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Assessment of population structure and management of *Cordia dodecandra* A. DC. in homegardens and tropical forest in Yucatán, México

Evaluación de la estructura poblacional y el manejo de *Cordia dodecandra* A. DC. en huertos familiares y selva tropical en Yucatán, México

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Abstract

Cordia dodecandra A. DC. is an arboreal component of forests and Maya homegardens in the state of Yucatán, México. Changes in land use and landscape fragmentation have led to declines in wild populations. Understanding this species' population structure is relevant to determining the current state of its populations and proposing strategies for its conservation. The population structure of *C. dodecandra* in forest and homegardens in Yucatan, and the management practices associated with the species were documented with interviews. Relative importance of the tree species in the associated vegetation was estimated. Seedling density (< 1m of height) was higher in the homegardens than the forest with an evident decrease in the density of juvenile individuals caused by practices such as weeding. In contrast, the forest contained a greater number of adult and larger individuals than in the homegardens. Individual *C. dodecandra* were taller in the forest, but those in the homegardens had a larger diameter at breast height. Although it has multiple uses (e.g. food, ornamental, wood) the *C. dodecandra* in homegardens received only minimal maintenance, possibly threatening its permanence in this system. This is concerning since the homegardens function as de facto germplasm banks for this species.

Keywords
agroforestry • tropical tree conservation • multipurpose native species • germplasm reservoirs

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Resumen

Cordia dodecandra A. DC. es un componente arbóreo de las selvas y huertos familiares mayas en Yucatán, México, pero el cambio en el uso de la tierra y la fragmentación del paisaje han ocasionado que sus poblaciones disminuyan. Determinar la estructura poblacional de esta especie es relevante para conocer el estado actual de sus poblaciones y proponer estrategias para su conservación. Se registró su estructura poblacional en selva y huertos familiares del oriente de Yucatán y, con entrevistas semiestructuradas, se documentaron las prácticas de manejo que recibe. Se estimó el valor de importancia de todas las especies arbóreas de la vegetación asociada. La densidad de plántulas (<1m de altura) fue mayor en huertos familiares que en selva, con un decremento evidente en la densidad de juveniles ocasionado por prácticas como el deshierbe. Los huertos familiares pueden funcionar como bancos de germoplasma para esta especie. En contraste, en la selva se obtuvo un mayor número de adultos e individuos más altos, pero con menor crecimiento en diámetro. *C. dodecandra* es una especie nativa y multipropósito (alimenticia, ornamental, maderable), en los huertos familiares recibe mínimo manejo, siendo el principal el deshierbe, y esto puede afectar su permanencia en el sistema.

Palabras clave

agroforestería • conservación de árboles tropicales • especies nativas multipropósito • reservorios de germoplasma

Introduction

Population structure refers to the spatial (horizontal and vertical) and/or age-based arrangement of individuals in a species and helps to elucidate aspects of species abundance and density (44). This parameter allows objective description of a population to emit criteria on species state of conservation and interpret the events and interactions that gave rise to its populations (2, 15). Population structure studies provide essential data on the different stages of a species' life cycle, the effectiveness of different types of management, and the environmental limitations for development of populations of a plant community (15, 25, 30). For example, seedling and juvenile density and permanence are affected by soil fertility, light, water and microclimate (14). A vital step in understanding a species' population structure is characterizing the associated vegetation since this addresses elements such as the dynamics and associations that influence populations (47).

Studying population structure also helps to evaluate how plant populations are affected by human activities such as deforestation, agriculture and livestock production (1, 43). The eastern region of the state of Yucatán, México, is heavily used for livestock production, which has generated changes in land use, vegetation structure, and forest fragmentation (28).

Cordia dodecandra is a tree of the Boraginaceae family, native to the forests of Mesoamerica, and adapted to diverse environments and agroforestry systems. It is a multipurpose species that is used as an ornamental, and for wood, food and medicinal purposes (46). The National Forestry Council (CONAFOR) has classified *C. dodecandra* as a priority due to overexploitation and destruction of its ecosystem. One contributor to this process is vegetation fragmentation which diminishes and isolates its populations (3, 4, 33, 46). However, it is still frequent in traditional agroecosystems such as homegardens, in which it is considered a structural component (21, 31).

