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RESEARCH

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A quick evaluation of ecological restoration based on arthropod communities and trophic guilds in an urban ecological preserve in Mexico City

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Abstract

Background: Restoration practices usually emphasize on the structural part of the biodiversity; also, most studies have focused on plants and very few have been conducted on arthropods and its function after restoration. The Pedregal de San Angel Ecological Reserve (PSAER) is a protected area immersed in Mexico City and it has been drastically affected by different anthropogenic disturbances. The aim of this study was to compare the relative diversity, richness, and abundance of species level identification, but also the composition through an analysis of ordination of taxonomic (species, family, and order level) and functional (trophic guild) traits of arthropods in three sites subjected to ecological restoration within the PSAER. Restored sites were also compared to conserved and disturbed sites, to evaluate whether restoration efforts are effective at the reserve.

Methods: Arthropods were sampled using pan traps during September 2013 in 11 sites (three restored, four conserved and four disturbed) inside the PSAER. All sampled species were taxonomically identified at species of morphospecies (inside a family) and assigned to a trophic guild. Differences in diversity, richness and abundance were evaluated through effective number of species, comparisons of Chao's1 estimated richness and a non-parametric Kruskal–Wallis test, respectively. Both taxonomic and trophic guild composition were evaluated using a multivariate analysis and a post hoc test.

Results: We found some differences in richness, abundance, and diversity between sites, but not a clear pattern of differentiation between restored to disturbed sites. The NMDS showed differences at species and order level, and with trophic guilds, among site types. Families were not useful to differentiate types of sites. Regarding guilds, predators were more abundant in conserved sites, while phytophagous insects were more abundant in disturbed sites.

Conclusions: Species and order level were useful to identify differences in communities of arthropods in sites with different management. The trophic guild approach provides information about the functional state of the restored sites. Nevertheless, our quick evaluation shows that restoration efforts at PSAER have not been successful in differentiate restored to disturbed sites yet.

Keywords: Diversity, Urban ecology, Trophic guilds, Restoration

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Background

Ecological restoration arises as an activity to mitigate the negative effects of disturbances on ecosystems, and its main purpose is to initiate or accelerate the process of recovery, and return to a pre-disturbance state [1]. To know whether the developed actions are successful to recover disturbed sites, so they resemble conserved sites, it is critical to monitor changes on the community structure of the taxa inhabiting such ecosystems, which also implies functional structure.

Most of the research on ecological restoration has been conducted in plant communities [2, 3] mainly because the natural succession of vegetation will determine the result of the restoration for other taxa [4]. Nevertheless, according to the Society for Ecological Restoration (SER) [1], the main goal of the ecological restoration is to recover not only the structure of the ecosystem but also its function. For this reason, it is critical to evaluate other taxonomic groups such as arthropods in order to integrate them as indicators of restoration programs, and to evaluate the effect of restoration from different ecosystem perspectives [5, 6].

Regarding to this, arthropods are the most diverse group of organisms on Earth, composing nearly 85% of all described species [7]. They can be classified depending on their guild (herbivores, predators or saprophagous) and the way of life and functions that they provide to the ecosystem (e.g. pollinators, pest controllers, scavengers, preys or biomass recyclers) [8, 9]. The great richness and diversity, variability in size, fast growth, high dispersion rates, sensitivity to environmental changes and short lifespan make arthropods an ideal study system to evaluate the effectiveness of the restoration programs in short periods of time [10–12]. Some factors that can determine the arthropod community are: i) changes in the quality, abundance and availability of resources [13–15], ii) spatial variation (horizontal and vertical) of plant communities [15], iii) origin (native or exotic) of plant species [16, 17], iv) habitat heterogeneity, v) degree of exposure to natural enemies [18, 19], and vi) disturbances [15, 20].

Although arthropods have been used largely in monitoring of restoration efforts [18], it is difficult to obtain species identification quickly, which commonly lead to the use of morphospecies [19, 21]. The use of coarse taxonomical identifications has been tested to evaluate the response of invertebrate communities to changes in habitats [22, 23], proving that the effectiveness of different levels depends -among other things- on physical and vegetal structures. Thus, an evaluation of the use of different taxonomical levels in a specific area could be useful to design a continuous monitoring in restoration programs.

In cities, overpopulation has induced a massive reduction of natural land uses, which in turn has led to habitat fragmentation, loss of biodiversity and a drastic reduction of the quality and quantity of the ecosystem services they provide [12, 24]. The Pedregal de San Angel Ecological Reserve (PSAER) is a protected area (since 1983) embedded in the south part of Mexico City [25], which has been drastically affected by different anthropogenic disturbances such as garbage accumulation, the reduction of the natural habitat by buildings, unauthorized people presence, accidental fires, extraction of native species and introduction of exotic species (both animals and plants), the extraction of basalt rock, as well as light and noise pollution [26]. For these reasons, several restoration efforts have been carried out to reduce the disturbances and to accelerate the recovery of such sites [27–29].

The aim of this study was to evaluate the effectiveness of ecological restoration on three sites within the PSAER. To do so, we compared arthropod richness, abundance, and diversity with conserved and disturbed sites. Also, we compared taxonomical (at different levels) and guild composition between types of sites. Although our sampling method is biased to flying and epigeous insects, this study represents the some of the firsts attempts to use entire arthropod communities to evaluate the restoration progress of three different sites within the PSAER; particularly, we addressed the following questions: 1) are there differences in richness, abundance, diversity and taxonomical composition at species level of the arthropod communities in conserved, restored and disturbed sites?, 2) the use of taxonomic orders or families leads to different results compared to species level? 3) is there a specific affinity of the three main trophic guilds (predators, herbivores and saprophagous) to the management categories used? and 4) are the restoration actions being effective? We expected a higher richness, diversity and abundance in conserved sites than in disturbed ones, according to declining arthropod diversity with plant species loss hypothesis [14], with the restored sites closer to conserved ones [30, 31]. We expected equivalent information provided by different taxonomic levels [22, 23, 32]. Also, we expected a better resolution of the differences between sites using trophic guilds, as trophic structure is a proxy for ecosystem function [33]. With all this information, we expect to be able to determine if restoration efforts in the PSAER have been good enough to differentiate restored to disturbed sites.

