Effect of exotic species management on the recovery of relict forests through citizen participation

Nihaib Flores-Galicia[1] · Erick Gutiérrez[2] · Irma Trejo[3]

Abstract

In the cities, remnants of the vegetation that originally occupied these areas can be found. Exotic species have established in these relicts, and therefore these spaces require management aimed at recovering native vegetation. In this study, we evaluated the impact of the removing exotic species on the floristic composition of the remnants of an oak forest. We compared the abundance/cover and composition of exotic plants in a forest that has been managed through citizen participation with that of reference forests (both with remnants, but the former without protection and the latter with protection). We established 48 sampling sites to characterize the vegetation in three strata (upper, middle, and low) and monitored changes in composition in managed forest sites for a period of 3 years. The results indicate that the managed forest hosts different species than those found in the reference forests, with lower abundance and cover of exotic plants in the upper and lower strata. Regarding temporal changes, we observed shifts in floristic composition before and after management activities, and a reduction in the cover of exotic species before and after management, with consistently low cover three years later. This underscores the effectiveness of citizen-led management activities, offering a viable alternative for restoring native vegetation in urban environments.

Keywords Civic ecology · Oak forests · Urban forest · Citizen science · Exotic plants

Introduction

Cities, which are conceived as socio-ecosystems, have gained great relevance for biodiversity due to the negative effects derived from the concentration of the human population, the production of pollutants, the change in land use and their exponential growth (Müller et al. 2013). The expansion of urban areas is usually associated with the destruction of the ecosystems that surround them. Despite this, some fragments of the original vegetation that occupied these spaces can remain within the cities and are called relict forests (Florgård 2007; Klaus and Kiehl 2021).

These spaces are of great importance for the people inhabiting cities, providing various ecosystem services and serving as museums of the ecosystems that once occupied those areas. Additionally, being part of the green infrastructure (Florgård 2007), they act as catalysts for socialization processes, such as social integration and interaction (Enssle and Kabisch 2020; Standish et al. 2013). For these reasons, conservation and, where appropriate, restoration must be priority activities. In cities, participatory restoration has proven to be an effective tool to help recover the remnants of vegetation, while helping people understand the importance of these relics for urban areas (Dolan et al. 2015; Krasny et al. 2015; Standish et al. 2013).

One of the most important activities in the recovery of relict vegetation is removing populations of invasive exotic species (Dolan et al. 2015). Some studies show

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that in urban environments, remove populations of exotic plants can be complicated since the dispersion of invasive exotic species to these areas is constant (Dolan et al. 2015; Gaertner et al. 2017). However, ignoring this activity can make the recovery process of urban green areas impossible or delayed, since the presence of exotic species prohibits the establishment of native species (Nguyen et al. 2021; Standish et al. 2013). The management of exotic species could be conducted through citizen participation, involving neighbors in removal work. Experiences of citizen participation in the removal of exotic species in urban areas have been studied (Connolly et al. 2013; Dolan et al. 2015; Heneghan et al. 2009), but little has been documented on changes in diversity after management by citizens over the years.

In Mexico City, numerous remnants of original vegetation exist (Ayala-Azcarraga et al. 2023). Among these, the most extensively researched ones, owing to their social, ecological and historical significance, are the vegetation fragments that have developed in the Xitle volcanic field, known as Pedregal de San Ángel (PSN) (Castillo-Argüero et al. 2004; Rzedowski 1994). While the vegetation in this region has been thoroughly investigated, there are limited studies on the oak forests that still persist within the urban area. In these remnants, issues have been reported due to the invasion of exotic species such as *Apium graveolens*, *Eucalyptus* spp., *Hedera helix*, *Leonotis nepetifolia*, *Pennisetum clandestinum*, and *Vinca minor*, to name a few (Castillo-Argüero et al. 2004; González-Hidalgo et al. 2001; SEDEMA 2011, 2018).

The remnants of the oak forest located in the southern area of Mexico City (CDMX) represent the last relicts within the urban area, which is why they are considered relevant ecosystems for the conservation of biodiversity. And although there are some studies of the oak forests in the southern peri urban area of the city (see for example: Bonfil Sanders et al. 2000), since 1953, no comprehensive studies have been carried out to characterize the diversity of these plant communities or to determine their degree of conservation within the urban area (Rzedowski 1994). Furthermore, it is unknown if management activities for the oak forest are effective for minimizing exotic species abundance and promoting native biodiversity.

