>Dorymyrmex bureni</i> (Trager) | - | 4 (0.06 ± 0.04) | - |
| <i>D. flavopectus</i> Smith | - | 48 (0.82 ± 0.36) | - |
| <i>D. grandulus</i> (Forel) | 3 (0.1 ± 0.1) | 1 (0.01 ± 0.01) | - |
| <i>Dorymyrmex</i> sp. | - | 4 (0.06 ± 0.05) | - |
| <i>Liometopum apiculatum</i> Mayr | - | 824 (14.20 ± 2.54) | - |
| Ecitoninae | | | |
| <i>Labidus coecus</i> (Latreille) | 12 (0.41 ± 0.41) | 10 (0.17 ± 0.14) | - |
| <i>Neivamyrmex manni</i> (Wheeler) | - | 1 (0.01 ± 0.01) | 1 (0.02 ± 0.02) |
| <i>N. opacithorax</i> (Emery) | - | 35 (0.60 ± 0.45) | - |
| Formicinae | | | |
| <i>Camponotus atriceps</i> (Smith) | 2 (0.06 ± 0.04) | 141 (2.43 ± 1.23) | 14 (0.35 ± 0.11) |
| <i>Camponotus</i> sp. 1 | - | 1 (0.01 ± 0.01) | - |
| <i>Camponotus</i> sp. 2 | 1 (0.03 ± 0.03) | 1 444 (24.89 ± 7.26) | 161 (4.12 ± 2.37) |
| <i>Camponotus</i> sp. 3 | - | 2 (0.03 ± 0.02) | - |
| <i>Formica</i> sp. | - | 15 (0.25 ± 0.12) | - |
| Myrmicinae | | | |
| <i>Crematogaster</i> sp. 1 | 8 (0.27 ± 0.20) | 1, (0.01 ± 0.01) | 1 (0.02 ± 0.02) |
| <i>Crematogaster</i> sp. 2 | 1 (0.03 ± 0.03) | - | - |
| <i>Crematogaster</i> sp. 3 | - | - | 1 (0.02 ± 0.02) |
| <i>Crematogaster</i> sp. 4 | 2 (0.06 ± 0.06) | - | - |
| <i>Monomorium cyaneum</i> Wheeler | 2 (0.06 ± 0.04) | 40, (0.68 ± 0.37) | - |
| <i>Monomorium</i> sp. 1 | - | 93 (1.60 ± 0.70) | - |
| <i>Pheidole</i> sp. 1 | 6 (0.20 ± 0.14) | 378 (6.51 ± 3.03) | 156 (4 ± 2.06) |
| <i>Pheidole</i> sp. 2 | 26 (0.89 ± 0.32) | 69 (1.18 ± 0.41) | 24 (0.61 ± 0.23) |
| <i>Pheidole</i> sp. 3 | 2 (0.06 ± 0.04) | 753 (12.98 ± 4.67) | 182 (4.66 ± 2.87) |
| <i>Pheidole</i> sp. 4 | - | 157 (2.70 ± 1.89) | 1 (0.02 ± 0.02) |
| <i>Pheidole</i> sp. 5 | - | 12 (0.20 ± 0.10) | 2 (0.05 ± 0.03) |
| <i>Pheidole</i> sp. 6 | 5 (0.17 ± 0.14) | 2 (0.03 ± 0.02) | 2 (0.05 ± 0.05) |
| <i>Pheidole</i> sp. 7 | 4 (0.13 ± 0.08) | 4 (0.06 ± 0.04) | 1 (0.02 ± 0.02) |
| <i>Pheidole</i> sp. 8 | - | 15 (0.25 ± 0.17) | 5 (0.12 ± 0.08) |
| <i>Temnothorax</i> sp. 1 | 19 (0.65 ± 0.39) | 33 (0.56 ± 0.27) | 7 (0.17 ± 0.13) |
| <i>Temnothorax</i> .sp. 2 | 29 (1.0 ± 0.47) | 29 (0.5 ± 0.38) | 26 (0.66 ± 0.32) |
| <i>Temnothorax</i> sp. 3 | 36 (1.24 ± 0.59) | 4 (0.06 ± 0.06) | 3 (0.07 ± 0.05) |
| <i>Temnothorax</i> sp. 4 | 4 (0.13 ± 0.08) | - | - |
| <i>Tetramorium</i> sp. | 9 (0.31 ± 0.14) | 25 (0.43 ± 0.20) | 28 (0.71 ± 0.30) |
| <i>Solenopsis geminata</i> (Fabricius) | - | - | 19 (0.48 ± 0.28) |
| Ponerinae | | | |
| <i>Odontomachus clarus</i> Roger | - | 3 (0.05 ± 0.03) | - |

(abundance average ± SE per trap); PF = primary forest, MF = mixed forest and RF = reforested forest.