Materials and methods

Site of study

The PSAER is an urban reserve inside Mexico City. Geologically, the area is result of the Xitle volcano eruption, ~ 1600 years ago [34]. It is located to the southwest of Mexico City (19° 20´ 11´´ N, 99° 10´15´´ W;

2,292– 2,365 m.a.s.l). The climate is temperate with a dry winter and a medium annual temperature of 15.6 °C and a pluvial precipitation of 833 mm [35]. The region shows two distinctive seasons: a dry one and a wet one, which promote a xeric scrub community dominated by *Pyttocaulom praecox* (Cav.) Rob & Brettell (Asteraceae) [36, 37]. The reserve contains three core zones located to the west (ZNP), east (ZNO) and southeast (ZNSO) and 13 buffer zones (from A1 to A13).

Although we provide a brief description of conserved, restored, and disturbed sites below, a detailed characterization is shown in Table 1.

Conserved sites in the PSAER display high spatial heterogeneity caused by the cooling of the lava flow; this geography provide different conditions of soil, moisture, temperature and light exposition [25], as well as caves, promontories, rock fissures and hollows. On the other hand, disturbed sites are characterized by an open vegetation and a relative flatness, caused by the introduction of soil used for gardening. In disturbed areas it is common to find trash, rubble, and gardening wastes.

Inside the reserve, three sites have been subjected to ecological restoration: *1*) the buffer zone 11 (hereafter called R1), a portion of the buffer zone 8 (R2) and a site located in the southeast core zone (R3). In addition to these three sites subjected to ecological restoration, we randomly selected 4 conserved (C1, C2, C3, C4) and 4 disturbed areas (D1, D2, D3, D4) (Fig. 1) based on our knowledge of the reserve. Characterization of each site is provided in Table 1.

Arthropod sampling

The sampling was performed in September of 2013, corresponding to the wet season where more density of arthropods has been observed in the reserve [39, 40]. A line of eight pan traps with a 10 m distance between them, were placed in all 11 sites (conserved, restored, and disturbed) (lines of 80 m total). Lines were placed 10 m away from the border of the area. Traps consisted in plastic bowls with a diameter of 17.5 cm in which 175 ml of a 5% solution of shampoo with honey scent was poured. To catch a higher variability of arthropods we used four colors [41–43]: solid orange, solid yellow, solid white and fluorescent yellow. Thus, we used two bowls of each color in each site. The traps operated for 540 min, from 8:00 to 17:00 h for one day. Here it is important to point out that although there are other methods which are commonly used to monitor insect diversity [44], such as pitfall traps or sweep netting, the use of pitfall traps was logistically impossible in our case because the dept of the soil is very low and most of the land is still basaltic rock. One of the advantages to use pan traps was that all the traps were working simultaneously.

The collected material was conserved in alcohol at 70%. Each specimen was identified at stereomicroscope to the finest taxonomic level possible using dichotomous keys, catalogues, or previous records at species level [45–53]. All the specimens were identified at least at the family level, and were assigned a trophic guild (predator, phytophagous or saprophagous) according to the description of the family provided in [34] which corresponds to most of the species in each family. When the taxonomic identification was not possible, we used the morphospecies criteria based on sightly differences of anatomical structures. Neither color nor size was considered to differentiate a morphospecies. Unidentifiable larvae were not considered in our analysis. Although it may be possible that some members of the family have different trophic habits, our lack of a species identification made difficult to use a better guild resolution.

Data analysis

To perform the diversity and richness analysis, we grouped all the replicates (sites) for conserved and for disturbed sites according to their category. The restored sites were considered individually for each analysis to gain a better knowledge of their restoration success.

To test for differences in diversity at species level identifications, we calculated the effective number of recognizable taxonomic units (RTUs) since we have a pool of species and morphospecies. To do so, we used the algorithm to calculate the effective number of species, which represents the number of species with the same abundance in a virtual community that equals the diversity obtained by any traditional index, so that comparisons between communities are more intuitive [54, 55]. In this case, we used the exponential of the values of the centered Confidence Interval (CI) at 95% of Shannon–Weaver entropy index, obtained with a bootstrap of 9999 replicates using PAST4.04 [56]. By doing this, we are not favoring common or rare RTUs [54]. If an overlap in the CI is detected, the evaluated parameters are considered as equal [55].