The aim of this study is to evaluate the effect of management activities carried out by citizens on the floristic composition of plant communities in an oak forest compared to sites without intervention. To do this: (i) we compare the composition and abundance of exotic species between the managed forest and the reference forests (found in nearby protected natural areas) and (ii) we determine if there are changes in composition and

dominance of exotic species in the managed forest over a period of 3 years.

Methods

The study area was limited to the relicts of a type of oak forest dominated by *Quercus deserticola* (OFQd) that currently exist in small areas in the south of CDMX, at altitudes ranging from 2350 to 2700 m a.s.l. The trees of this OFQd reaching a height of 6–10 m and grow in dense masses. This oak forest developed in clearings that were not covered by lava, which was the product of a volcanic eruption that occurred more than 1,700 years ago. In this lava field, other types of vegetation developed: towards the lower areas a xeric scrub, in the middle area different types of oak and mixed forests and towards the higher areas coniferous forests (Rzedowski 1994).

Within the urban area, there are relics of OFQd with different protection statuses according to local regulations. One is the Cerro de Zacatepetl Area of Environmental Value (CZ), and the other is the Bosque de Tlalpan Ecological and Cultural Zone Protected Natural Area (BT). These areas had kept protection against changes in land use and the regulation of human activities (such as species extraction, logging, recreation, among others) for at least the last 50 years, predating the urbanization of the area. Consequently, these areas are well-preserved (SEDEMA 2011, 2018). Outside of CZ and BT, there is another fragment of the OFQd in a 5 ha park with no formal protection called Viaje a la Naturaleza forest (VN). In VN, issues such as garbage problems, annual removal of all shrubby individuals, introduction of exotic species by some neighbors, and the presence of invasive exotic species were observed (Urroz 2022). Since 2020, various management activities have been carried out through citizen participation in this park (VN), as described below. Both CZ and BT, due to their well-preserved state, were considered reference forests, while VN, due to the activities undertaken since 2020, was labeled as a managed forest.

To characterize the plant communities, we stablished a total of 48 random sampling sites, of which, 20 sites were placed in VN in which management activities were carried out through citizen participation (managed forest). The other 28 sampling sites were established in the reference forests: 11 in CZ and 17 in BT (Fig. 1).