Meanwhile, RF had 25. The Chao-1 curve showed that the richness of species was higher for RF than PF and MF (Fig. 1).

Abundance was significantly different between forest zones ($\chi^2_{(0.05)2} = 67.62$, $p < 0.0001$). RF generated the differences, and it was the site that had the highest quantity of ants, while the comparison of PF and MF did not show differences ($DM = 1.98$; $p > 0.05$). The result of the diversity analysis suggests a low dominance in PF in comparison with MF and RF, both of which had relatively similar values of higher dominance.

Heterogeneity was significantly higher in RF than in PF ($t_{0.05(2)196.6} = 5.48$, $p < 0.0001$) and MF ($t_{0.05(2)904.3} = 7.30$, $p < 0.0001$). The comparison between PF and MF did not display significant differences ($t_{0.05(2)308.2} = 0.72$, $p = 0.42$) (Table 2).

The index of Renkonen showed that the composition of the ants communities was different between the forest zones. Thus, the similarity between PF and RF was 22.1 % and between PF and MF was 37.1 %. The highest similarity was observed between RF and MF with 54.3 %.

The PCA reached 100 % of the explained variance and showed in the first axle, with 63.3 % of the variance, that was comprised by

TABLE 2
Dominance, evenness and diversity values of the ant communities from temperate forests

| | PF | MF | RF |
|-------------|------|------|------|
| $1/\lambda$ | 0.12 | 0.21 | 0.20 |
| J' | 0.82 | 0.63 | 0.58 |
| H' max | 1.23 | 1.25 | 1.39 |

Dominance ($1/\lambda$), evenness (J') and Shannon diversity (H' max); PF = primary forest, MF = mixed forest, RF = reforested forest.

Camponotus spp., *Crematogaster* spp., *Monomorium* sp., *Pheidole* spp., *Temnothorax* spp. and *Odontomachus clarus*. The second axle explained 36.7 % and was conformed of *Dorymyrmex grandulus*, *Labidus coecus*, *Neivamyrmex manni*, *Crematogaster* sp. 3, *Pheidole* sp. 2, *Pheidole* sp. 7, *Temnothorax* sp. 1, *Tetramorium* sp. and *Solenopsis geminata*. The results showed a clear difference between the zones of the forest. PF registered important abundances of species of *Crematogaster*, while MF registered *Tetramorium* sp., *Crematogaster* sp. 3 and *S. geminata* and RF registered *Camponotus* sp. 2, *Monomorium* sp., *M. cyaneum*, *Pheidole* sp. 4 and *O. clarus*, some of them recorded only in this zone (Table 1, Fig. 2).

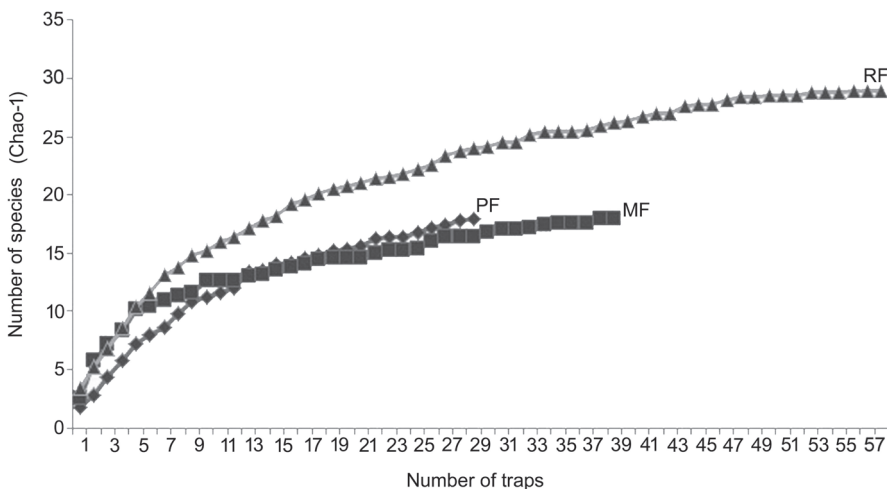


Fig. 1. Potential number of species for each ant community after Chao-1, according to temperate forest conservation. PF = primary forest, MF = mixed forest and RF = reforested forest.



