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BOTÁNICA

Diversity and use of trees and shrubs in smallholder farming systems in the Colombian Andes

Diversidad y uso de árboles y arbustos en sistemas de pequeña agricultura en los Andes colombianos

Néstor García[1*] | Juanita Peñaranda[1] | Natalia Sarmiento[1]

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ABSTRACT

This article describes the diversity and use of trees and shrubs in smallholder farming systems in three municipalities of the department of Boyacá in the Colombian Andes, and tests the relations between species richness, use, and a set of socio-economic and structural variables. We conducted ethnobotanical walks and semi-structured interviews on 24 farms to characterize all tree and shrub species. In total, we recorded 142 species with a predominance of natives (88) versus exotics (54). Species richness ranged between four and 40 (X = 25.17; SD = 10.13) per farm and was homogeneous among the municipalities ($P > 0.05$, Kruskal-Wallis test). We recorded 52 wild species, eight of them endemic, all representative of the surrounding native flora, of which 23 % had some type of use. Cultivated species were mostly represented by exotics that had been planted primarily as live fences, ornamentals, or edibles. Species richness was positively correlated with the size of the farms ($r_s = 0.664$, $P << 0.001$) and negatively with their proximity to areas with natural vegetation ($r_s = -0.515$, $P = 0.010$). Smallholder agriculture favors the establishment of trees and shrubs; we, therefore, stress the important role of these productive systems for the conservation of biodiversity in the Colombian Andes.

Keywords. Agroforestry, ethnobotany, family farming, home gardens, living fences

[1] Pontificia Universidad Javeriana, Departamento de Biología, Facultad de Ciencias, Bogotá, Colombia. nestor.garcia@javeriana.edu.co, juanita.penaranda@javeriana.edu.co, sarmiento.n@javeriana.edu.co
* Corresponding author

RESUMEN

Este artículo describe la diversidad y uso de árboles y arbustos en sistemas de pequeña agricultura en tres municipios del departamento de Boyacá en los Andes colombianos y analiza las relaciones entre la riqueza, el uso de las especies y un grupo de variables socioeconómicas y estructurales. Se realizaron caminatas etnobotánicas y entrevistas en 24 fincas para caracterizar todas las especies de árboles y arbustos. En total, se registraron 142 especies con predominio de las nativas (88) versus las exóticas (54). La riqueza de especies varió entre cuatro y 40 (X = 25,17; SD = 10,13) por finca y fue homogénea entre los municipios (P > 0,05, Kruskal-Wallis test). Se registraron 52 especies silvestres, ocho de ellas endémicas, todas representativas de la flora nativa circundante, de las cuales 23 % tienen algún tipo de uso. Las especies cultivadas estuvieron representadas principalmente por plantas exóticas sembradas, por lo general, como cercas vivas, ornamentales o comestibles. La riqueza de especies se correlacionó positivamente con el tamaño de las fincas (r_s = 0,664, P<< 0,001) y negativamente con la proximidad de las fincas a áreas con vegetación natural (r_s = -0,515, P = 0,010). La pequeña agricultura favorece el establecimiento de árboles y arbustos, por lo cual, se enfatiza el importante papel de estos sistemas productivos para la conservación de la biodiversidad en los Andes colombianos.

Palabras clave. Agricultura familiar, agroforestería, cercas vivas, etnobotánica, huertas familiares

INTRODUCTION

Although there is no unified concept around smallholder farming, these productive systems are generally considered to be characterized by two basic aspects: they depend almost exclusively on family labor and cover small areas (Ortiz *et al*. 2018). According to the different typologies for classifying smallholder agriculture, the farms tend to have less than two hectares, although some can reach up to five hectares (Salcedo *et al*. 2014, Graeub *et al*. 2016, Ortiz *et al*. 2018). Another aspect that characterizes smallholder farms is their lower environmental impact compared to large commercial systems (Ortiz *et al*. 2018). Increasing evidence shows that smallholder farming is environmentally friendly because it reduces commercial inputs, soil, and water, and increases biodiversity (Webb and Kabir 2009, Vieira and Van Wambeke 2014, Nicholls *et al*. 2016, Ortiz *et al*. 2018).

Smallholder farms retain scattered tree cover in spaces such as home gardens, living fences or relics of native vegetation (Garen *et al*. 2011). In these systems, trees have various functions including the provision of basic resources for the livelihoods of families such as food, construction materials, or medicines (Garen *et al*. 2011). Trees also contribute to increasing connectivity for other organisms such as insects or birds (Bhagwat *et al*. 2008) or to generate favorable conditions for the establishment of herbs, vines or epiphytes (Haro-Carrión *et al*. 2009, DaRocha *et al*. 2016). Trees can increase the productivity of agricultural systems as they contribute to the redistribution of nutrients and an association with fungi and bacteria by improving soil conditions (Altieri 1995). Likewise, trees regulate the surface temperature of the soil by reducing solar radiation and improve conditions of humidity by intercepting and redistributing rainfall (Altieri 1995).

The diversity of trees in smallholder farms depends on the remaining natural vegetation, the structural characteristics of the farms, and the socio-economic conditions of the owners (Rooduijn *et al*. 2018). The proportion of native and exotic species can vary according to the location and purpose of the production system; farms further away from urban centers whose purpose is family livelihood tend to have a greater proportion of native arboreal species. In contrast, farms close to urban centers tend to have less tree diversity with a predominance of exotic species (Pinto Rayol *et al*. 2017). Most of the native wild species can disperse naturally into the productive areas due to their proximity to the surrounding natural vegetation, but their abundance depends on the structure of the farms and on the socio-economic conditions of the owners (Rooduijn *et al.* 2018). This type of agricultural system can conserve even endemic or endangered species (Kabir and Webb 2008, Salako *et al.* 2014, Rooduijn *et al.* 2018). Often the richness of native species may be greater, but exotic species tend to be more abundant (Thijs *et al.* 2015)

One of the principals uses of tree species in smallholder farms is for food, mainly fruits (Pulido *et al.* 2008, Garen *et al.* 2011, Thijs *et al.* 2015, Pinto Rayol *et al.* 2017). Other uses include the production of wood and firewood, living fences, medicines, as shade or as ornamentals (Pulido *et al.* 2008, Garen *et al.* 2011, Abebe *et al.* 2013, Thijs *et al.* 2015, Pinto Rayol *et al.* 2017). Products derived from trees may be used for domestic consumption or commercialized, depending on the socio-economic conditions of the families (Thijs *et al.* 2015).