In each of the sampling sites, we stablished plots to characterize three plant strata. Each plot was made up of three squares: one of 30×30 m, one of 5×5 m and one of 1×1 m in which the vegetation of three vertical strata was recorded: upper, middle and low respectively.
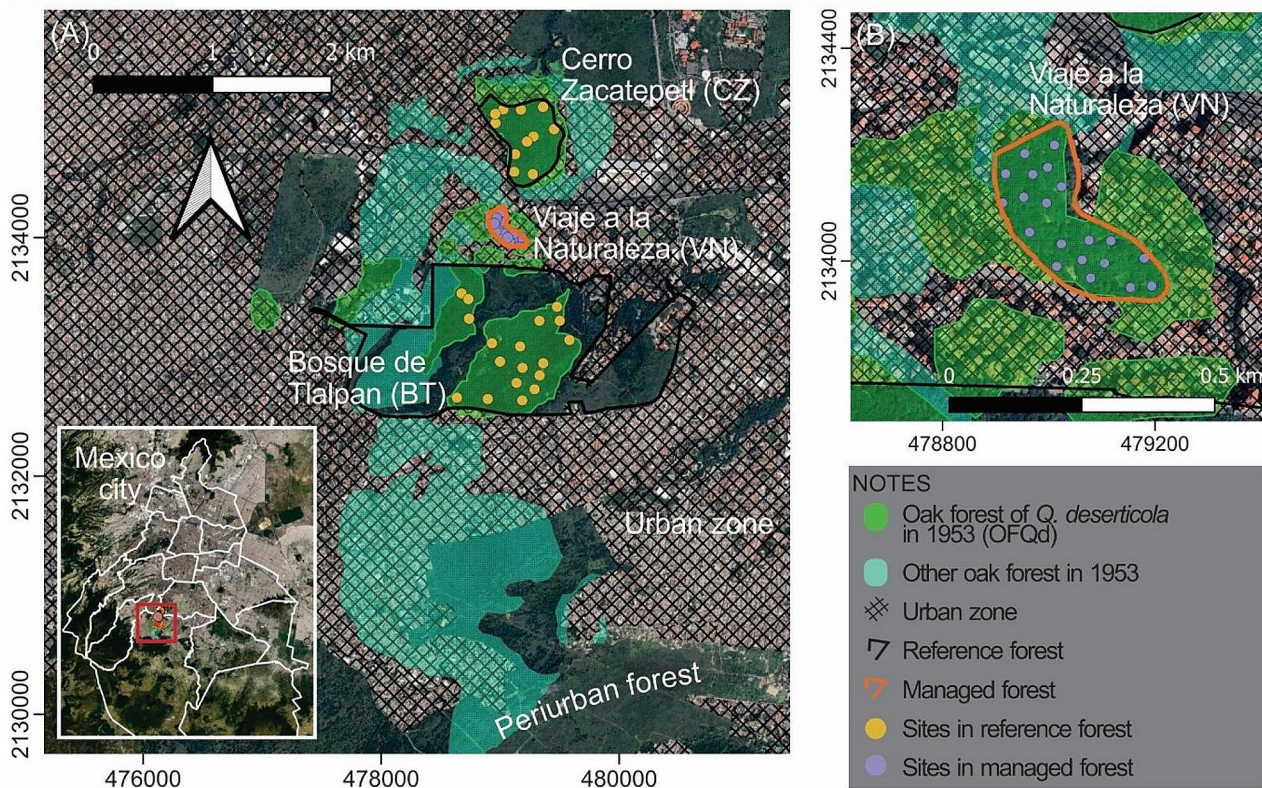
Fig. 1 Map showing the cover of oak forests in 1953 according to (Rzedowski 1994) and the location of the sampling sites. (**A**) Sampling sites of the BT and CZ reference forests. (**B**) Close-up of the location of the sites in the managed forest (VN)

In the plot of 30×30 m (900m^2), we recorded all the individual with normal diameter (DN: 1.3 m) ≥ 4 cm, in the plot of 5×5 (25 m^2) we recorded the individuals with DN < 4 cm, and in the plot of 1×1 m (1 m^2), individuals with a height < 1.3 m were recorded. We determined the species occurrence and abundance (in the plots of 1m^2 the cover was determined) in all samples. In the 900 and 25 m^2 squares the DN was recorded.

Management activities through citizen participation

In December 2020, the inhabitants of the surrounding area of the VN forest decided to implement management measures, with the aim of recovering the OFQd. The measures applied consist of the removal of dominant exotic species from the lower stratum (species names-acronyms used in figures: *Hedera helix*- He he, *Jacaranda mimosifolia*- Ja mi, *Leonotis nepetifolia*- Le ne, *Pennisetum clandestinum*- Pe cl y *Vinca minor*- Vi mi), in 2020 and 2021. Starting in 2022, all exotic species observed in the lower stratum began to be removed (Supplementary information). Additionally, the following recovery measures were implemented: the removal of impermeable surfaces, the delimitation of trails, the restriction of the mobility of users to the trails, the transplantation

of native plant species in areas without tree cover, the extraction of garbage from the forest and the prohibition of throwing waste in the forest (Urroz 2022).

To remove exotic species, workshops on exotic plant identification were conducted for neighbors and workers. Two workshops were held before commencing the removal work, and six were conducted in 2021, with an attendance ranging from 10 to 30 people. The removal was carried out in 2021 through monthly or bimonthly work sessions and starting in 2022, the removal of an individual or population that was detected sporadically was carried out.

Evaluation of changes in vegetation composition (between forests and between seasons)

To evaluate the degree of conservation of the managed forest with respect to the reference forests, we visited all sampling sites in August 2023 and the vegetation in the three strata described above was recorded. To evaluate changes in composition over time (in different seasons), we visited the sampling sites within the managed forest in November 2020 (before management activities), August 2021, November 2021 and August 2023 (during management activities). In these visits, only the vegetation of

the lower stratum was recorded since the removal activities of exotic species were limited to the plants of this stratum.