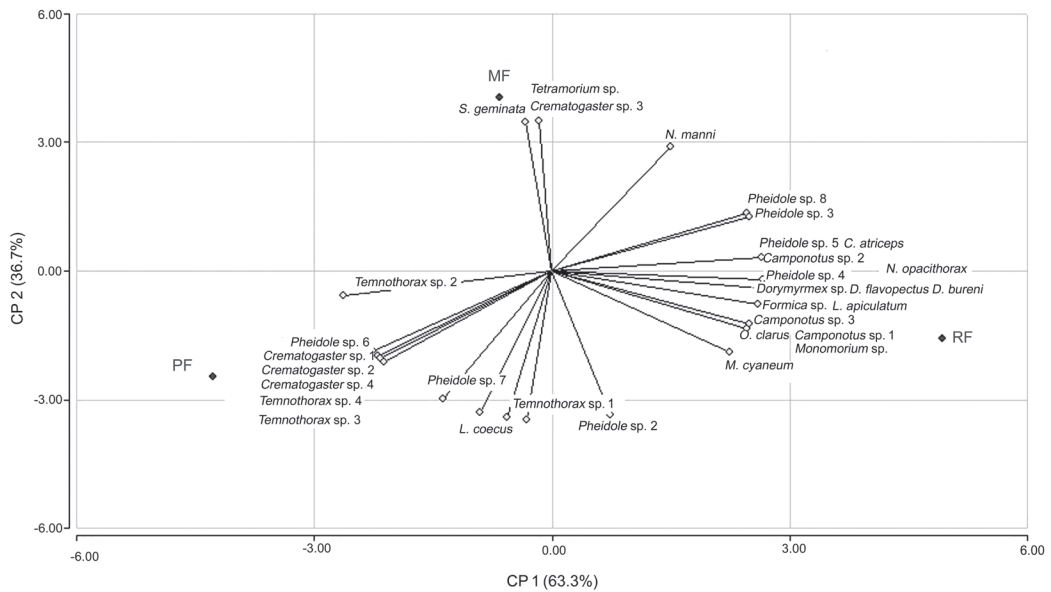


Fig. 2. Bi-plot that shows the ordination by PC analysis of three temperate forest zones with different levels of conservation based on the abundance of ant species (vectors) for PF = primary forest, MF = mixed forest, RF = reforested forest. Data transformed by $\sqrt{n + 0.5}$.

Comparison of abundance and diversity of arthropods with ants: According to the Kruskal-Wallis test, the results showed important differences. In PF ($\chi^2_{(0.05)4} = 33.2$, $p < 0.0001$), these differences were due to the abundance of beetles (Median \pm Interquartile Deviation = 5.2 ± 4.4); in MF ($\chi^2_{(0.05)3} = 21.89$, $p < 0.0001$), the ants were the most abundant (4.3 ± 2.5), followed by grasshoppers (2.4 ± 0.6), spiders (3.3 ± 1.5) and hemipterans (1.9 ± 1.7). In this case, the beetles were not considered in the analysis because there was only one individual in the traps during the study. Finally, in RF ($\chi^2_{(0.05)4} = 117.4$, $p < 0.0001$), the groups with statistical differences were the ants (12.74 ± 6.0) and grasshoppers (1.2 ± 0.7), which had the highest and the lowest median quantity of capture, respectively (Table 3).