The central altiplano of the department of Boyacá is one of several farming belts in Colombia. In this region, part of the food production and rural employment is generated in smallholder farming systems where small-scale production for the families´ livelihood predominates (Cadavid 2013, Sánchez 2018). The landscape of this region has a matrix that is fundamentally composed of agriculture and livestock with small remnants of natural vegetation (Sánchez 2018). Most of the native trees are dispersed throughout the farms, growing together with a great variety of exotic species. This floristic diversity is constantly modified by the farmers, who carry out practices that favor the establishment and conservation of trees (Sánchez 2018).

Here we assess the diversity and use of tree and shrub species present in smallholder farming systems located in the central altiplano of Boyacá, in the Colombian Andes. To better understand the role of smallholders in the conservation and use of arboreal vegetation, the following research questions were addressed: What species of trees and shrubs are present in the farms? How the richness and use of exotic and native species vary? What socio-economic traits of the families and physical aspects of the farms correlate with species richness?

MATERIAL AND METHODS

Study Area

The research was conducted during 2017 in the municipalities of Ventaquemada (5° 22’ 20” North - 73° 31’ 22” West), Turmequé (5° 19’ 26” North - 73° 29’ 26” West) and Tibasosa (5° 44’ 46” North - 73° 00’ 04” West), located in the central altiplano of the department of Boyacá, Eastern Cordillera of the Colombian Andes (Fig. 1). The climate is temperate according to the Köppen classification, with an

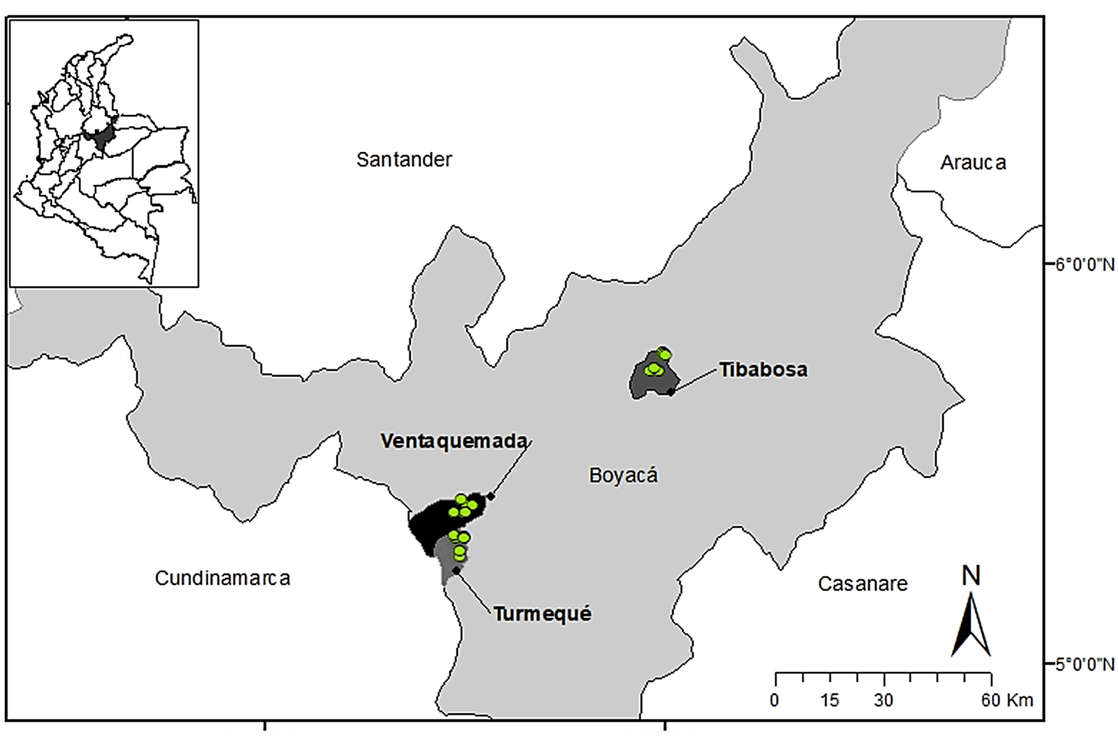

Figure 1. Location of the municipalities and farms studied (in green).

average annual temperature of 14.6 °C and an average annual rainfall of 939 mm (climate-data.org). The farms surveyed in this study are distributed between 2380 and 3050 m altitude, which corresponds to Montane humid forest (Holdridge 1987) with a predominance of the plant families Asteraceae, Melastomataceae, Rosaceae, and Poaceae.

Agriculture and livestock production are the main economic activities of this region. Some of the most commonly cultivated species are corn (*Zea mays* L.), *cubios* (*Tropaeolum tuberosum* Ruiz & Pav.), squash (*Cucurbita pepo* L.), potatoes (*Solanum tuberosum* L.), *papayuela* (*Vasconcellea pubescens* A.DC.), broad beans (*Vicia faba* L.), *arracacha* (*Arracacia xanthorrhiza* Bancr.), peach (*Prunus persica* (L.) Batsch), and beans (*Phaseolus vulgaris* L.) (Sánchez 2018). These agricultural systems have gone through a historical transformation. According to Sánchez (2018), during the 1960s traditional agricultural systems used native seeds and organic inputs. But in the mid-1970s the implementation of a commercial production model increased the use of agrochemicals and machinery, promoting the elimination of native forests to expand the agricultural frontier. At this time, reforestation activities were also promoted using exotic tree species such as pine (*Pinus patula* Schiede ex Schltdl. & Cham.), eucalyptus (*Eucalyptus globulus* Labill.) and acacia (*Acacia melanoxylon* R.Br.). These conditions lasted for a few decades; however, farmers began to see a significant decrease in their natural resources vital for food production. This situation marked the current trend of conversion to family smallholder systems, adopting more environmentally friendly practices. Nowadays, farmers prefer to use organic inputs, as well as soil and water conservation practices, planting trees as living fences or conserving natural vegetation relics (Sánchez 2018).