Statistical analysis

To compare the composition between the managed forest and the reference forests, we used a permutation analysis (PERMANOVA). Before performing the analysis, the abundance data were transformed using the Hellinger method (Borcard et al. 2018). To visualize these results, we performed a multivariate NMDS clustering analysis using a distance matrix calculated with the Bray-Curtis dissimilarity coefficient for each stratum. The PERMANOVA was performed using the adonis2 function from the Vegan package (Oksanen et al. 2013), for the NMDS the metaMDS function from the Vegan package was used (Oksanen et al. 2013). To compare the dominance of exotic species, we performed a Kruskal's non-parametric test using abundance data (middle and upper stratum) or cover (low stratum). The kruskal.test function from the Vegan package was used (Oksanen et al. 2013). Subsequently, we performed an analysis to detect differences between the groups using the Wilcoxon test. The function pairwise.wilcox.test from the Vegan package was used (Oksanen et al. 2013).

Due to the marked seasonality of these forests, to analyze changes in composition before and after citizen intervention, comparisons were made between November 2020 and November 2021 (dry season) and between August 2021 and July-August 2023 (rainy season). Because the data were not normally distributed, a non-parametric Friedman test was performed for comparisons. We used the friedman.test function from the Vegan package to perform the test (Oksanen et al. 2013). To compare the composition, we performed a permutation

analyzes (PERMANOVA) and an NMDS to visualize the similarity. For these last two analyzes we used the procedure and packages described above.

Results

We recorded a total of 155 species in the studied sites. In the Bosque de Tlalpan (BT), 78 species were found, of which 12 were exotic, in the Cerro de Zacatepetl (CZ) 65 species of which 9 were exotic, and in Viaje a la Naturaleza (VN) 78 species with 16 exotic (Supplementary information).

Differences between managed forest and the reference forests

We observed significant statistical differences in the abundance of individuals of exotic species between the sites of the managed forest (VN) and the reference forests (CZ, BT) for the upper (Kruskal Wallis $x^2 = 15.11$, $p = < 0.001$) and low stratum (Kruskal Wallis $x^2 = 12.62$, $p = 0.002$), but not for the middle stratum (Kruskal Wallis $x^2 = 3.80$, $p = 0.15$). The Wilcoxon post-hoc tests indicate that in the upper stratum the abundance of exotic species was greater in the Bosque de Tlalpan and in the Cerro de Zacatepetl than in Viaje a la Naturaleza (BT-CZ $p = 0.93$; BT-VN $p = 0.002$; CZ-VN $p = 0.01$). In the lower stratum, a greater abundance of exotic species was observed in the Bosque de Tlalpan than in Cerro de Zacatepetl and Viaje a la Naturaleza (BT-CZ $p = 0.05$; BT-VN $p = 0.002$; CZ-VN $p = 1$) (Fig. 2).

The species composition was different between the sites in all the strata evaluated (upper stratum: pseudo $F = 12.30$, $p = < 0.001$; middle stratum: pseudo $F = 4.58$,
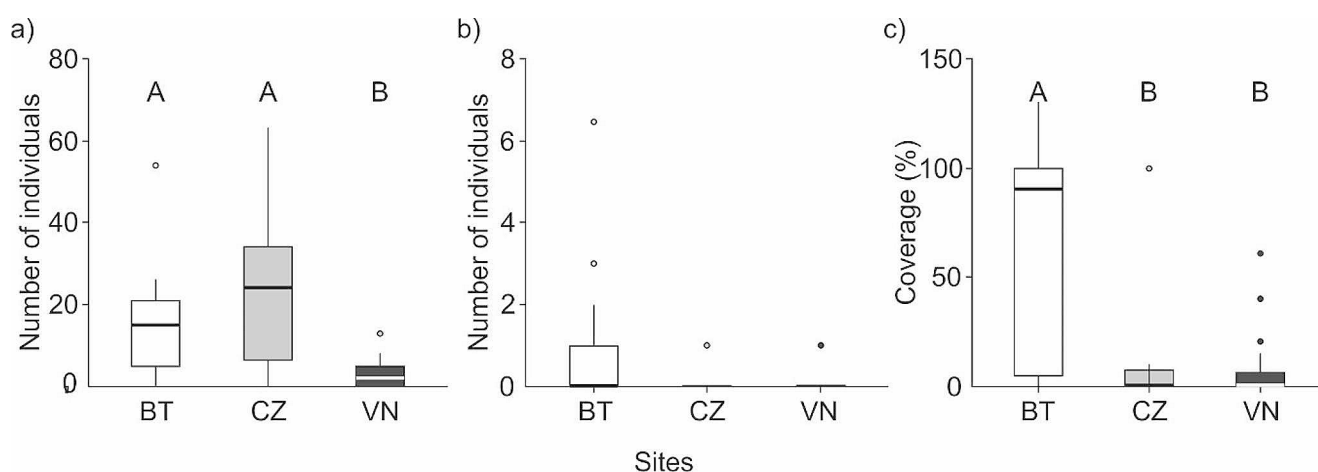
Fig. 2 Box and whisker plot of the abundance or cover of exotic species in each of the forests studied, (**a**) upper stratum (plot area 900 m^2), (**b**) middle stratum (plot area 25 m^2), (**c**) low stratum (plot area 1 m^2). Capital letters (A, B) indicate significant statistical differences between sites