To compare richness, we calculated the confidence interval at 95% of Chao's1 index (bias corrected) estimated richness sensu Gotelli and Colwell [57] for site, using centered bootstrapping (9999 replicates) with PAST4.04. This method offers an estimated approach of the existing species (RTUs, in our case), still when they were not sampled. It considers the presence of organisms found in only one site (singletons) and in two sites (doubletons) through the next expression:

$$S_{estimated} = S_{observed} + \left(\frac{F_1(F_1 - 1)}{2(F_2 + 1)}\right)$$

where:

Table 1 General characteristics of the study sites within the PSAER, Mexico City, accordingly with data of Estañol-Tecuatl & Cano-Santana [38], and Antonio-Garcés et al. [28]

Site	Years managed	Area	Disturbances	Restoration practices	Vegetation summary
Conserved sites	Does not apply	Does not apply	Does noy apply	Does not apply	Plant community is characterized by native species, like *Pittocaulon praecox*, *Echeveria gibbiflora*, *Dahlia coccinea* and *Muhlenbergia robusta*. The mean plant richness is 48 spp. and, regarding to the relative coverage, only the 1.4% is characterized by exotic plants
R1	8	0.225 ha	The area was affected during 2004 and 2005 by the partial construction of a parking lot, which included the elimination of the original vegetation and the basaltic rock, as well as the filling with sand and flattened of the exposed surface. The construction of the parking lot was later cancelled	The recovery of the original substrate by i) the extraction of the foreign material with a bulldozer, and ii) the addition of fragmented basalt rock, creating a gradient accordingly with their diameter (at the bottom, rocks of ≥ 1 m, then rocks of 50 cm and smaller rocks conformed the upper layer). iii) The removal of inorganic wastes. iv) The extraction of 13.8 m^3 of different exotic plant species (*C. clandestinus*, *Ricinus communis* and *Eucalyptus* spp.)	*Buddleja cordata* (native) canopy with a coverture of 90%. *Cissus verticillata* (native) as dominant schrub in 34% of the area, and a herbaceous layer consistent mainly of *Cenchrus clandestinus* (exotic) with 55% of coverture, and *D. coccinea* (native) with 21% of coverture
R2	8	0.52 ha	Accumulation of inorganic garbage and gardening debris from an adjacent soccer field from 1974 to 2005 The edges of this zone present leftovers of rubble originated from the maintenance of the buildings in the campus	i) The extraction by hand of 183.7 m^3 of organic wastes, inorganic garbage and rubble. ii) The removal of the 83.7% of the eucalypt population by cutting them and leaving only the tree stump iii) The introduction of 1,079 seedlings of 10 native species, and approximately 53,000 seeds of *Muhlenbergia robusta*, a native species. iv) The control of the *Mirabilis jalapa* population by the extraction of their shoot and root systems by hand	*B. cordata* (native) and *Schinus molle* (exotic) canopy present in less of the 30% of the area. *Montanoa tomentosa* (native) as dominant schrub, but only in around 25% of the area. Herbaceous layer mainly of *C. clandestinus* (exotic) with around 60% of coverture
R3	6	0.35 ha	Before this site was considered as a protected area, it was divided in two parts to allow the vehicle transit	i) To promote the natural growth of the native vegetation, the flattened area was covered by a 3 m thick layer of basalt rock	Canopy of *B. cordata* (native) with around 9% of coverture. Absence of dominant shrubs. Herbaceous layer consistent mainly of *Wigandia urens* (native) with around 40% of coverture and *C. clandestinus* with around 12% of coverture
Disturbed sites	Does not apply	Does not apply	Extraction of basalt rock, accumulation of garbage and invasion of exotic species	Does not apply	The mean plant richness in these sites is 24 spp. On average, the 65.8% of their relative coverage is dominated by exotic species, mainly *Eucalyptus camaldulensis* and *C. clandestinus*, as well as the native species *Tripogandra purpurascens*

The years managed encompass the time elapsed since the first restoration practices and the year of sampling (2013)