Data collection

The selection of the smallholder farms was carried out during three workshops with the community, one in each municipality. Members of various community organizations participated in these workshops. In each municipality, eight farms were chosen, for a total of 24 in the study. For their selection, the following was considered: that the family had only one property; that the farm owner was a member of the family group; and that agricultural activities contributed to the family incomes.

To characterize socio-economic traits of the families and physical aspects of the farms, semi-structured interviews were conducted with the farm owners. Variables that were taken into account for the analysis were the following: owner´s age and schooling, household members working at the farm, farm's age (owner tenure time), area, distance to natural vegetation and distance to the closest urban center. Aspects of farm management such as the implementation of polycultures or reforestation activities were also documented.

Through the technique of ethnobotanical walks (Martín 2001), tree species were located and questionnaires were applied to record each species, its growth habit (shrub or tree), use and management category (wild or cultivated), and the area of the farm where it was located. Three categories were defined to classify areas within each farm: (1) the production areas (includes the garden, the cultivation and grazing areas); (2) living fences; and (3) areas with wild vegetation (includes forest relics, thickets, and creek edges). Uses were classified into seven categories following Pérez and Matiz-Guerra (2017): (1) agroecological (includes use as living fences); (2) food; (3) environmental (includes uses for protection of water sources); (4) handicrafts; (5) construction; (6) medicinal; and (7) ornamental.

The species were preliminarily identified in the field and botanical samples were collected for complete identification in the Herbarium of the Pontificia Universidad Javeriana (HPUJ). The nomenclature of the species and the information on their origin (native or exotic) was based on the Catálogo de Plantas y Líquenes de Colombia (Bernal *et al.* c2019).

Kruskal-Wallis tests were used to compare species richness, and farm size and altitude between the three municipalities. Correlations between species richness and owner's age and schooling (from the most basic to the most advanced, primary, secondary and technical), household members working at the farm, farm age and area, distance to the natural vegetation relicts, and distance to the closest urban center were assessed using Spearman's rank correlation coefficient.

RESULTS

Structure of households and farms studied

The size of the farms ranged from 0.02 to 8 ha (X = 1.96; SD = 1.86) (Table 1). Both the size and altitude at which the farms were located did not vary among the three municipalities ($P > 0.05$, Kruskal-Wallis test). The distance of the farms to the closest urban center ranged between 0.92 and 6.96 km (X = 3.45; SD = 1.61). Polycultures were planted in 23 farms, and in twelve farms there were areas with natural vegetation or the perimeter of the farm bordered areas with natural vegetation, such as forest relics or riverine vegetation. The distance of the farms to the natural vegetation varied between 0.01 to 1.21 km (X = 0.36; SD = 0.39).

Farm owners´ ages ranged from 28 to 72 years (X = 54.63; SD = 12.24) (Table 1). The families were composed of three to nine members, but only between one and five participated in the farm work. The level of schooling was variable: half of the owners had only primary education, while three had not studied and nine had secondary, technical, or professional education (Table 1). The families lived between 5 and 33 years on the farms. The majority (79 %) of the owners dedicated all their work time to the farm.

Tree and shrub richness and composition

In total, 142 species of trees and shrubs were identified (Table 2). The plant family with the greatest richness was Asteraceae (17 species), followed by Solanaceae (eleven species), Fabaceae and Rosaceae (nine species each), Myrtaceae (eight species), Melastomataceae

Table 1. Characteristics of households and farms surveyed in the central altiplano of Boyacá, Colombia.

Farm	Municipality	Species richness	Farm area (ha)	Owner's age (years)	Owner's schooling	Farm age (years)	Family members working on farm	Farm distance to urban center (km)	Farm distance to natural vegetation (km)
1	Ventaquemada	35	0.96	61	Universitary	13	3	2.57	0.66
2	Ventaquemada	30	1.6	63	None	40	2	1.13	0.01
3	Ventaquemada	17	3	49	Technical	15	2	4.16	0.61
4	Ventaquemada	13	0.32	48	Primary	22	2	2.34	0.77
5	Ventaquemada	25	1	60	Technical	6	3	5.43	0.56
6	Ventaquemada	19	0.64	68	Primary	-	1	6.73	0.01
7	Ventaquemada	12	0.32	32	Secundary	32	4	2.42	0.67
8	Ventaquemada	36	2	32	Secundary	32	3	2.68	0.4
9	Turmequé	35	2.5	70	Primary	68	3	0.92	0.18
10	Turmequé	19	3	65	None	65	4	6.96	0.04
11	Turmequé	33	2.5	40	Technical	40	4	5.48	0.05
12	Turmequé	34	3	60	None	60	5	3.89	0.27
13	Turmequé	38	4	55	Technical	55	5	3.99	0.07
14	Turmequé	26	1.64	28	Technical	28	4	2.02	0.15
15	Turmequé	29	1.92	52	Technical	20	2	1.88	0.01
16	Turmequé	25	2	68	Primary	47	2	1.45	0.08
17	Tibasosa	34	8	55	Primary	33	3	4.61	0.01
18	Tibasosa	13	0.16	49	Primary	25	2	3.86	1.09
19	Tibasosa	4	0.02	72	Primary	5	1	3.85	1.1
20	Tibasosa	21	1.2	49	Primary	49	5	2.58	0.01
21	Tibasosa	17	0.12	62	Primary	62	2	4.19	0.55
22	Tibasosa	13	0.7	51	Secundary	50	1	3.72	1.21
23	Tibasosa	40	5.5	65	Primary	65	1	3.37	0.01
24	Tibasosa	36	0.9	57	Primary	8	1	2.55	0.21
Mean/mode		25.2	2.0	54.6	Primary	36.5	2.7	3.4	0.4
SD		10.1	1.9	12.2		21.3	1.3	1.6	0.4

(seven species), Verbenaceae (five species), and Ericaceae, Malvaceae and Rutaceae (four species each). The most species-rich genera were *Baccharis* and *Solanum* with four species each, and *Citrus*, *Fuchsia*, *Miconia*, *Prunus* and *Syzygium* with three species each.