$p = < 0.001$; low stratum: pseudo $F = 4.83$, $p = < 0.001$) (Fig. 3).

Temporal changes (Pre and post citizen intervention)

We observed differences in species composition before and after management, irrespective of the sampling season. We find that the cover of exotic species was lower in the second dry season (one year after management) than in the first (before management) (Friedman $x^2 = 8.89$, $p = < 0.01$). We did not observe differences were observed between the first (one year after management) and the second (two years after management) rainy season (Friedman $x^2 = 0.08$, $p = 0.78$) (Fig. 4).

The species composition was different between the first (before management) and second (one year after management) dry season (pseudo $F = 3.70$, $p = < 0.001$) and for the first (one year after management) and second (two years after handling) rainy season (pseudo $F = 7.18$, $p = < 0.001$) (Fig. 5).

Discussion

Citizen participation in the maintenance of areas with relict vegetation within urban areas is essential for the conservation of biodiversity in cities (Klaus and Kiehl 2021; Krasny et al. 2015; Standish et al. 2013). This study shows that activities such as the management of exotic species are important in the recovery/restoration tasks of
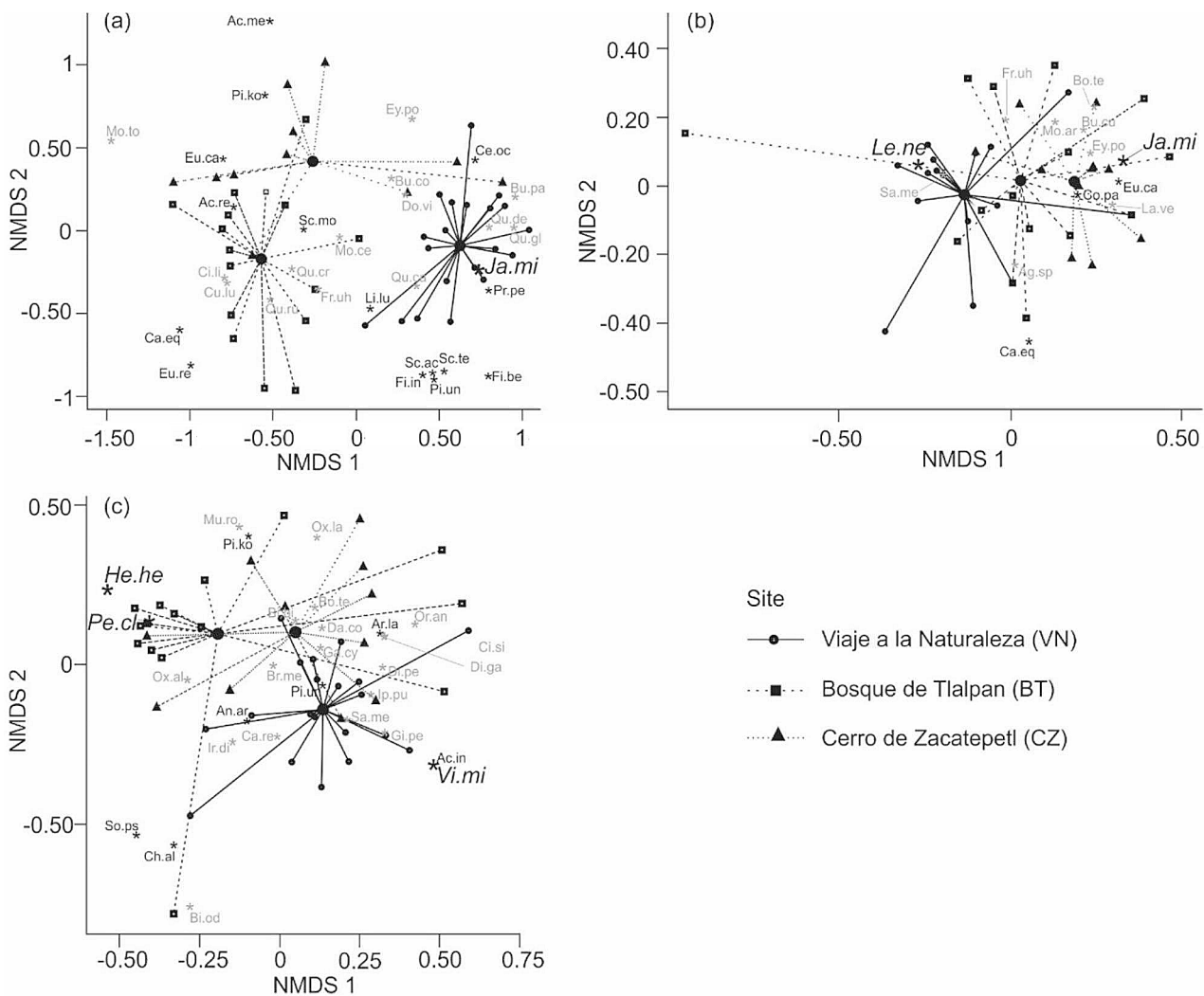
Fig. 3 Graph of the non-metric dimensional scaling analysis of the plant communities in the 3 forests for the (**a**) upper stratum, (**b**) middle stratum, and (**c**) low stratum. The location of the species in two-dimensional space is indicated with an asterisk, exotic ones in black and native ones in gray. Only native species that were observed at more than 3 sites and all exotic species are shown (abbreviations of names are found in Supplementary information). The bigger circles are the centroids
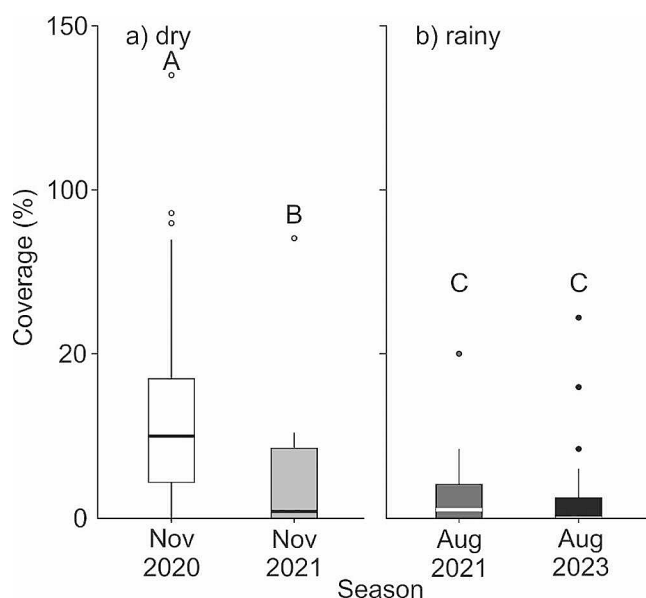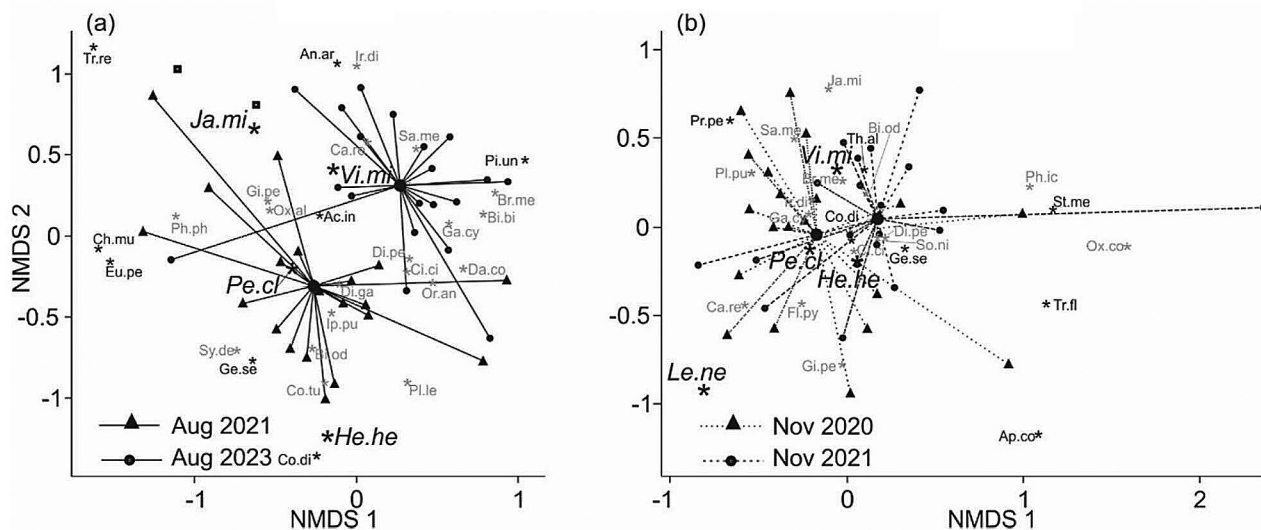
Fig. 4 Changes in the cover of exotic species in the lower stratum for different seasons in the forest with management (VN). The letters indicate significant statistical differences between the seasons (A, B, C)