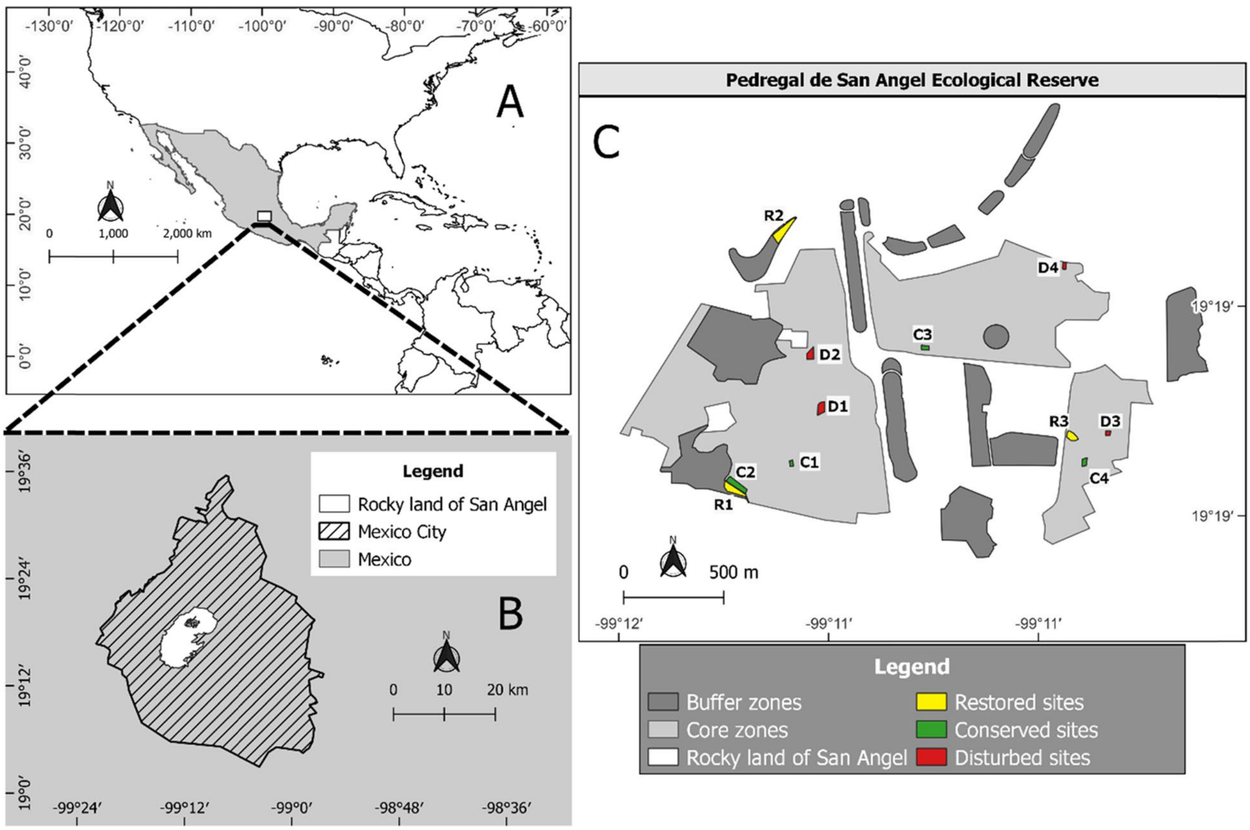

Fig. 1 **A** Location of the Pedregal de San Angel, in Mexico City. **B** Original extension of the Pedregal and location of the PSAER (2020), **C** Sampling sites in the PSAER, noted as white polygons

S = richness, F_1 = number of *singletons*, and F_2 = number of *doubletons*.

In our case, singletons were considered as RTUs that appears either in just one of the restored sites (independently), or in just one time in the grouped conserved or disturbed sites. The same sites criterion was used for doubletons, as RTUs that appeared twice.

To test for differences in abundance between treatments and because our data did not meet the assumptions of a normal distribution, we perform a non-parametrical Kruskal–Wallis test using the *kruskal.test* function in the package *stats* in R 4.0.3 [58]. We used the type of site as a fixed factor. In this case, besides the grouping of conserved and disturbed sites, we also grouped the three restored sites as one group to facilitate comparisons of this data with ANOSIM (see below). Since there were differences between type of sites, we used the *pairwise.wilcox.test* function (also contained in *stats*) to detect differences between pairs.

To evaluate the sites ordination in relation with the abundances and the RTUs composition, we performed a non-metric multi-dimensional scaling (NmMDS) using Bray–Curtis distance since it considers non only presence-absence data, but abundance, trough PAST4.04, using an 11 (sites) × 159 (morphoespecies) matrix. The same analysis was performed for orders using a 11 (sites) × 11 (orders) matrix; for families using an 11 (sites) × 78 (families) matrix and for trophic guilds using an 11 (sites) × 3 (trophic guilds: predators, phytophagous or saprophagous) matrix. In NmMDS, there is a value called stress, which is a measure of goodness of fit. Here, we consider a rule of thumb which states that values under 0.2 are considered adequate, *i.e.* the lower the value, the better fit. In the latter, we perform a x^2 test to identify if trophic guilds were over (or under) represented in each type of site. Also, we performed an analysis of similarities (ANOSIM) to detect differences among categories, both for taxonomical and trophic guilds arrangements. This analysis compares the values of any method used to calculate distances, inter and intra factor [59] through the following expression:

$$R = \frac{(\overline{r}_b - \overline{r}_w)}{\frac{1}{2}M}$$

where $\overline{r}_b$ is the mean of the distance range between factor; $\overline{r}_w$ is the mean of the distance range within factor;

and $M = \frac{n(n-1)}{2}$, with n as the sample number. If $P < 0.05$, the program runs a pairwise test to detect the differences among groups.

Results

We found a total of 857 organisms of 159 RTUs coming from 78 families, 10 orders and three subphyla (Supplementary table 1). Nevertheless, we worked with 11 order-level groups, as we consider Heteroptera and Homoptera as different orders because several heteropterans may be predators, hematophagous, polliniphagous, spermophagous and even folivorous, and homopterans (Sternorrhyncha and Auchenorrhyncha) are only sap feeders. This way, we were able to get a better knowledge of the diverse functional groups in the PSAER. The distribution of the orders among the sites is shown in Table 2.

Restored sites were different to conserved or disturbed sites in terms of diversity, which showed an overlapped CI, going from 31 to 45 effective number of RTUs in conserved sites, and from 36 to 48 in disturbed sites (Fig. 2). Site R1 was different to the other restored sites with a lower CI of two to three effective numbers of RTUs. R2 and R3 showed an overlapped CI, going from 17 to 28 and from 12 to 24, respectively ($P < 0.05$). In terms of richness, R1 showed less estimated RTUs with 7 to 30. All other conserved, disturbed, and restored sites showed at least 99 to 199 estimated RTUs, and there were no significant differences between them (Fig. 3).

The Kruskall-Wallis test showed differences in abundance ($\chi2 = 11.97$, g.l. = 2, $P = 0.002$) between types of sites. The pairwise test indicated differences between conserved and disturbed sites ($P = 0.018$) and between restored and disturbed sites ($P = 0.003$). No differences were found between restored and conserved sites ($P = 0.605$) (Fig. 4).

In the NmMDS for abundance and composition of RTUs the stress value was 0.1925, and the analysis aggregated two distinctive groups conformed by conserved and disturbed sites. The restored sites resulted scattered around the disturbed ones (Fig. 5).

The NmMDS based on orders (stress = 0.1248) and trophic guilds (stress = 0.1386) showed a better fit. In these cases, conserved and disturbed sites were grouped separately, and restored sites were scattered around conserved and disturbed sites (Figs. 6 and 7), respectively.

The NMMDS based on families had a higher stress that accepted (stress = 0.2112), so their ordination plot is not presented here.