The number of tree and shrub species per farm ranged between four and 40 (X = 25.17; SD = 10.13) (Table 1). Species richness was homogeneous among the farms of the three municipalities (P > 0.05, Kruskal-Wallis test). The most frequent species in the farms were *Sambucus nigra* L. and *Vasconcellea pubescens*, which were recorded from 18 farms, *Eucalyptus globulus* and *Fuchsia boliviana* Carrière in 17 farms, *Acca sellowiana* (O.Berg) Burret in 16 farms, *Prunus persica* in fifteen farms and *Solanum betaceum* Cav. in thirteen farms (Table 2). In general, these are species used for their edible fruits or as living fences. In contrast, about 48 % of the species (68) were registered only once or twice in the smallholder farms.

Most of the species documented on the farms were shrubs (68), 60 were trees, and fourteen were recognized as trees or shrubs. Most of the species were native (88), of which eight were endemic to Colombia (Table 2); 54 species were introduced from other regions of the world. Likewise, most species were cultivated (75), 52 were wild and fifteen species were wild or sometimes cultivated. The most frequent wild species were *Oreopanax incises* (Schult.) Decne. & Planch., *Miconia squamulosa* Triana, *Myrsine guianensis* (Aubl.) Kuntze, and *Monnina aestuans* (L.f.) DC., while the most frequently cultivated species were *Vasconcellea pubescens, Eucalyptus globulus, Acca sellowiana*, and *Prunus persica*. Some of the species that are both wild and cultivated on farms were *Sambucus nigra, Alnus acuminata* Kunth*, Myrcianthes leucoxyla* (Ortega) McVaugh and *Fuchsia boliviana* (Table 2).

The distribution of these species in the farms was as follows: 117 species were found in productive areas – that is, in home gardens, cultivated areas or scattered among pastures –, 70 of which are native. We also found 54 species in living fences, 39 of which are native, and 43 species in the unmodified original vegetation stands that are present on some of the farms, 41 of which are native.

We documented the use of 96 species which were classified into seven categories. Ninety-eight percent of cultivated species and 23 % of wild species had at least one use; no uses were reported for two cultivated species. The most frequent use category was Agroecological since 39 species were used as living fences, including *Sambucus nigra, Eucalyptus globulus, Alnus acuminata*, and *Fuchsia magellanica* Lam. We found 37 species with ornamental uses; the most frequent were *Sambucus nigra, Fuchsia boliviana, Fuchsia magellanica*, and *Pittosporum undulatum* Vent. We recorded 29 species used as foods, especially fruits; the most frequent were *Vasconcellea pubescens, Acca sellowiana, Fuchsia boliviana, Prunus persica*, and *Solanum betaceum*. Fifteen species were registered as medicinal, of which the most frequently used were *Sambucus nigra, Smallanthus sonchifolius* (Poepp.) H.Rob.*, Cupressus lusitanica* Mill.*, Rosmarinus officinalis* L.*, Eucalyptus globulus* and *Aloysia citriodora* Palau. Only two species (*Miconia squamulosa* and *Myrsine guianensis*) were used for construction, other two species (*Escallonia paniculata* (Ruiz & Pav.) Schult. and *Abatia parviflora* Ruiz & Pav.) were used for environmental purposes, and only *Erythrina rubrinervia* Kunth was used to make handicrafts (Table 2).

Socio-economic and agroecological factors and species richness

A positive correlation was found between species richness and farm size (r_s = 0.664, P << 0.001) and a negative correlation between species richness and distance to areas of natural vegetation (r_s = -0.515, P = 0.01). As for the other socioeconomic and structural variables, no correlation was found in relation to species richness.

DISCUSSION

Diversity

The results show an important diversity of tree species associated with smallholder farms. In these spaces, wild native species converge with native or exotic species planted by the owners. Wild species correspond to elements of the original vegetation that were not destroyed or to new elements that have arrived through natural dispersal. It has been documented that smallholder farms can act as sinks for wild species (Rooduijn *et al.* 2018). Plants dispersed by wind or birds and with a high tolerance for solar radiation can be successful in these types of transformed environments (Thijs *et al.* 2015). These traits likely explain the occurrence of species of the Asteraceae, Ericaceae or Melastomataceae families among the wild plants of the farms.