Taking into account the richness of species for each group of arthropods, important differences were found according to the zone of the forest. In PF ($\chi^2_{(0.05)4} = 53.03$, $p < 0.0001$), these differences were caused by the richness of morphospecies of beetles (4.0 ± 2.0). In MF ($\chi^2_{(0.05)3} = 19.8$, $p < 0.0001$), as well as in RF

($\chi^2_{(0.05)4} = 73.02$, $p < 0.0001$), the important difference was due to the low quantity of morphospecies of grasshoppers (MF = 2.0 ± 0.5 ; RF = 1.0 ± 0.5) (Fig. 3).

Relationship between abundance of ants and arthropods: In PF, there was a positive and significant correlation between ants and beetles ($r = 0.578$, $p < 0.0001$) that may be causal. The significance of Path Analysis showed that the presence of ants had an important causal relationship due to the presence of beetles and not by other types of arthropods. In contrast, in MF there were neither important correlations nor relationships between the ants and other arthropods. Additionally, RF had two significant positive correlations between ants-spiders ($r = 0.473$, $p < 0.0001$) and ants-beetles ($r = 0.629$, $p < 0.0001$). Furthermore, the Path Analysis suggested a direct causality between spiders and beetles to infer the presence of ants (Table 4 and Fig. 4).

Relationship between richness and diversity of ants and arthropods: The

TABLE 3
Multiple comparisons by Dunn's test for abundance of arthropods in contrasted temperate forest zones

| Groups | Primary forest (PF) | | | |
|------------------------|---------------------|--------------|-------------|-------------|
| | Spiders | Grasshoppers | Hemipterans | Beetles |
| Ants | DM = 0.09 | DM = 1.12 | DM = 0.22 | DM = 3.04** |
| Spiders | | DM = 1.02 | DM = 0.12 | DM = 3.13** |
| Grasshoppers | | | DM = 0.89 | DM = 4.16** |
| Hemipterans | | | | DM = 3.26** |
| Mixed forest (MF) | | | | |
| Ants | DM = 1.76** | DM = 2.80** | DM = 2.05** | - |
| Spiders | | DM = 1.03 | DM = 0.29 | - |
| Grasshoppers | | | DM = 0.74 | - |
| Reforested forest (RF) | | | | |
| Ants | DM = 8.34** | DM = 12.51** | DM = 8.94** | DM = 9.07** |
| Spiders | | DM = 4.17** | DM = 0.60 | DM = 0.72 |
| Grasshoppers | | | DM = 3.56** | DM = 3.44** |
| Hemipterans | | | | DM = 0.12 |

** means difference between groups at level $\alpha = 0.05$; DM = mean difference; Data transformed by $\sqrt{n} + 0.5$.

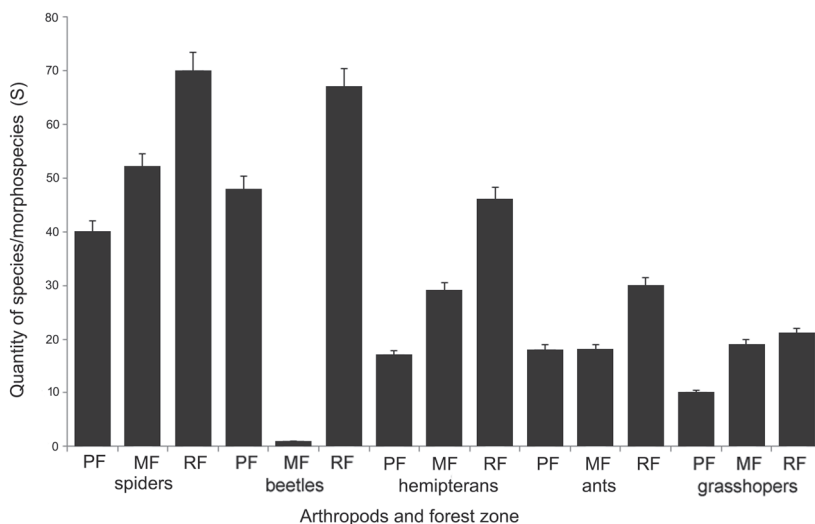
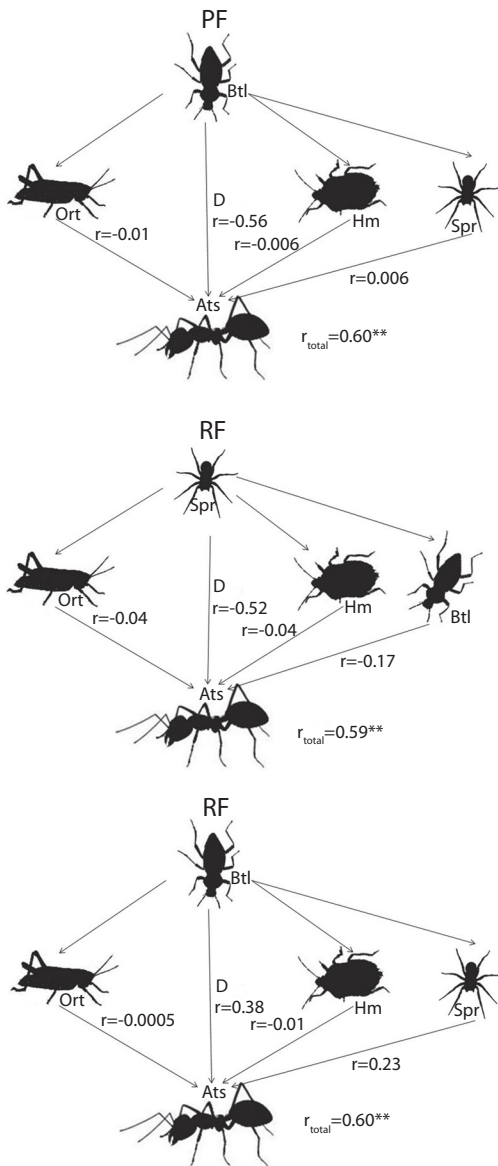