The χ^2 test showed statistical differences among trophic guilds in each type of site ($\chi^2 = 108.88$, g.l. = 4, $P = 0.0001$). Based on adjusted residuals, we observed an overrepresentation of predators in conserved sites (standardized residual = d = 3.193), but an underrepresentation in restored sites (d = -3.452). Moreover, we found an overrepresentation of phytophagous in disturbed sites (d = 7.015) and an underrepresentation in restored sites (d = -6.722). Finally, there was an overrepresentation of saprophagous in restored sites (d = 9.701), and an underrepresentation in conserved and disturbed sites (d = -2.0349 and -7.427, respectively).

The ANOSIM showed that the Bray–Curtis distance between groups was statistically significant for RTUs ($R = 0.443$, $P = 0.006$), order ($R = 0.33$, $P = 0.014$), and

Table 2 Number of morphospecies by order sampled in 11 sites of different status (restored, conserved or disturbed) in the PSAER, Mexico City

		Orders										
Sites	Status	Dip	Auch	Hym	Col	Ara	Thy	Het	Ort	Lep	Iso	Bla
C1	Conserved	10	8	7	4	1	-	1	1	1	-	-
C2	Conserved	10	6	5	5	-	1	-	-	-	-	1
C3	Conserved	5	4	2	3	-	1	-	-	-	-	-
C4	Conserved	9	4	14	2	1	1	-	-	-	-	-
R1	Restored	7	2	1	-	1	1	1	-	-	-	-
R2	Restored	22	11	10	2	2	-	1	-	1	-	-
R3	Restored	9	6	5	1	4	1	2	-	-	-	-
D1	Disturbed	10	10	7	5	2	1	0	1	-	2	-
D2	Disturbed	9	11	8	8	1	-	1	1	-	-	-
D3	Disturbed	8	12	4	7	3	1	1	1	-	1	-
D4	Disturbed	10	6	4	3	2	1	-	-	1	-	-

Dip Diptera, *Auch* Auchenorryncha, *Hym* Hymenoptera, *Col* Coleoptera, *Ara* Arachnida, *Thy* Thysanoptera, *Het* Heteroptera, *Ort* Orthoptera, *Lep* Lepidoptera, *Iso* Isopoda, *Bla* Blattodea

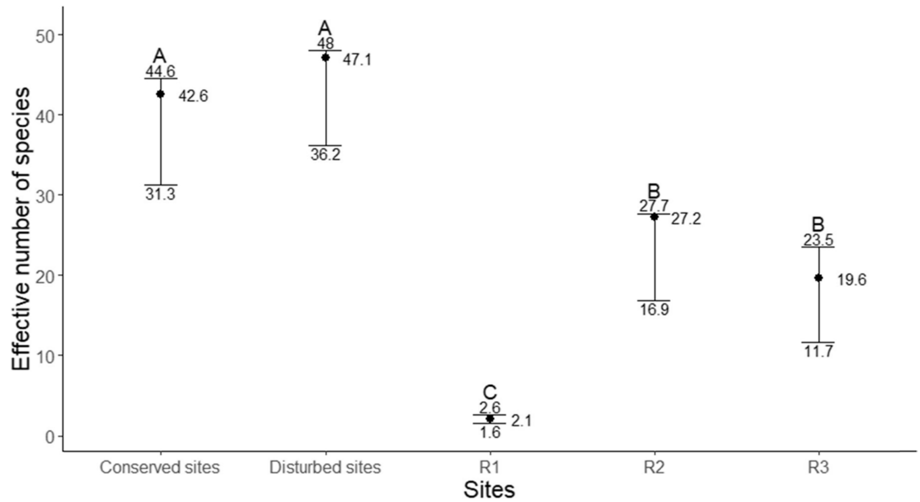

Fig. 2 95% Confidence Intervals of arthropod diversity in conserved, disturbed, and restored sites in the PSAER, based on 857 arthropods in total. Conserved and disturbed sites were grouped respectively to facilitate the interpretation. Captures in all conserved and disturbed sites were pooled and treated as just one site, in each case. Dots represent the effective number of RTUs obtained through the Shannon–Weaver entropy index calculated from our real data, which is right sided of the bar. Lower and upper bar represents minimum, and maximum obtained through a bootstrap resampling with 9999 replicates. Different letters represent different groups due the lack of an overlapped area

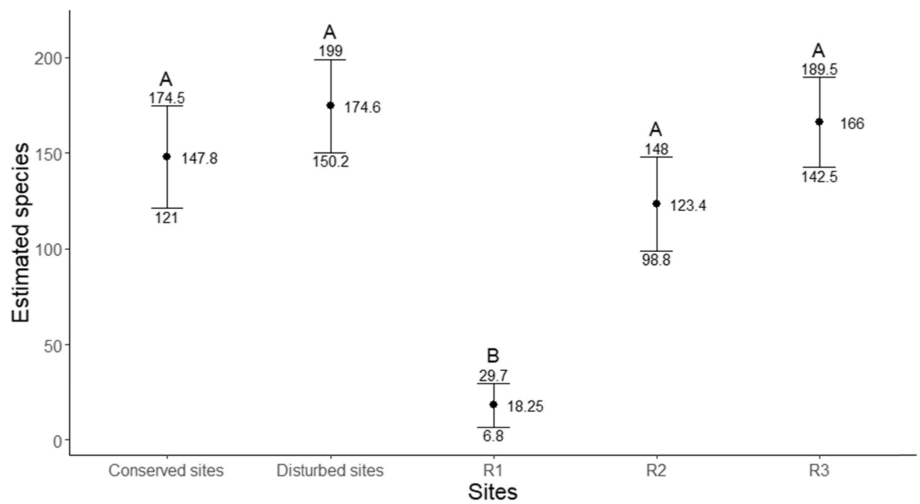

Fig. 3 95% Confidence Intervals of arthropod richness obtained through Chao1 species estimation in conserved, disturbed, and restored sites in the PSAER, based on 857 arthropods in total. Conserved and disturbed sites were grouped to facilitate the interpretation. Lower and upper bar represents minimum, and maximum obtained through a bootstrap resampling with 9999 replicates. The spots represent real richness obtained in our sampling, which is right sided of the bar. Different letters represent different groups due the lack of an overlapped area

trophic guilds ($R = 0.2667$, $P = 0.034$), but no for families ($R = 0.2517$, $P = 0.053$) (see Table 3).