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Adoxaceae					
Sambucus nigra L.	Shrub / Tree	Exotic	Cultivated / Wild	Agr,Med, Orn	18 (0.75)
Viburnum tinoides L.f.	Shrub / Tree	Native	Wild		3 (0.13)
Viburnum triphyllum Benth.	Shrub / Tree	Native	Cultivated / Wild	Agr,Orn	5 (0.21)
Anacardiaceae					
Mangifera indica L.	Tree	Exotic	Cultivated	Food	1 (0.04)
Schinus molle L.	Tree	Exotic	Cultivated	Orn	1 (0.04)
Toxicodendron striatum (Ruiz & Pav.) Kuntze	Tree	Native	Wild		2 (0.08)
Annonaceae					
Annona cherimola Mill.	Tree	Native	Cultivated	Food	5 (0.21)
Araliaceae					
Oreopanax incisus (Schult.) Decne. & Planch.	Tree	Native	Wild		7 (0.29)
Schefflera actinophylla (Endl.) Harms	Tree	Exotic	Cultivated	Agr	1 (0.04)
Schefflera arboricola (Hayata) Merr.	Shrub	Exotic	Cultivated	Orn	2 (0.08)
Asparagaceae					
Yucca gigantea Lem.	Tree	Exotic	Cultivated	Orn	3 (0.13)
Asteraceae					
Alloispermum pachensis (Hieron.) H.Rob.	Shrub	Native	Wild		1 (0.04)
Baccharis bogotensis Kunth	Shrub	Native*	Wild		2 (0.08)
Baccharis latifolia (Ruiz & Pav.) Pers.	Shrub	Native	Wild	Agr	2 (0.08)
Baccharis prunifolia Kunth	Shrub	Native	Wild		2 (0.08)
Baccharis tricuneata (L.f.) Pers.	Shrub	Native	Wild		3 (0.13)
Barnadesia spinosa L.f.	Shrub	Native	Wild		3 (0.13)
Chromolaena sp.1	Shrub	Native	Wild		1 (0.04)
Chromolaena sp.2	Shrub	Native	Wild		2 (0.08)
Diplostephium rosmarinifolium (Benth.) Wedd.	Tree	Native	Wild		1 (0.04)
Montanoa ovalifolia DC.	Shrub / Tree	Native	Wild		2 (0.08)
Montanoa quadrangularis Sch.Bip.	Shrub / Tree	Native	Cultivated	Agr	2 (0.08)
Munnozia senecionidis Benth.	Shrub	Native	Wild		1 (0.04)
Smallanthus pyramidalis (Triana) H.Rob.	Tree	Native	Cultivated / Wild	Agr	2 (0.08)
Smallanthus sonchifolius (Poepp.) H.Rob.	Shrub	Native	Cultivated	Food,Med	9 (0.38)
Stevia lucida Lag.	Shrub	Native	Wild		2 (0.08)
Tithonia diversifolia (Hemsl.) A.Gray	Shrub	Exotic	Cultivated	Agr,Orn	2 (0.08)
Verbesina sp.	Tree	Native	Wild		1 (0.04)

(*Continued*)

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Berberidaceae					
Berberis glauca Kunth	Shrub	Native	Wild		2 (0.08)
Berberis rigidifolia Kunth	Shrub	Native*	Wild		2 (0.08)
Betulaceae					
Alnus acuminata Kunth	Tree	Native	Cultivated / Wild	Agr	11 (0.46)
Bignoniaceae					
Tecoma capensis (Thunb.) Lindl.	Shrub	Exotic	Cultivated	Orn	1 (0.04)
Tecoma stans (L.) Kunth	Shrub / Tree	Native	Cultivated	Agr	1 (0.04)
Boraginaceae					
Cordia cylindrostachya (Ruiz & Pav.) Roem. & Schult.	Tree	Native	Wild		4 (0.17)
Tournefortia polystachya Ruiz & Pav.	Tree	Native	Wild	Med	1 (0.04)
Cactaceae					
Opuntia sp.	Shrub	Native	Cultivated / Wild	Orn	3 (0.13)
Campanulaceae					
Siphocampylus sp.	Shrub	Native	Wild		1 (0.04)
Caricaceae					
Vasconcellea pubescens A.DC.	Shrub	Native	Cultivated	Food	18 (0.75)
Clusiaceae					
Clusia multiflora Kunth	Tree	Native	Wild		1 (0.04)
Clusia sp.	Shrub / Tree	Native	Cultivated	Agr, Orn	2 (0.08)
Cunoniaceae					
Weinmannia tomentosa L.f.	Tree	Native	Wild		4 (0.17)
Cupressaceae					
Cupressus lusitanica Mill.	Tree	Exotic	Cultivated	Med	9 (0.38)
Elaeocarpaceae					
Vallea stipularis L.f.	Shrub	Native	Cultivated / Wild	Orn	7 (0.29)
Ericaceae					
Cavendishia bracteata (J.St.Hil.) Hoerold	Shrub	Native	Wild		1 (0.04)
Gaultheria sp.	Shrub	Native	Wild		2 (0.08)
Gaultheria myrsinoides Kunth	Shrub	Native	Wild		3 (0.13)
Macleania rupestris (Kunth) A.C.Sm.	Shrub	Native	Wild		2 (0.08)
Escalloniaceae					
Escallonia paniculata (Ruiz & Pav.) Schult.	Tree	Native	Cultivated	Env	2 (0.08)
Escallonia pendula (Ruiz & Pav.) Pers.	Tree	Native	Cultivated	Agr	3 (0.13)

(Continued)

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Euphorbiaceae					
Croton pungens Jacq.	Tree	Native	Wild		2 (0.08)
Euphorbia pulcherrima Klotzsch	Shrub	Exotic	Cultivated	Agr, Orn	2 (0.08)
Ricinus communis L.	Shrub	Exotic	Cultivated / Wild	Agr, Med	3 (0.13)
Fabaceae					
Acacia melanoxylon R.Br.	Tree	Exotic	Cultivated / Wild	Med	7 (0.29)
Caesalpinia spinosa (Molina) Kuntze	Tree	Native	Cultivated	Med	2 (0.08)
Crotalaria agatiflora Schweinf.	Shrub	Native	Cultivated	Orn	1 (0.04)
Dalea cf. *cuatrecasasii* Barneby	Shrub	Native	Wild		3 (0.13)
Erythrina edulis Micheli	Tree	Native	Cultivated	Food	1 (0.04)
Erythrina rubrinervia Kunth	Tree	Native	Wild	Han	1 (0.04)
Inga cf. *cayennensis* Benth.	Tree	Native	Cultivated / Wild	Agr, Food	2 (0.08)
Senna multiglandulosa (Jacq.) H.S.Irwin & Barneby	Shrub / Tree	Native	Cultivated		1 (0.04)
Senna viarum (Little) H.S.Irwin & Barneby	Tree	Native	Cultivated	Agr	4 (0.17)
Quercus humboldtii Bonpl.	Tree	Native	Cultivated / Wild	Agr	5 (0.21)
Hypericaceae					
Hypericum strictum Kunth	Shrub	Native*	Wild		1 (0.04)
Juglandaceae					
Juglans neotropica Diels	Tree	Native	Cultivated / Wild	Orn	4 (0.17)
Lamiaceae					
Rosmarinus officinalis L.	Shrub	Exotic	Cultivated	Food, Med	9 (0.38)
Lauraceae					
Laurus nobilis L.	Tree	Exotic	Cultivated	Food	7 (0.29)
Persea americana Mill.	Shrub	Exotic	Cultivated	Food	4 (0.17)
Loranthaceae					
Gaiadendron punctatum (Ruiz & Pav.) G.Don	Shrub / Tree	Native	Wild		1 (0.04)
Lythraceae					
***Cuphea dipetala* (L.f.) Koehne**	Shrub	Native*	Wild		4 (0.17)
Lafoensia acuminata (Ruiz & Pav.) DC.	Tree	Native	Cultivated	Agr, Orn	4 (0.17)
Malvaceae					
Abutilon megapotamicum (A.Spreng.) A.St.-Hil. & Naudin	Shrub	Exotic	Cultivated	Orn	1 (0.04)
Abutilon pictum (Gillies ex Hook.) Walp.	Shrub	Exotic	Cultivated	Orn	6 (0.25)