Fig. 3. Species richness of ants and morphospecies (remain arthropods) registered by trap, in three temperate forest zones with different conservation levels. PF = primary forest, MF = mixed forest, RF = reforested forest.

correlation analysis between the species of ants and the richness of morphospecies of other arthropods showed significant relationships with some groups. The richness of morphospecies of hemipterans had a positive correlation in PF ($r = 0.44$, $p = 0.008$) and a negative correlation in MF ($r = -0.32$, $p = 0.03$). The richness of morphospecies of beetles had a positive

coefficient in PF ($r = 0.32$, $p = 0.04$) and in RF ($r = 0.56$, $p < 0.0001$). The spiders had only one significant correlation in MF ($r = 0.36$, $p = 0.01$) (Table 5). The Path Analysis suggested two causal relationships. The hemipterans had a direct causal relation with the richness of species of ants in PF, while the beetles had the same result in RF (Fig. 5). Also, there were



other causal relationships with ants, but they were not significant.

The results in the comparisons of the diversity of each group of arthropods found important differences in all cases, except for the diversity between ants ($H' = 1.82$) and grasshoppers ($H' = 1.91$). In MF, in contrast, hemipterans ($H' = 2.32$) and spiders ($H' = 3.39$) had communities more diverse than ants. In PF, the beetles ($H' = 2.75$) and the spiders ($H' = 2.84$) were more diverse than ants ($H' = 2.33$), but hemipterans ($H' = 1.82$) and grasshoppers ($H' = 1.30$) had a significantly lower diversity than the one calculated for ants. In RF, the comparison between the communities of arthropods and ants indicated higher values for all arthropods ($H'_{spiders} = 3.45$; $H'_{beetles} = 3.38$; $H'_{hemipterans} = 2.90$; $H'_{grasshoppers} = 2.69$) than for the communities of ants ($H' = 1.96$) (Table 6).

The correlation analysis showed that only the diversity of grasshoppers in PF and spiders in RF were important with the diversity of ants (Table 5), and path analysis in this case did not show causal relationships.

Fig. 4. Correlation coefficients by path analysis between the quantity of arthropods caught and the quantity of ants recorded by pitfall traps, in three contrasted conservation temperate forest zones. PF = primary forest, RF = reforested forest. D = direct effect; Spr = spiders, Btl = beetles, Hm = hemipterans, Ort = grasshoppers, Ats = ants. ** significant level at $\alpha = 0.05$. Data transformed by $\sqrt{n+0.5}$. In MF significant causal relationships were not found. MF = mixed forest, significant relationships were not found.