as that of Dolan et al. (2015), have evaluated success for short periods of time and have found that the management of exotic species by residents of a green urban area in Indiana, United States, helped control an invasive exotic species (*Lonicera maackii*). The data obtained in our study demonstrate that in the managed forest sites (VN) the average cover of exotic species in the lower stratum was less than or equal to that of the reference forest sites (BT and CZ). Furthermore, the cover of exotic species decreased before and after management activities carried out by citizen, changing from 33.3% before the implementation of management activities to 7.5% after two and a half years of management. An example of the decrease in the cover of invasive exotic species over time that we quantified is in the case of *Pennisetum clandestinum*, which was more abundant before the management activities, as shown in the ordering analyses.

It is important to note that, despite the observed reduction in cover during the analysis period, management activities did not eliminate the presence of exotic species in the managed forest. This could be attributed to the dispersion of exotic species into the managed forest after the commencement of the work. This phenomenon was observed in the case of *Anagyris arvensis* and *Acalypha indica*, both exotic species recorded in 2023 but not in 2020 or 2021. The dispersal of exotic species towards urban green areas is a common process in cities (Dolan et al. 2015; Müller et al. 2013). In the area, the arrival of exotic species has been documented in green areas with no historical records of their presence 70 years ago (Castillo-Argüero et al. 2004). Additionally, the lower layer is

these spaces. In previous works, it has been found that recovery activities such as tree transplantation, propagule collection (Krasny et al. 2015), monitoring (Callaghan et al. 2019) and the identification of exotic species for management (Jordan et al. 2012) can be carried out successfully by citizens.

This study focuses on documenting that the removal of exotic species by citizens in urban green areas is successful over time and that this management generates changes in the composition of native species. Works such

Fig. 5 Graph of the non-metric dimensional scaling analysis of the lower stratum communities before management (Nov 2020) and after management (Nov 2021, Aug 2021, Aug 2023). (**a**) dry season, (**b**) rainy season. The location of the species in two-dimensional space is

indicated with an asterisk, exotic ones in black and native ones in gray. Only native species that were observed at more than 3 sites and all exotic species are shown (abbreviations of names are found in Supplementary information). The bigger circles are the centroids

highly susceptible to being occupied by exotic species. A study in urban forests on the northern Atlantic coast of the United States found that over time, different species could colonize these areas, and the lower stratum was the most vulnerable to the invasion of exotic plants (67% of recorded individuals were exotic species) (Bierzychudek 2020), both *A. arvensis* and *A. indica* belong to this stratum. This suggests that although management activities have effectively reduced the coverage of exotic species, the continuity of this trend in the long term is uncertain if management activities cease (Vidra et al. 2007).