(Continued)

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Hibiscus mutabilis L.	Shrub	Exotic	Cultivated	Orn	1 (0.04)
Hibiscus rosa-sinensis L.	Shrub	Exotic	Cultivated	Orn	2 (0.08)
Melastomataceae					
Bucquetia glutinosa (L.f.) DC.	Shrub	Native*	Wild		3 (0.13)
Miconia aff. *cundinamarcensis* Wurdack	Tree	Native*	Wild		3 (0.13)
Miconia sp.	Shrub / Tree	Native	Wild		2 (0.08)
Miconia squamulosa Triana	Shrub / Tree	Native	Wild	Con	10 (0.42)
Monochaetum myrtoideum Naudin	Shrub	Native	Wild		1 (0.04)
***Tibouchina grossa* (L.f.) Cogn.**	Shrub	Native	Wild		4 (0.17)
Tibouchina urvilleana (DC.) Cogn.	Shrub	Exotic	Cultivated	Orn	1 (0.04)
Meliaceae					
Cedrela montana Turcz.	Tree	Native	Cultivated	Agr, Orn	8 (0.33)
Moraceae					
Ficus carica L.	Tree	Exotic	Cultivated	Food	6 (0.25)
Myricaceae					
Morella parvifolia (Benth.) Parra-Os.	Shrub	Native	Wild	Food	3 (0.13)
Myrtaceae					
Acca sellowiana (O.Berg) Burret	Shrub	Exotic	Cultivated	Food	16 (0.67)
Callistemon speciosus (Sims) Sweet	Tree	Exotic	Cultivated	Agr	2 (0.08)
Eucalyptus globulus Labill.	Tree	Exotic	Cultivated	Agr, Med	17 (0.71)
Myrcianthes leucoxyla (Ortega) McVaugh	Tree	Native	Cultivated / Wild	Agr	10 (0.42)
Psidium guajava L.	Tree	Exotic	Cultivated	Food, Orn	5 (0.21)
Syzygium jambos (L.) Alston	Tree	Exotic	Cultivated	Food	1 (0.04)
Syzygium paniculatum Gaertn.	Tree	Exotic	Cultivated	Agr, Orn	7 (0.29)
Syzygium malaccense (L.) Merr. & L.M.Perry	Tree	Exotic	Cultivated	Food	1 (0.04)
Nyctaginaceae					
Bougainvillea glabra Choisy	Shrub	Exotic	Cultivated	Orn	5 (0.21)
Oleaceae					
Fraxinus chinensis Roxb.	Tree	Exotic	Cultivated		1 (0.04)
Ligustrum japonicum Thunb.	Shrub / Tree	Exotic	Cultivated	Agr	1 (0.04)
Olea europaea L.	Tree	Exotic	Cultivated	Food	1 (0.04)
Onagraceae					
Fuchsia boliviana Carrière	Shrub	Exotic	Cultivated / Wild	Food, Orn	17 (0.71)
Fuchsia triphylla L.	Shrub	Exotic	Cultivated	Orn	2 (0.08)

(Continued)

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Fuchsia magellanica Lam.	Shrub	Exotic	Cultivated	Agr, Orn	11 (0.46)
Pappaveraceae					
Bocconia frutescens L.	Shrub	Native	Wild		2 (0.08)
Phyllanthaceae					
Phyllanthus salviifolius Kunth	Tree	Native	Cultivated	Agr	2 (0.08)
Pinnaceae					
Pinus patula Schiede ex Schltdl. & Cham.	Tree	Exotic	Cultivated	Agr	1 (0.04)
Pinus radiata D.Don	Tree	Exotic	Cultivated	Agr	9 (0.38)
Piperaceae					
Piper bogotense C.DC.	Tree	Native	Wild		4 (0.17)
Pittosporaceae					
Pittosporum undulatum Vent.	Tree	Exotic	Cultivated	Agr, Orn	10 (0.42)
Podocarpaceae					
Podocarpus oleifolius D.Don	Tree	Native	Cultivated	Agr	1 (0.04)
Polygalaceae					
Monnina aestuans (L.f.) DC.	Shrub	Native*	Wild		9 (0.38)
Primulaceae					
Myrsine guianensis (Aubl.) Kuntze	Tree	Native	Wild	Con	5 (0.21)
Rosaceae					
Cotoneaster pannosus Franch.	Shrub	Exotic	Cultivated	Agr	3 (0.13)
Eriobotrya japonica (Thunb.) Lindl.	Tree	Exotic	Cultivated	Food	1 (0.04)
Hesperomeles goudotiana (Decne.) Killip	Shrub / Tree	Native*	Wild	Food	3 (0.13)
Malus pumila Mill.	Tree	Exotic	Cultivated	Food	9 (0.38)
Prunus persica (L.) Batsch	Tree	Exotic	Cultivated	Food	15 (0.63)
Prunus serotina Ehrh.	Tree	Exotic	Cultivated	Agr, Food, Med	7 (0.29)
Prunus domestica L.	Tree	Exotic	Cultivated	Food	10 (0.42)
Pyracantha coccinea M.Roem.	Shrub	Exotic	Cultivated	Agr, Orn	4 (0.17)
Pyrus communis L.	Tree	Exotic	Cultivated	Food	4 (0.17)
Rutaceae					
Citrus × aurantium L.	Tree	Exotic	Cultivated	Food	1 (0.04)
Citrus limon (L.) Osbeck	Tree	Exotic	Cultivated	Food	1 (0.04)
Citrus sinensis (L.) Osbeck	Tree	Exotic	Cultivated	Orn	1 (0.04)
Coleonema album (Thunb.) Bartl. & H.L.Wendl.	Shrub	Exotic	Cultivated	Med	1 (0.04)
Salicaceae					