Discussion

Since our data lack a species identification in most of the cases, we were unable to obtain a finest trophic guild assignment to our RTUs (using nectarivores or folivores instead of phytophagous, for example), which could provide a better understanding of the dynamic of the PSAER.

Although, several limitations were evident in our methodology, such as the sampling method used, the time of collection and the bias of the pan traps for flying insects, we are aware of them. Given those limitations, we found a differentiation in taxonomical composition in terms of RTU's and orders between types of sites, these apparently

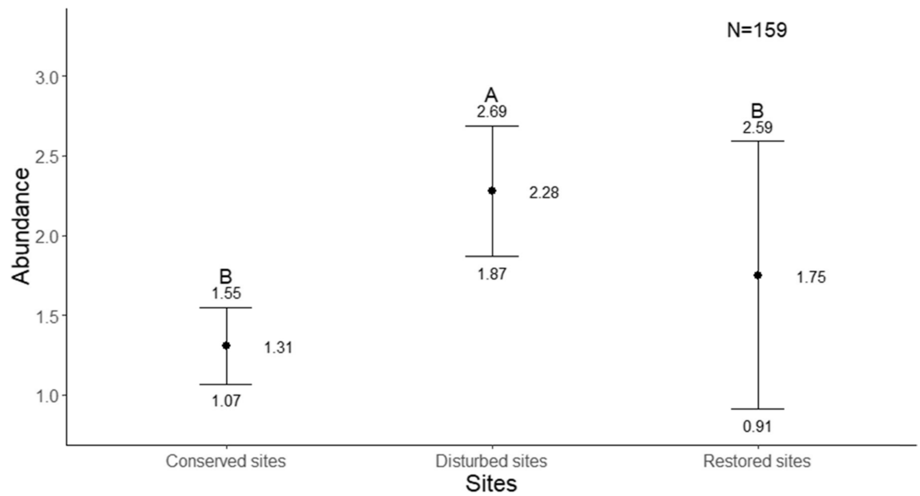

Fig. 4 Pairwise comparison of arthropod abundance in conserved, restored, and restored sites in the PSAER, based on 857 arthropods in total. Conserved, restored, and disturbed sites were grouped respectively to facilitate the interpretation with ANOSIM differences, which are based in Bray–Curtis distances. The points represent the real mean abundance obtained in our sampling, which is to the right of the bar. Maximum and minimum were calculated through standard error. Different letters represent different groups

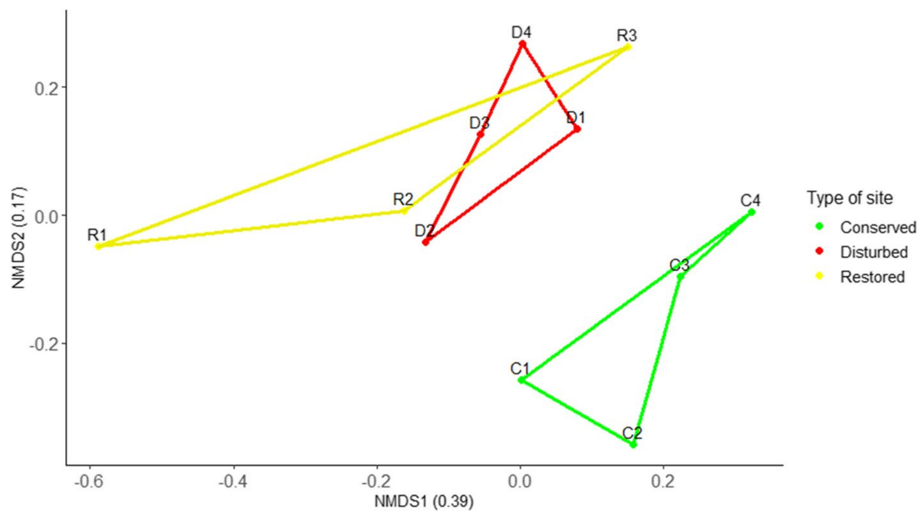

Fig. 5 Non-metric Multidimensional Scaling showing the ordination of the 11 study sites in the PSAER, based on RTUs. Dots represent conserved sites; triangles represent disturbed sites and squares represent restored sites. The lines are the convex hulls of the polygons formed in each case

absence of differences in diversity and richness are given by different organisms. This way, despite the caveats in our design, we consider that our results are useful to compare on a preliminary way the community of arthropods in the PASER. This is the first approach to examine whether broader classifications may be useful in future monitoring efforts, and to set a baseline of the state of the restoration at the time of the sampling.

Our results showed differences in abundance among conserved and disturbed sites, whereas restored sites shared values with conserved sites. The restored site R1 presented lower richness compared to all other sites. Also, differences in diversity as effective number of RTUs between restored against conserved and disturbed sites, were observed.