Some studies carried out with *C. dodecandra* are related to their growth in forest plantations (3, 33), ethnobotany (46), domestication syndrome (9) and others to agroforestry systems (4, 5, 37). However, studies on its population dynamics in natural and managed environments, that allow designing strategies for species recovery, are lacking.

In the Maya homegardens of Yucatán, plant species are managed to promote growth, propagation, conservation and production (27, 31, 32). Microclimate is controlled by modifying the tree canopy and ground cover to control moisture retention and soil organic matter content. This changes system productivity and even influences seed bank germination potential. On the other hand, in the forests *C. dodecandra* is not managed except when its fruits or wood are eventually harvested (5, 46).

Species population studies are important in developing strategies for their conservation and recovery in wild and managed environments (40). We hypothesize that in homegardens will found greater number of seedlings compare to forest, due to the differences in management conditions. The objective was to analyze *C. dodecandra* population structure in Maya homegardens and semi-evergreen tropical forest to estimate its populations' current status and identify differences between the two systems in terms of associated vegetation, size, density and management.

METHODS

Site description

The study area was within the municipality of Tizimín, in the east of Yucatán (21°12' N; 87°43' W). Climate is warm subhumid with summer rains, an average annual temperature of 24-26 °C, and annual rainfall of 800 to 1000 mm. Predominant soil types in the region are Luvisol and Leptosol (18). Nine homegardens within this municipality, were chosen, due to the low density and frequency in which adult tree of *C. dodecandra* are present. Only in one area of semi-evergreen tropical forest was possible to locate the presence of *C. dodecandra*.

Vegetation associated with *Cordia dodecandra*

Diversity in the vegetation associated with *C. dodecandra* was documented using non-probabilistic sampling implemented at convenience by selecting sites where adult *C. dodecandra* trees with fruit production were present. In the forest, twelve 10 x 10 m plots were laid out, each containing at least one *C. dodecandra* individual. Vegetation documentation was done from June to September 2017 by recording all trees with a ≥ 5 cm diameter at breast height (DBH) inside the plots (29). During the same period, a census was done of tree species (≥ 5 cm DBH) in the nine studied homegardens. Total sampled area was 1.2 ha in both the homegardens and forest. Height and DBH data were collected for everyone of each tree species, and these data used to calculate abundance, dominance and frequency as well as the plant Species Importance Value (SIV) (34).

***Cordia dodecandra* population structure**

Population structure was determined by measuring height, and DHB (diameter at the height of base for individuals smaller <5 cm diameter and <1.5 m height) or DBH for all *C. dodecandra* individuals. Five categories were established based on height and DHB, to allow comparison between the studied systems (table 1). Height was measured using a measuring tape or metric rod, and DBH with a diameter tape according to established techniques (7).

***Cordia dodecandra* management**

Nine semi-structured interviews were applied to identify management strategies and practices that provide *C. dodecandra*, the reasons that people expose to do such practices, as well as spaces where they spread and the uses, they give to each of its parts. The results of the interviews were captured in a database and analyzed to obtain frequencies of the management practices.

Data analysis

Richness of the vegetation associated with the studied *C. dodecandra* in homegardens and semi-evergreen tropical forest was estimated using the Shannon-Wiener diversity index (H'), while similarity was estimated using the Jaccard index. Both were run with the PAST ver. 3.1.6 statistics package. Spatial distribution of *C. dodecandra* in each of the environments was evaluated by calculating the Morisita index (24). An independence test was conducted to evaluate differences between the observed frequencies for the categories based on height and diameter data between forest and homegardens, and the Habberman test was conducted to detect the categories that depart significantly from the expected frequencies (8, 26).

Results

Vegetation associated with *Cordia dodecandra*

In the semi-evergreen tropical forest were identified 20 botanical families, 36 genera and 36 species. The best represented family was Fabaceae with nine species. The species *Bursera simaruba* (Burseraceae) and *Luehea speciosa* (Malvaceae) were the most abundant with seventeen recorded individuals each. In the homegardens were identified 27 botanical families, 50 genera and 66 species. Rutaceae was the best-represented family with ten species.

Table 1. Height/DBH categories established to analyze population structure of *C. dodecandra.*

Tabla 1. Categorías por altura y diámetro establecidas para analizar la estructura poblacional de *C. dodecandra.*

	Category 1	Category 2	Category 3	Category 4	Category 5
Height (m)	≤0.4	0.41-1.0	1.1- 4.0	4.1- 9.0	9.1≥
DBH (cm)	≤1.0*	1.1-10.0*	10.1-15.0	15.1-20.0	20.1≥

DBH = Diameter at Breast Height. / DAP = Diámetro a la Altura del Pecho.