(Continued)

Table 2. List of trees and shrubs in smallholder farms of the central altiplano of Boyacá, Colombia. *Endemic species. Use categories: Agroecological (Agr), Food, Environmental (Env), Handicrafts (Han), Construction (Con), Medicinal (Med), Ornamental (Orn).

Family / Scientific name	Growth habit	Origen	Management category	Use category	Farms frequency
Abatia parviflora Ruiz & Pav.	Tree	Native	Cultivated / Wild	Env	1 (0.04)
Salix humboldtiana Willd.	Tree	Native	Cultivated	Agr, Orn	6 (0.25)
Xylosma spiculifera (Tul.) Triana & Planch.	Shrub / Tree	Native	Wild		3 (0.13)
Sapindaceae					
Dodonaea viscosa (L.) Jacq.	Shrub	Native	Cultivated / Wild	Agr, Orn	4 (0.17)
Solanaceae					
Brugmansia arborea (L.) Steud.	Shrub	Native	Cultivated	Agr, Orn	7 (0.29)
Cestrum buxifolium Kunth	Shrub	Native	Wild	Med	4 (0.17)
Cestrum sp.	Shrub	Native	Cultivated	Orn	3 (0.13)
Lycianthes lycioides (L.) Hassl.	Shrub	Native	Wild		4 (0.17)
Salpichroa tristis Miers	Shrub	Native	Wild		1 (0.04)
Saracha quitensis (Hook.) Miers	Shrub	Native	Wild		1 (0.04)
Solanum betaceum Cav.	Shrub	Exotic	Cultivated	Food	13 (0.54)
Solanum pseudocapsicum L.	Shrub	Native	Cultivated	Agr, Orn	8 (0.33)
Solanum quitoense Lam.	Shrub	Native	Cultivated	Food	7 (0.29)
Solanum sp.	Shrub	Native	Wild		1 (0.04)
Streptosolen jamesonii (Benth.) Miers	Shrub	Exotic	Cultivated	Agr, Orn	1 (0.04)
Urticaceae					
Boehmeria nivea (L.) Gaudich.	Shrub	Exotic	Cultivated	Med, Orn	6 (0.25)
Verbenaceae					
Aloysia citriodora Palau	Shrub	Exotic	Cultivated	Food, Med	11 (0.46)
Citharexylum subflavescens S.F.Blake	Tree	Native	Cultivated	Agr	6 (0.25)
Duranta mutisii L.f.	Shrub	Native	Cultivated	Agr, Orn	5 (0.21)
Lantana camara L.	Shrub	Native	Wild		3 (0.13)
Lippia alba (Mill.) Britton & P.Wilson	Shrub	Native	Cultivated	Med	1 (0.04)

Another interesting aspect of tree and shrub diversity on the farms is the predominance of native species over exotic species, consistent with what is reported in the literature for smallholder farming systems in the Neotropics (Albuquerque *et al*. 2005, Garen *et al*. 2011, Abebe *et al*. 2013, Pérez and Matiz-Guerra 2017, Rooduijn *et al*. 2018). However, although exotic species were less diverse than native ones, they are the most frequent on farms. In fact, of the seven most frequent species, six were exotic and only one was native. This lower diversity but high frequency of exotic species may be related to the fact that in human-modified systems exotic species tend to offer many more services (Garen *et al*. 2011). In fact, 98 % of the exotic species were useful in the studied farms. In contrast, native species were less frequently utilized and were used in a smaller proportion (23 %). The most frequent native species were found in no more than half of the farms and corresponded to cultivated species, all with some use-value for the owners.

Regardless of the origin and the diversity of tree and shrub species found in smallholder farms, our results suggest that these productive spaces may have a key role in biodiversity conservation. In this sense, several authors have reported that environments altered by humans, such as home gardens, are spaces for the conservation of wild species and are germplasm reservoirs of a wide variety of cultivated plants (Bhagwat *et al.* 2008, Pulido *et al.* 2008, Webb and Kabir 2009, Rooduijn *et al.* 2018). Some of the most characteristic genera of the Andean flora, such as *Baccharis, Solanum, Fuchsia, Miconia, Piper, Chromolaena, Cestrum, Oreopanax, Tibouchina, Myrsine* or *Monnina* (García *et al.* 2006, Fernández-Alonso and Hernández-Schmidt 2007, González-M and López-Camacho 2012) are represented by one or several species within the farms studied (Table 1). Likewise, it is significant that eight of the wild species are endemic to Colombia (Bernal *et al.* c2019). Additionally, some of the genera of cultivated plants frequently reported in Neotropical agricultural systems such as *Abutilon, Annona, Citrus, Inga, Manguifera, Prunus, Psidium, Solanum* or *Syzygium* (Pulido *et al.* 2008, Pérez and Matiz-Guerra 2017, Pinto Rayol *et al.* 2017, Villa and García 2018), are also represented in the farms studied with one or more species (Table 1). These results reinforce the idea that smallholder farms can play a significant role in biodiversity conservation strategies.

What are the characteristics of the smallholder farming systems that favor this tree and shrub diversity? One of the practices that favor the existence of wild diversity in the farms is the maintenance of the original native vegetation or allowing the establishment of wild plants that arrive by natural dispersal. The motivations of owners who allow the establishment of these wild species may be related to their perception of the environment. The tendency for organic practices on these farms implies that the owners value the services that wild species can offer, such as shade in pastures, a supply of food for birds and insects or the protection of hatcheries or water sources. The establishment of wild species is influenced by the surrounding flora, but their maintenance on farms depends on the actions or practices of the owners (Rooduijn *et al.* 2018).