It has been reported that arthropods abundance can increase in habitats dominated by invasive plant species [60], due to the availability of resources for generalist species [61]. Although this tendency varies depending on the species or habitats involved (for example, [62]), this could

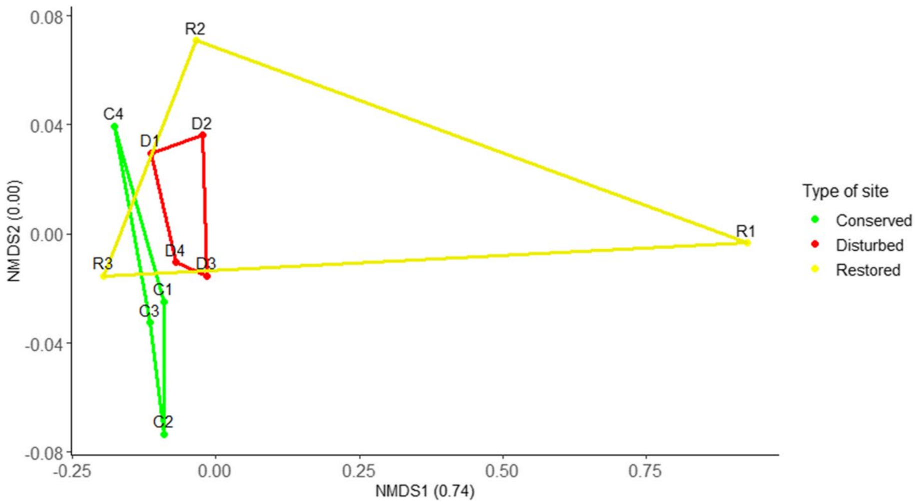

Fig. 6 Non-metric Multidimensional Scaling showing the ordination of the 11 study sites in the PSAER, based on taxonomic orders. Dots represent conserved sites; triangles represent disturbed sites and squares represent restored sites. The lines are the convex hulls of the polygons formed in each case

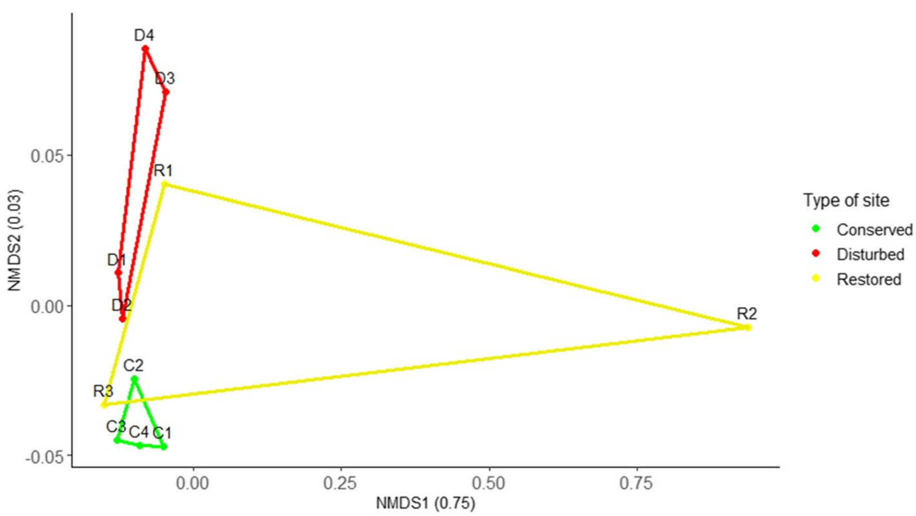

Fig. 7 Non-metric Multidimensional Scaling showing the ordination of the 11 study sites in the PSAER, based on trophic guilds. Dots represent conserved sites; triangles represent disturbed sites and squares represent restored sites. The lines are the convex hulls of the polygons formed in each case

Table 3 Pairwise comparisons obtained through ANOSIM between types of site in the PSAER, based in Bray–Curtis distance

	RTUs		**Order**		**Trophic guilds**	
Site comparisons	***R***	***P***	***R***	***P***	***R***	***P***
Restored / Disturbed	0.074	0.373	0.185	0.2047	0.093	0.283
Restored / Conserved	0.556	**0.027***	0.351	0.056	0.259	0.188
Conserved / Disturbed	0.698	**0.028***	0.885	**0.0263***	0.469	**0.026***

* = significant differences

be the case for the PSAER, as the higher abundance was found in disturbed sites, which are dominated by invasive species like the grass *Cenchrus clandestinus* [38]. Thus, as the restored sites can not be differentiated from disturbed sites in terms of taxonomic nor guild composition (see below), the same species beneficiated of the presence of exotic plant species in disturbed sites may be present in restored sites, displaying similar abundances.

Site R1 showed the lowest richness of all the studied sites. Since its restoration process began at the same time than R2, and prior to the process in R3, it is possible that the lower richness found in R1 is associated with a low habitat heterogeneity (as in [38]) or low availability of food resources [14] as the site is dominated by the shrub *Buddleja cordata* with 90% of coverture ([62], Table 1), which, although is a native species, offers limited resources compared to a more diverse site. This may also explain the low effective number of RTUs in this site, as we observed a high dominance of a single species of chironomid, which may be feeding on the nectar or pollen of this particular plant species [63].

Conserved sites showed a similar amount of arthropod diversity in comparison with the disturbed sites, although the latter showed a higher dominance of exotic plants. This could mean that arthropods are not responding exclusively to the plant community. As has been showed in other studies, there may be influence of other characteristics such as the area of the patch and the type of substrate [64], the presence of keystones structures [65], the plant coverage [9] or the intake of soil P or NO_3^- or even the communication between patches. Moreover, it has been shown that sites with different management may sustain different arthropods communities [66], which may increase the overall beta diversity [67]. If that is the case, taxonomical or guild composition could be considered more important than richness or diversity in the PSAER to evaluate the effect of the restoration practices because they reflect the functionality of the ecosystem rather than only the structure-.