* Values are DHB = Diameter at Height of Base. / Los valores son DAB = Diámetro a la Altura de la Base.

The genus *Citrus* (Rutaceae) was the best represented with six species and the most abundant species was *Citrus aurantium* with 38 individuals, followed by *Spondias purpurea* (Anacardiaceae) with 28.

Values for the SIV in the forest were highest for *C. dodecandra*, followed by *Vitex gaumeri* and *L. speciosa*. Convenience sampling caused *C. dodecandra* to have the highest frequency, density and dominance values (table 2). In the homegardens, SIV were highest for *Spondias purpurea* and *Citrus aurantium*; due to its basal area, *S. purpurea* was the dominant species. Its high density made *C. aurantium* the most abundant species, while *C. dodecandra* was the most frequent (table 3).

Table 2. Species Importance Value (SIV) for vegetation associated with *C. dodecandra* in semi-evergreen tropical forest in Yucatán, México.

Tabla 2. Valor de importancia de las especies asociadas a *C. dodecandra* en selva tropical sub-perenifolia de Tizimín, Yucatán, México.

Family	Species	Relative Dominance	Relative Density	Relative Frequency	SIV
Boraginaceae	*Cordia dodecandra*	21.24	12.92	10.81	44.97
Lamiaceae	*Vitex gaumeri*	19.12	7.86	6.30	33.29
Malvaceae	*Luehea speciosa*	9.477	9.55	6.30	25.33
Burseraceae	*Bursera simaruba*	7.57	9.55	7.21	24.33
Fabaceae	*Piscidia piscipula*	7.98	3.93	5.40	17.32
Malvaceae	*Hampea trilobata*	1.96	7.30	6.31	15.58
Remaining 30 species		32.63	48.87	39.64	139.15

Table 3. Species Importance Value (SIV) for vegetation associated with *C. dodecandra* in homegardens in Yucatán, México.

Tabla 3. Valor de importancia de las especies asociadas a *C. dodecandra* en huertos familiares de Yucatán, México.

Family	Species	Relative Dominance	Relative Density	Relative Frequency	SIV
Anacardiaceae	*Spondias purpurea*	14.94	8.46	4.67	28.07
Rutaceae	*Citrus aurantium*	8.45	11.48	4	23.93
Boraginacea	*Cordia dodecandra*	8.66	8.46	6	23.12
Meliaceae	*Cedrela odorata*	7.33	6.34	4.67	18.34
Sapindaceae	*Meliccocus bijugatus*	6.62	3.32	4	13.94
Remaining 61 species		43.08	51.36	63.99	192.43

Tree species diversity, as represented in the Shannon-Weiner index, and it was higher in the homegardens (H=3.574). The Jaccard similarity index showed low similarity between the two systems (j = 0.121; or 12%). They shared 12% of their species, or 13 of the 102 species recorded in both systems (table 4).

Cordia dodecandra population structure

There were 320 *C. dodecandra* individuals recorded, 40 of them were in the forest and 289 in the homegardens. Based on the Morisita index values (1.13 Iσ in forest; 1.75 Iσ in homegardens), *C. dodecandra* spatial distribution was aggregate in both systems.

Vertical structure varied (ji2 = 63.2; d. f.= 4; p=≤ 0.0001), among the size categories seedlings (category 1) were more frequent in homegardens than in the forest; while category 2 and category 5 were more frequent in the forest than those that were expected. The highest density in both systems was Category 1, although this was more evident in the homegardens (228 individuals) (figure 1, page 146). According to Haberman's standardized residuals, the categories that presented differences between them were 1 (1.96), 2 (1.86) and 5 (4.59).

In the same way, the diametric structure varied (ji 2 = 37.4; d. f.=4; p=≤ 0.0001), observing a greater number of individuals in the early stages of development (category 1). At higher diameters (Category 2 and up), the homegardens contained a higher number of larger diameter individuals than the forest (figure 2, page 146). According to Haberman's standardized residuals, the categories that presented differences between them were 1 (1.36), 2 (1.51) and 3 (2.77).