TABLE 4

Pearson correlation coefficient for quantity of ants and arthropods caught in three contrasted temperate forest zones

| Arthropods | ants in PF | ants in MF | ants in RF |
|--------------|------------|------------|------------|
| Spiders | 0.132 | 0.213 | 0.473** |
| Beetles | 0.578** | - | 0.629** |
| Hemipterans | 0.068 | -0.063 | 0.301 |
| Grasshoppers | -0.137 | 0.251 | 0.117 |

PF = primary forest, MF = mixed forest, RF = reforested forest; **significant level at $\alpha = 0.05$. Data transformed by $\sqrt{n+0.5}$.

TABLE 5

Pearson correlation coefficients for arthropod morphospecies richness and ant species richness as well as diversity values registered by trap in three temperate forest zones

| Arthropods | Richness of morphospecies/species | | |
|--------------|-----------------------------------|---------|---------|
| | Ants PF | Ants MF | Ants RF |
| Spiders | 0.054 | 0.36** | 0.10 |
| Beetles | 0.32** | - | 0.56** |
| Hemipterans | 0.44** | -0.32** | -0.11 |
| Grasshoppers | 0.11 | 0.10 | -0.09 |
| Arthropods | Diversity (H') | | |
| | Ants PF | Ants MF | Ants RF |
| Spiders | 0.004 | -0.24 | 0.45** |
| Beetles | -0.026 | - | -0.13 |
| Hemipterans | 0.36 | 0.42 | 0.18 |
| Grasshoppers | -0.53** | 0.25 | -0.28 |

Shannon diversity (H'); PF = primary forest, MF = mixed forest, RF = reforested forest; ** significance level $\alpha = 0.05$.

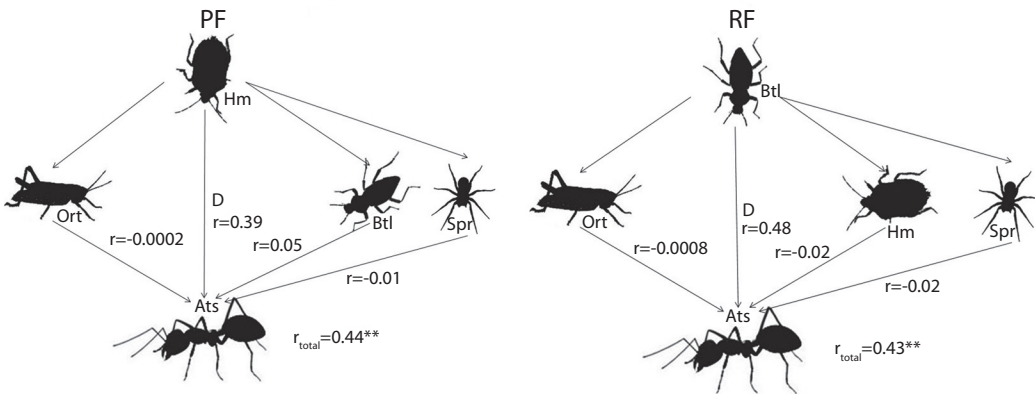


Fig. 5. Correlation coefficients by path analysis between morphospecies (arthropods) and species (ants) richness recorded by pitfall traps, in three contrasted conservation temperate forest zones. PF = primary forest, RF = reforested forest. D = direct effect; Spr = spiders, Btl = beetles, Hm = hemipterans, Ort = grasshoppers, Ats = ants. ** significant level $\alpha = 0.05$. Data transformed by $\sqrt{n} + 0.5$. In MF no significant causal relationships were found. MF = mixed forest, significant relationships were not found.

DISCUSSION

Although ants are a relatively well known biological group (Vásquez-Bolaños, 2011) for temperate forests of Mexico, information about richness and diversity of species is still scarce. Thus, there is no information available against which to compare the results obtained in this document. Nevertheless, the present research provides new data for two priority conservation

areas of the central zone of Mexico, such as the Monarch Butterfly Biosphere Reserve and the Sanctuary of Protection of Forests and Water Dams Brockman-Villa Victoria (List, Muñozcano, & De la Peña, 2009). Comparing these results with studies conducted in relatively similar biomes in other regions of the world, the richness of species found here is higher to the one registered by Lessard, Dunn and Sanders (2009), who found 17 species in a mixed