Another aspect that favors tree diversity on farms is the presence of various spaces within the farms, such as home gardens, living fences or forest relics. This complex structure is characteristic of smallholder farming systems and has been described in various family production systems around the world (Kehlenbeck *et al.* 2007, Pulido *et al.* 2008, Abebe *et al.* 2013, Mohri *et al.* 2013). In the studied farms, most of the tree species diversity was found in productive areas, which included home gardens and cultivated or grazing areas. The fact that these are precisely the areas of greatest human intervention indicates that the presence of trees and shrubs depends on the decisions of the owners. This confirms the statement by Thijs *et al.* (2015) who recognize that the occurrence of tree species in agricultural systems is highly influenced by human interventions. In Panama, for example, farmers perform various tree management practices, assigning value to native species (Garen *et al.* 2011). Living fences also turn out to be another space that protects a variety of trees and shrubs, since these are important spaces for the establishment of wild plants along with the species planted by the owners. The role of living fences as areas for the establishment and conservation of tree species has already been documented for the Colombian Andes (Pulido-Santacruz and Renjifo 2011). Spaces with remaining native vegetation, such as forest relics, also contribute significantly to maintaining tree diversity on these farms.

Uses

Our results showed that farmers maintain species that provide them with some service. The uses reported for tree species on these farms, in general, coincided with those reported in other studies in smallholder farming systems (Pulido *et al.* 2008, Garen *et al.* 2011, Abebe *et al.* 2013, Thijs *et al.* 2015, Pinto Rayol *et al.* 2017). The predominance of species planted to form living fences or due to their ornamental value may be related to the proximity of farms to urban areas. This trend has been documented in studies of home gardens (Pulido *et al.* 2008, Caballero-Serrano 2016), which highlight that the distance to urban centers or markets influences the composition of the flora, increasing the richness of ornamental species that are usually exotic. Despite this trend, it is important to highlight that the trees of these farms not only represented an aesthetic or recreational value, but they also had a productive subsistence purpose, which is shown by the 29 species that had use as food, the majority producing fruits. In general, the management of various arboreal species for food purposes is a characteristic of small farming systems (Pulido *et al.* 2008). Virtually all edible species are cultivated by the owners, and the tree-species documented here are used as food throughout the Colombian high Andes (Pérez and Matiz-Guerra 2017). This could indicate an owner´s interest in maintaining a food source for the local market and for family consumption, which is a distinctive feature of smallholder farming (Thijs *et al.* 2015, Ortiz *et al.* 2018).

The medicinal use of tree species was less frequent. It may be related to the fact that only the farm´s owner was interviewed, which could imply a bias since people familiar with medicinal plants could not have participated in the study. Another aspect that is relevant is the sporadic use of tree species as timber for construction or the lack of reports of their use as fuels, which corresponds to use categories frequently reported in the literature for woody plants (Garen *et al.* 2011). This may be related to the environmental and socio-economic conditions of this region since households have other combustible sources such as gas or coal; and, in general, their dependence on wood and firewood has decreased.

It is worth noting that at least one-third of the species recorded are conserved in these farms despite not having an obvious use. Within this group are wild species that are dispersed in productive areas or are part of living fences or forest relics. Although the owners do not assign them a particular use, they may be recognized as having some environmental or aesthetic value by the owners. It is precisely in smallholder farming systems where such cultural values, which go beyond commercial production, can influence the diversity of species (Ortiz *et al.* 2018).

Factors that influence species richness

We found that only size of the farms and proximity to areas with natural vegetation significantly influenced species richness. These results concur with other papers on smallholder farming systems (Caballero-Serrano *et al.* 2016, Pinto Rayol *et al.* 2017, Rooduijn *et al.* 2018). To the extent that the farms are larger, they can hold more tree species (Pinto Rayol *et al.* 2017). Likewise, to the extent that the remaining vegetation surrounds the farms, there is a greater chance of dispersal of wild species (Rooduijn *et al.* 2018). It seems that forest fragmentation can increase the establishment of wild species in this type of agricultural system due to a clustering effect (Rooduijn *et al.* 2018). In this sense, the remaining forests act as a source of propagules that end up being established in neighboring agroecosystems (Pinto Rayol *et al.* 2017). In this panorama, it is relevant to explore the role of smallholder farms as areas of connectivity for the biodiversity of the Colombian Andean region and to recognize the importance of spaces with human intervention for biodiversity conservation strategies (Thijs *et al.* 2015).

CONCLUSIONS

Our results show a remarkable tree and shrub diversity in the smallholder farms studied. We found that wild species, remnants of the original vegetation, or naturally dispersed, together with species grown by the owners converge on the farms mainly for utilitarian purposes. In these family farms, various agroecological practices are carried out, including the management of polycultures or the planting and tolerance of trees and shrubs. Likewise, the farms have several spaces, such as home gardens, living fences, cultivation and grazing areas or relics of the remaining vegetation, all of which can favor the conservation of tree species. Given these conditions, farms can play an important role as conservation spaces for native and exotic flora in the region.

The owners plant trees or shrubs usually to create living fences, decorate the spaces of the farm or supplying food, especially fruits. They also allow the establishment of wild species, although usually not for a specific utilitarian purpose since only 23 % of wild plants were recognized as useful. It is likely that as they transition towards more sustainable productive systems, the owners will-recognize some ecological or cultural importance in the wild tree flora that leads to favoring their maintenance on the farms.

Species richness is influenced by the size of the farms and the presence or proximity of remaining natural vegetation. Both conditions contribute to maintaining a greater number of species. Other socio-economic aspects of families or farm structure did not significantly influence species richness.

AUTHORS PARTICIPATION

JP and NS co-designed the experiment, conducted interviews, collected specimens, and performed statistical analyses. NG participated in all the above aspects of the research as well as wrote the manuscript and conducted the final corrections.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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