Cordia dodecandra management

The interviewees indicate that *C. dodecandra* had been in the homegardens for over 40 years (45%), that is, before the present owners occupied the land. Interviewees also said that it is uncommon to find more than two adult trees together, although in a smaller proportion (22%) more than eight individuals of *C. dodecandra* are maintained to market the fruit and wood.

Table 4. Species shared in homegardens and semi-evergreen tropical forest in Yucatán, México.

Tabla 4. Especies compartidas entre huertos familiares y selva tropical subperenifolia en Yucatán, México.

Family	Specie
Burseraceae	*Bursera simaruba*
Fabaceae	*Caesalpinia gaumeri*
Polygonaceae	*Coccoloba bardabensis*
Bixaceae	*Cochlospermum vitifolium*
Boraginaceae	*Cordia dodecandra*
Araliaceae	*Dendropanax arboreus*
Malvaceae	*Luehea speciosa*
Fabaceae	*Lysiloma latisiliquum*
Sapotaceae	*Manilkara zapota*
Sapindaceae	*Meliccocus oliviformis*
Fabaceae	*Piscidia piscipula*
Fabaceae	*Platymiscium yucatanum*
Lamiaceae	*Vitex gaumeri*

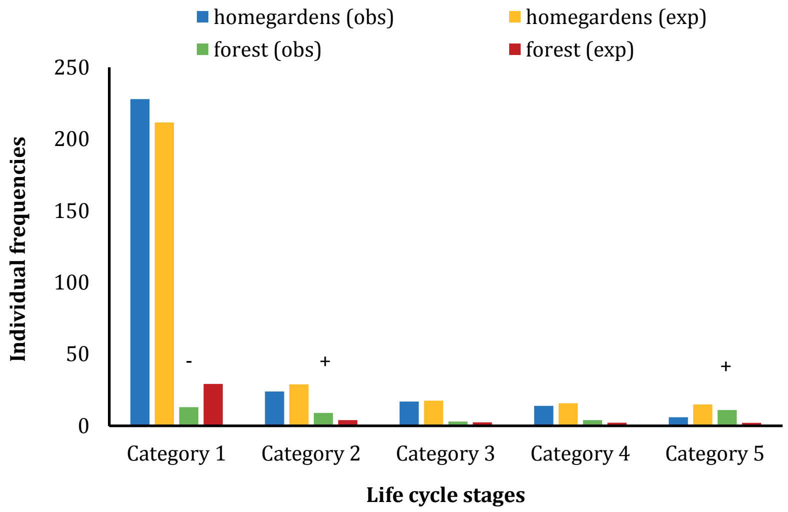

Figure 1. Observed and expected frequencies in the vertical structure of *Cordia dodecandra* individuals from homegardens and forest in Tizimin, Yucatán, México.

Figura 1. Frecuencias observadas y esperadas en la estructura vertical de *Cordia dodecandra* en huertos familiares y selva de Tizimin, Yucatán, México.

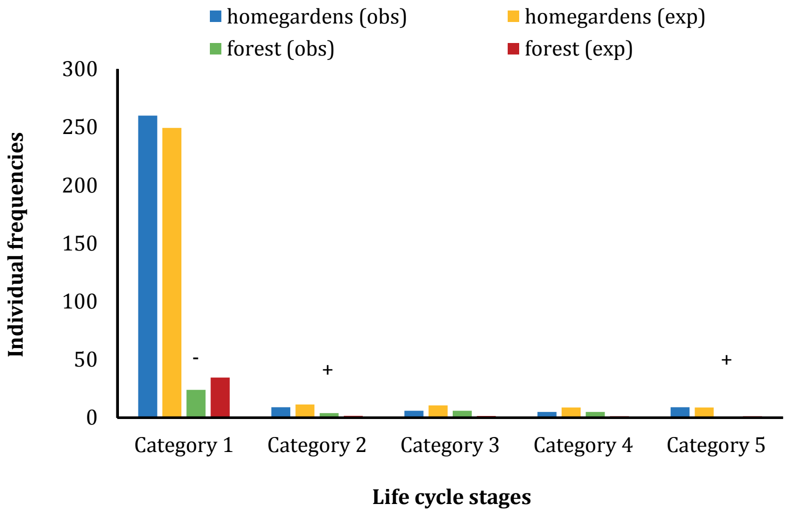

Figure 2. Observed and expected frequencies in the diameter structure of *Cordia dodecandra* individuals from homegardens and forest in Tizimin, Yucatán, México.