TABLE 6
Comparison of Shannon diversity index by t-test to the communities from three temperate forest zones

| PF | | | | |
|-----|------------------------------|------------------------------|------------------------------|-----------------------------|
| | Spr | Btl | Hm | Ort |
| Ats | $t_{0.05(2)268.02} = 4.0^*$ | $t_{0.05(2)463.93} = 4.2^*$ | $t_{0.05(2)386.38} = 5.1^*$ | $t_{0.05(2)327.19} = 9.3^*$ |
| MF | | | | |
| | Spr | Btl | Hm | Ort |
| Ats | $t_{0.05(2)260.93} = 18.0^*$ | - | $t_{0.05(2)204.17} = 4.4^*$ | $t_{0.05(2)189.4} = 0.8$ |
| RF | | | | |
| | Spr | Btl | Hm | Ort |
| Ats | $t_{0.05(2)475.21} = 24.8^*$ | $t_{0.05(2)291.66} = 17.5^*$ | $t_{0.05(2)326.18} = 12.4^*$ | $t_{0.05(2)70.03} = 7.5^*$ |

ants (Ats), spiders (Spr), beetles (Btl), hemipterans (Hm) and grasshoppers (Ort); PF = primary forest, MF = mixed forest, RF = reforested forest. (*) = significant differences.

forest of oaks. The abundance is also higher than that other studies (Castro-Delgado et al., 2008). It is possible that the diversity reported here could become higher if more collection methods were added and/or if the sampling efforts had increased time and space. Lubertazzi and Tschinkel (2003) found between 25 to 46 species using pit fall traps, versus 72 species collected using additional sampling techniques, which would be useful for the collection of those species whose ecological habits cannot keep them from the pit fall traps. Some studies have shown that the physiological differences of species of trees, besides promoting a larger structural complexity, can promote the specialization in dosel ants, increasing regional diversity (Yanoviak & Kaspari, 2000; Lubertazzi & Tschinkel, 2003). This is particularly important in the zone of PF, which was the most structurally complex and which had large number of epiphyte plants.

Results suggest that the communities of ants are very different between the zones, regardless of the season. In PF, species of *Crematogaster* were registered that are associated with conservation environments, while in MF and RF there were more abundant species of anthropophilic species of *Camponotus y Solenopsis*. In this way, it is inferred that the communities have sensibly responded to the changes in vegetable cover, as it has been reported in other studies (Rivera & Armbrrecht,

2005). However, the results are not matched with studies performed in areas subject to forestry management. For example, in RF a higher abundance and values of richness and diversity of ants was observed, in addition to a completely different composition of species compared to MF and PF. In this sense, Watt et al. (2002) found a significantly higher richness in forests with partial cuttings than in forests completely cut, but with differences in the composition of species.

Ants have been considered good bioindicators to evaluate the conservation or disturbance of habitat, in part because of the fact that the richness of ant species is narrowly correlated with the diversity and abundance of other taxa and also with the patterns of recolonization in affected zones (Andersen & Majer, 2004). The results show the importance of ecological interactions to identify the causal origin, which can depend on environmental conditions and not only on the mathematical causes that are observed in the regression analysis or correlation. In the present study, the significance of the causal relationships was due to the zone of the forest and partially three correlations: abundance, richness and diversity. In terms of abundance, the quantity of captured ants had a significant correlation with beetles in PF, and beetles and spiders in RF. The Path Analysis showed that the causal relationships were by direct route. The richness of hemipterans in

PF and beetles in RF also had an important causal relationship with the richness of ants species. Even though other significant correlations were present, these were not supported by the causal relationships, with the ones found between spiders and hemipterans in MF as an example. Because of the fact that ants and spiders are predators, antagonistic relations such as competition and predation between species can affect the observed results (Moya-Laraño & Wise, 2007). In comparison, some hemipterans and beetles identified here at the family level can be considered ecologically close to ants. Schuh and Slater (1995) mention that the hemipterans Cydnidae, Lygaeidae, Miridae and Nabidae are associated with ants as their predators or imitators; besides, the Membracidae where some species are attended by ants. The beetles of Pselaphidae families, registered in this study, have been associated with nests of Formicidae due to the fact that they feed on the regurgitations of their hosts (Cammaers, 2001). For other families of beetles such as Leptodiridae, Nitidulidae and Scydmaenidae, their presence in the ant colonies is part of their diagnosis (Arnett et al., 1980). This also has been found in some subfamilies of Staphylinidae, such as Osoneriinae and Staphylininae (Newton, 1990; Navarrete-Heredia et al., 2002).