Studies using arthropods as monitoring tools of restoration efforts have been conducted in specific taxonomic groups, such as beetles [68], orthopterans [69], ants [70] or lepidopterans [71, 72]; however a wider taxonomical scope may show a broader pattern where the effect of restoration over different sites and/or different strategies could be identified [2, 66, 67, 73], this is our case.

Although the use of species or morphospecies has been considered the most useful approach to evaluate differences in habitats management in some studies [32, 74, 75], the use of high taxonomic classifications has proved to be a cost effective way to obtain similar results [22, 32]. Nevertheless, as data about the utility of different taxonomic levels have not be consistent among distinct studies [22, 76], it is necessary to test the taxonomic sufficiency in order to optimize resources [77].

In this regard, in our study three out of four NmMDS (RTUs, order and trophic guild compositions) showed spatial differences between conserved and disturbed sites, with restored sites scattered distinctly in each plot. In the RTUs plot, restored sites appeared closer to the disturbed sites, while in the order and trophic guilds plot, restored sites were dispersed indistinctly between the disturbed and conserved sites. However, the stress of the order analysis showed that this was the better criterion to summarize the variation in the PSAER.

Thus, our data suggest that if we are interested just in taxonomical similitude of sites in the PSAER, it is possible to obtain reliable information about the effectiveness of restoration using order classification, which is consistent with other studies [22, 23]. Nevertheless, at least a family classification is recommended in order to assign a coarse trophic guild and to evaluate the restoration of functional structure [1].

Although the ANOSIM shows differences in conserved against disturbed sites using RTUs, orders and trophic guilds, in the two last cases restored sites were considered equal to disturbed but also to conserved ones. This implies that with a coarse view or regarding functional structure, restored sites cannot be differentiated of conserved sites in the PSAER. This suggest that besides the absence of clear differences in richness, total abundance and diversity between types of sites, there are differences in the relative abundance and taxonomical or trophic composition, as has been reported in other studies dealing with disturbed or under restoration sites [60, 66].

In general, the presence of predators is considered a signal of a healthy ecosystem, as it suggests the presence of suitable preys [78], which is consistent with their presence in conserved sites, and a desirable result in restored sites. Moreover, predators can facilitate the recovery of plant biomass in restoration projects [79]. On the other hand, the high dominance of phytophagous in disturbed sites could be explained by the "resource concentration hypothesis", which states that specialist herbivores should be found in high concentrations in habitats dominated by their host plants [80], which is probably the case for *C. clandestinus* in the PSAER (Table 1).

Chapin and Starfield [81] proposed the "novel ecosystem" concept, which refers to a site that presents a new combination of species and relative abundances that do not were present previously, as a result of human activities, which could be the case of R1 in our study, given its tendency to diverge in both plant (Table 1) [38] and arthropod communities. Nevertheless, the SER has proposed a list of nine points that must be accomplished in an ecosystem subjected to restoration actions so they can be effectively restored [1], including the "characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure". Under this approach, neither of the sites of the PSAER could be considered successfully restored, although some responses of the arthropods to the restoration efforts were observed. Although, since R3 has the more similar trophic guild composition to conserved sites and the same values of effective number of species and estimated richness than R2, which are also higher than in R1, it seems like passive restoration is the best management in terms of cost-benefits regarding arthropods communities in the PSAER.

In restoration ecology, is it typically assumed that if the original plant community is present, the fauna will be present as well [6, 64, 82]. Nevertheless, it is possible that other factors drive the presence of arthropods in a plant-restored site, such as the physical structure, the chemical properties of the soil, the particular life history traits of each species or the elapsed time after the intervention [2, 67]. In that case, it is possibly that for a successful recovery of the original arthropod community, it would be needed to target specific actions for them, as has been proposed particularly for pollinators [5]. Although a review on the theme was published in 1991 [83], an update on the topic feels necessary to achieve integrated restorations.

Conclusions

In this study we found that restored sites showed lower values of diversity measured as effective number of species compared to conserved or disturbed sites, with one site (R1) exhibiting the lowest effective number of RTUs. Although richness values for two restored sites (R2 and R3) were similar to those in conserved and disturbed sites, the restored site R1 showed a significant decrease in richness. Moreover, abundance in restored sites of the PSAER showed shared values with conserved and disturbed sites. According to results obtained with NmMDS and ANOSIM analysis, information provided by orders, trophic guilds and RTUs are not similar. For order and trophic guilds composition, restored sites are either similar to conserved or disturbed sites, while for RTUs composition, restored sites are similar to disturbed sites only. With de data analyzed in this work, restoration actions should be enhanced to achieve the objectives of the ecological restoration. Also we propose that more studies should be done in order to cover epigeal and soil insects rather than only flying ones.

Abbreviations

PSAER: Pedregal de San Angel Ecological Reserve; SER: Society of Ecological Restoration; RTUs: Recognizable Taxonomic Units; NmMDS: Non-metric Multi-Dimensional Scaling.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40693-022-00108-8.

Additional file 1: Table S1. List of species and morphospecies registered in four conserved sites (CS), three restored sites (RS) and four disturbed sites (DS) in the PSAER. The number represents the abundance of each morphospecies.

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Authors' contributions

EF, ZC, JHC conceived and designed the research, EF performed insect collections; EF analyzed the data; ZCS, JHC contributed reagents/materials/analysis tools; EF, ZC, MCHP & JHC wrote and edited the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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