Figura 2. Frecuencias observadas y esperadas en la estructura del diámetro de *Cordia dodecandra* en huertos familiares y selva de Tizimin, Yucatán, México.

The main uses reported for *C. dodecandra* are fruit consumption (68%), use of the leaves as abrasive pads for cleaning (10%) and wood (10%). Pruning, irrigation and weeding were common maintenance practices in all homegardens, particularly for fruit trees. However, very little maintenance was given to *C. dodecandra* in the homegardens because the wood is extremely hard.

The interviewees (55%) knew that it is present in the forest, but it is increasingly scarce, and 89% said they did not harvest *C. dodecandra* wood from the forest. They do not collect fruit from wild individuals because the fruit is smaller in size and more sour.

Discussion

Vegetation associated with *Cordia dodecandra*

Tree species composition in the studied semi-evergreen tropical forest was similar to reported elsewhere for the same type of ecosystem on the Yucatán Peninsula (16, 38), with Fabaceae, Sapindaceae and Sapotaceae being the best represented families. The dominance of these families in the forest is linked to vegetation management by the Maya people for over a millennium (13); they selected for multi-purpose species that would provide year round resource availability (11).

Bursera simaruba, *Luehea speciosa*, *Vitex gaumeri* and *Piscidia piscipula* had the highest abundances, which coincides with previous studies in this ecosystem, where they are common (11, 47). The Shannon diversity index value for the studied forest was 3.09, which is considered low compared to previous reports for this forest type in Yucatán: 4.3 (47); 4.2 (16); and 4.3 (17).

In homegardens, Rutaceae had the highest species richness, because species in these families are selected for their economic and nutritional value (11, 13, 23, 35). The most abundant of tree species in homegardens were *S. purpurea*, *C. aurantium* and *C. dodecandra.* All three are highly valued for their fruit, but *C. dodecandra* is also appreciated for the ornamental value of its flowers, its leaves are useful abrasives in household cleaning and its wood is quite valuable and an important income source. However, this species requires over 30 years of growth before its wood is useful, putting it at a disadvantage compared to faster growing timber species such as *Swietenia macrophylla* and *Cedrela odorata* (4). One strategy used to optimize cultivation space while timber species reach productive sizes is to combine them with fast-growing species such as *Tamarindus indica, Bixa orellana* and *Leucaena leucocephala* (31, 41).

Recorded tree diversity in the studied homegardens was lower than other reports with species numbers between 60 and 230 (13, 23, 42). Home size and sampling strategy may explain some of this discrepancy since only plants with DBH ≥ 5 cm were included. However, the biodiversity recorded in the homegardens compares favorably to local forests, because dynamics such as nutrient recycling, erosion control, and micro-climate management, among others, promote the permanence of plant species that may be in a vulnerable state in their natural environment (12).

Species similarity between the homegardens and forest was low (12%). Shared tree species include *B. simaruba*, *P. piscipula* and *V. gaumeri,* all considered useful for wood and honey production (6); this implies that their coincidence in both systems is due largely to the economic benefits they offer (48). This low value coincides with previous reports of low similarity in this region: 15% (39) and 18% (13). Indeed, homegarden agroecosystems are sometimes called vegetation islands due to the stark differences in species diversity between them and the surrounding forest. Homegardens can supply one or more family needs (*e.g.* food, medicine, fodder, ornamentation) (36).

Cordia dodecandra spatial distribution was aggregate in both systems. In forests this pattern is attributable to causes such as low seed production, and competition with other species for resources such as light, which affects the number of branches, canopy size, and flower and fruit production (45). In addition, this species' fruit is large and heavy, causing it to hang low, and limiting dispersion since they fall near the parent plant, thus increasing plant number per area unit. Spatial distribution in the homegardens is a consequence of the species' reproductive strategy in combination with management practices. Interviewees stated that they collect fruit for consumption and that uncollected is left lying around the parent plant. They also observed that the main non-human consumers of the fruit are bats and domesticated animals such as chickens, goats and turkeys.