Another relevant point to consider is the challenge of detecting inconspicuous or low-abundant exotic species by citizens involved in management activities. This was evident in the case of *Chenopodium murale*, *Geranium seemannii*, *Trifolium repens*, and *Stellaria media*, which were recorded in nearly all samplings since 2021. These species were not highly abundant or frequent in the samplings and typically do not exceed 20 cm in height (except for *C. murale*, which reaches 60 cm) (de Rzedowski and Rzedowski 2001). The difficulty in identifying inconspicuous species by citizens has been noted in previous studies, and it is likely that with greater citizen specialization in the detection of exotic species, rare or very small species can be accurately identified (Jordan et al. 2012).

The fact that complete elimination of exotic species from the managed forest has not been achievable, either due to propagule influx from other sites or the challenge of detecting inconspicuous exotic species, does not undermine the success of management activities. Similar reductions have been documented in management efforts by government authorities and scientific experiments, as evidenced by studies such as Bierzychudek 2020; Johnson and Handel 2016 and Vidra et al. 2007. For instance, a restoration project conducted in urban forests in New York reported a 50% coverage of three exotic plant species in the lower stratum. After 20 years of management, their coverage reduced to 7% (Johnson and Handel 2016). In our study, we observed that exotic species had a coverage of 33.3% before management, eight months after management (Aug-2021), it decreased to 10.4%, and two and a half years later (Aug-2023), it further diminished to 7.5%.

Regarding the contrasts in the composition between the managed forest (VN) and the reference forests (BT and CZ), the results show that the similarity in the composition of the upper and low stratum of some sites in the reference forests was higher with the managed forest sites than with the reference forest sites themselves. This result is given by two phenomena: (i) the greater similarity of some sites in the reference forests due to the presence of exotic species that were used in reforestations carried out in the middle of the last century (such as *Eucalyptus* spp. and *Acacia* spp.) (Rzedowski 1994). Furthermore, in the sites with reforestation, the dominance in the lower stratum of an invasive exotic grass species, *P.*

clandestinum, was observed, probably favored by the greater opening of the canopy that tree individuals of *Eucalyptus* spp. have. (Livesley et al. 2014) and by the allelopathic effect that these species have in the native plants of this stratum (Castillo-Argüero et al. 2004). And (ii) the greater similarity between some sites in the reference forests with the managed forest sites that were dominated by native species, such as *Quercus* spp. and *Eysenhardtia polystachya* in the upper stratum, and *Cissus sicyoides*, *Dicliptera peduncularis*, *Dioscorea galeottiana*, *Gaudichaudia cynanchoides* and *Salvia mexicana* in the lower stratum. All of these species had been recorded before the area was urbanized (Rzedowski 1994). All of the above indicates that the composition of the managed forest is similar to the sites with the highest degree of conservation of the reference forests.

The differences in composition between the different seasons of the managed forest indicated that the floristic composition changes both in the dry season and in the rainy season. These differences may be related to the decrease in the cover of exotic species such as *P. clandestinum* and *Hedera helix*, which were more abundant in the first seasons of both the dry (November 2020) and the rainy (August 2021). Additionally, ordination analyzes indicate that these differences are also related to changes in the cover of native species such as *Brachypodium mexicanum*, *C. cisyoides* and *G. cynanchoides*. These species had low cover before the management activities (November 2020), but for the subsequent sampling seasons (August 2021, November 2021 and August 2023) their cover increased significantly. The above indicates that in the managed forest not only did the cover of exotic species decrease, but also the cover of some native species increased.

Conclusion

Our findings demonstrate that citizen-led management significantly reduces the coverage of exotic species, and if sustained, this reduction persists over time. The management was effective for the most abundant exotic species, while for the less abundant or inconspicuous ones, it did not show the same effectiveness. Therefore, if the objective is to eliminate all exotic species, specialized support will be required, both in knowledge and resources. Based on this, it is recommended that citizens participate in the recovery efforts of relict forests and urban green areas, not only through the removal of exotic species. It is likely that citizens can support the propagation of native species, engage in soil improvement activities (e.g., generating compost), monitor pests, contribute to reforestation, and participate in environmental education activities. These activities should be planned through workshops and in collaboration with academic institutions and the government.

Declarations

Competing interests The authors declare no competing interests.

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