When environmental changes have occurred, the ant communities can reflect the effect over other taxa. The spiders and beetles showed significant statistical correlation with causal support in two of the three zones of forests studied, including PF and RF, but in MF there was no causal relationship. In this last site, trees of *C. lindleyi* have been planted so closely to each other that it is possible to see changes at floor level, because there is no leaf covering or herbaceous growth. Furthermore, the soil is compacted and lacks humidity, which has promoted the disappearance of important taxa that were not present in MF such as beetles. This affected the functional processes of the ecosystem such as the reuse of matter, decomposition, herbivories feeding and predation, among others (Lassau, Hochuli, Cassis, & Reid, 2005).

The change in vegetation caused by reforestation has had an important effect on the structure, composition and richness of species of the consumer communities. In this case, the presence of different ant communities, depending on the zones of the forest, suggests the influence in the conditions of the habitat over those species. Ants have a limited role as bio-indicators of this change because of the correlation between abundance and richness of other species that had mathematic and causal significance –such as spiders, beetles and hemipterans– but that were not found in all the forests nor with all the groups of arthropods here studied.

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RESUMEN

Diversidad de comunidades de hormigas (Hymenoptera: Formicidae) y sus conexiones con otros artrópodos en tres bosques templados del centro de México. Por sus características ecológicas las hormigas se han considerado útiles para la bioindicación. Sin embargo, entre los rasgos de un grupo bioindicador, debe haber una respuesta consistente y repetible a la perturbación. En este sentido, se han encontrado respuestas divergentes, incluso entre taxones estrechamente relacionados. El objetivo de este trabajo fue comparar la diversidad de las comunidades de hormigas en tres tipos de bosque templado con diferente nivel de perturbación y correlacionar su abundancia, riqueza de especies y la diversidad con aquella que se encuentra en otras comunidades de artrópodos en los mismos bosques. El trabajo se realizó en tres localidades del norte del Estado de México donde fueron identificados tres tipos de bosque diferenciados por grado de disturbio: 1) bosque primario (PF), con especies típicas de un bosque conservado; 2) bosque mixto (MF) con especies de bosque conservado y propias de reforestación y 3) bosque reforestado (RF) con

especies utilizadas en reforestación e indicadoras de perturbación. En cada tipo de bosque se seleccionó un área de 2 500 m² donde fueron colocadas 16 trampas de caída con una separación de 10 m. Fueron realizadas dos recolectas una de febrero a marzo 2009 (estación seca) y otra de agosto a septiembre 2010 (estación lluviosa), lo que dio un total de 192 trampas. Los especímenes obtenidos fueron identificados al nivel taxonómico más específico posible. Todos los datos de las capturas fueron transformados a $\sqrt{n+0.5}$ y fueron calculados los índices de diversidad de Shannon y Simpson y riqueza de especies tanto para hormigas como para escarabajos, chapulines, chiches y arañas. Los valores de riqueza, diversidad y abundancia fueron correlacionados con el coeficiente de Pearson y para evaluar posibles relaciones causales entre estos se realizó un análisis de sendero. Los resultados sugieren una influencia importante del sitio sobre las comunidades de hormigas y sus valores de riqueza, abundancia y diversidad están correlacionadas con las comunidades de arañas, escarabajos, chapulines y chiches, pero no para todos los sitios estudiados. Las respuestas a los cambios ambientales no sólo están en las proporciones numéricas de la abundancia, riqueza y diversidad sino también en las interacciones ecológicas indirectas y causales. Los resultados sugieren que las respuestas de las hormigas a los cambios ambientales no necesariamente se reflejan sobre comunidades de otros organismos por lo que su papel como bioindicadores puede ser limitado.

Palabras clave: reforestación, bioindicadores, riqueza de especies, ecología del paisaje, funciones ecológicas, análisis causal.

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