Vertical structure also differed between the systems. Forest individuals were taller, a trait shaped by dynamics such as competition for resources, especially light. *Cordia dodecandra* is not shade tolerant and so requires canopy clearings to reach maturity (46). This growth pattern is associated with light availability and has been observed in other tropical species such as *S. macrophylla* and *C. odorata*; light availability has been considered a precursor to development of this growth pattern (18). Basal area was greater in homegarden individuals, perhaps because the distance between trees in this system is greater than in the forest, which favors branch and diameter growth. This in turn can affect fruit production and the reproduction dynamic. In contrast, size in forest individuals would be limited by dynamics such space reduction due to deforestation of adjacent areas, which restricts tree species to smaller areas, leading to intra- and interspecies competition for resources, and generating differences in growth and development rates between individuals (19).

Differences between the homegardens and forest population structure (number of seedlings, juveniles and adults) are the consequence of several factors. Changing climate conditions have led to longer droughts or excessive rainfall in the forest, which lowers the number of seedlings. Most are located under or near the parent plant, leading to competition for resources such as light and water (45). Furthermore, herbivory by wild animals can increase the mortality in early stages (10). Conditions in the homegardens are much more conducive to *C. dodecandra* reproduction and development since resources are more available. The individuals of *C. dodecandra* in the homegardens were located near dwellings and different water sources, and the distance between trees was greater. This facilitates access to resources (*e.g.* water and light) which stimulates growth and development of plants in different stages.

The transition from seedling to juvenile and adult in the forest may be affected by factors such as space reduction and low seedling production. The homegardens, in contrast, are propitious for propagation of *C. dodecandra* since seed viability and microclimate conditions lead to high numbers of early stage seedlings.

However, practices such as raking and weeding lower the density of later stage individuals; this is necessary to maintain open areas for productive activities.

Considered a structural species in homegardens and quite frequent in these agroecosystems, cultivation of *C. dodecandra* by the Maya dates back over a thousand years (21, 27). This species is resistant to climate variations (46) and has thus formed part of the studied homegardens for decades. Interviewees referred to trees of 30 to 40 years of age, suggesting that they may have been present when the homegardens were established and were selected for by strategic clearing of the original vegetation. Though frequent in homegardens throughout the state of Yucatán (48), the long growth period of *C. dodecandra* has limited its uses to consumption of its fruit and its function as an ornamental, with little use made of its wood and leaves (21, 22). Non-native species such as *Bixa orellana*, *Citrus aurantium*, *Musa paradisiaca* and *Coco nucifera*, among others, are increasingly frequent in homegardens since they are profitable, useful, fast-growing and their products are widely used in local cuisine. This is another possible factor contributing to the displacement of *C. dodecandra* and other native species in the homegardens of Yucatán.

Since *C. dodecandra* is drought-resistant and native to the region it requires no watering, pruning or fertilizing to grow and produce, although pruning would improve trunk quality in individuals intended for wood production (4). This minimal required management, the species' easy adaptation to homegarden environments, high seedling (Category 1) propagation in this environment and the survival of adult individuals make this species ideal for homegarden use.

According to CONAFOR, *C. dodecandra* is in a vulnerable category (33), since its wild populations in the forests are increasingly scarce, for this reason homegardens are presented as a setting suitable for their conservation, due to that these agroecosystems are considered as germplasm reservoirs for the species. From homegardens we can obtain seedlings of *C. dodecandra* that are then reintroduced to their natural habitats.

Conclusions

Tree species diversity was lower in the semi-evergreen tropical forest than homegardens. The two systems also differed in terms of *Cordia dodecandra* population variables. Individuals were taller in the forest than in the homegardens, but they had a larger diameter in the homegardens. Population succession data showed adults dominated in the forest, which restricts the species' development in this system and interferes with its replacement and permanence. Seedlings were much more numerous in the homegardens although few reached adult stage due to weeding and pruning, which prevent further development. Although *C. dodecandra* is a structural species in homegardens, no management practices were identified aimed at promoting its growth and propagation. Its presence in this type of agroecosystem may therefore be more tenuous than previously believed. Management plans need to be promoted highlighting this native species' importance as a way of conserving its germplasm for subsequent reintroduction into the surrounding forests.

The results show that homegardens are environments conducive to the spread of *C. dodecandra*, in the eastern state of Yucatán, but due to size of homegardens, it is a slow growing species and decrease in the fruit consumption there are few producers who maintain the species in their homegardens. Similar studies are necessary in other environments where this species is distributed to design appropriate strategies for each of the regions where it is located. Studies on genetic diversity are also recommended to know whether or not management is causing changes at this level.

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