Agroforestry systems for biodiversity and ecosystem services: the case of the Sibundoy Valley in the Colombian province of Putumayo

Vandréé Julián Palacios Bucheli and Wolfgang Bokelmann

*Faculty of Life Sciences, Humboldt-Universität zu Berlin, Berlin, Germany; †Lebenswissenschaftliche Fakultät, Albrecht Daniel Thaer-Institut für Agrar- und Gartenbauswissenschaften, Humboldt-Universität zu Berlin, Berlin, Germany

1. Introduction

Indigenous communities around the world have relied on agroforestry, as their ancestral way of agriculture, since their earliest history. Through agroforestry systems, these communities have met their basic needs for food, medicine, fuels, raw materials for construction and handicrafts, and for their free cultural development. The biodiversity of these traditional agroecosystems and the additional resources of their neighbouring area have secured the livelihoods and well-being of many.

Nevertheless, the traits and functions of agroecosystems are changing worldwide (Dash and Misra 2001; Trinh et al. 2003), and consequently, many native and wild species, landraces, and crop varieties are declining (Turner et al. 2013). The Sibundoy Valley, in the Colombian Province of Putumayo, is no exception. There, as monocultures and livestock farming become important revenue sources, agroforestry systems and their related biodiversity resources are vanishing. However, this biodiversity must be preserved so that numerous indigenous and peasant families, and even those devoted to other economic activities within the region, may continue profiting from its ecosystem services. This research paper illustrates this need by describing how important biodiversity is to provide ecosystem services to the Inga and Camëntsá indigenous communities.

1.1. Biodiversity: the basis for ecosystem services delivery

The food security, health care, and ecosystem resilience of indigenous communities are strongly rooted in the maintenance of biodiversity (Gari 2001). For them, environmental conservation is both a goal and a means to enhance well-being and livelihood (Agbogidi and Adolor 2013). Biodiversity helps to prevent climate change, achieves ecological balance at the household farm level, attains food security, and increases the communities’ market possibilities (Claverías and Quispe 2001). Annual and biannual crops, perennial and semi-perennial plants, and wild species in the systems under biodiversity schemes allow the households to reach a permanent production on a daily, weekly, and monthly basis as well as long-term outputs, for example, from woody species. This enables families to reduce the market risks since they may trade a large variety of goods (Jamnadass et al. 2013). Biodiversity correlates with a region’s ecosystems, genes, and total species (Agbogidi and Adolor 2013). Likewise, high biodiversity levels are related to large mass quantities of flora; therefore, they enhance carbon sequestration processes (Schroth et al. 2011).

The biodiversity that indigenous communities maintain through traditional agroecosystems is
fundamental to their livelihoods (Pimbert 2009; PAR 2010). At least three South America native groups rely on the forest’s biodiversity and that of cultivated fields to ensure their food security, medical care, and ancient heritage (Egeland and Harrison 2013). Because of diverse geographical conditions, some species and varieties grown exclusively in given regions. And some of those unique genetic materials are particularly nutritious. For instance, a comparative analysis by Caicedo and Chaparro (2013) of two different daily food intakes, in the Colombian Amazon jungle, revealed that the traditional diet was 39% more nourishing than the non-traditional one in terms of kilocalories, protein, iron, and vitamin A. Although the study did not describe the traditional diet in detail, it determined that at least 18 species and animals harvested and bred in the traditional agroecosystems provided the necessary nutrients to the households.

The indigenous communities of the Sibundoy Valley use and maintain biodiversity through their agroforestry systems. Those systems include woody perennial species, crops, and/or animals growing and/or breeding together in a unit of land (Nair 1993; Young 1997; Huxley 1999; Beetz 2011; Alao and Shuaibu 2013). Since agroforestry systems are agroecosystems, they provide and receive ecosystem services and disservices (Swinton et al. 2007; Zhang et al. 2007; Garbach et al. 2014). Therefore, these agroecosystems deliver provisioning services directly (Figure 1), and the management of their ecosystems determines the delivery of those services, and ultimately the mankind’s well-being. The ecosystem services are, thus, inextricably linked to the protection of biodiversity (Garbach et al. 2014), and agroforestry may ensure adequate biodiversity levels for appropriate ecological processes and resilience. Figure 1 illustrates how biodiversity is fundamental for the delivery of ecosystem services to the indigenous communities.

The Camëntsá and Inga communities ensure their livelihoods through agriculture. However, based on their wisdom, knowledge, and expertise, they prefer agroforestry over monoculture. There are three types of agroforestry systems in the Sibundoy Valley: (i) silvopastoral, (ii) agrosilvopastoral, and (iii) agrisilvicultural.

The (i) silvopastoral systems consist mostly of livestock farming for milking purposes and the care of pastures. The (ii) agrosilvopastoral systems develop home gardens through ancestral-traditional

![Figure 1. Final ecosystem services from agroforestry systems.](image-url)
agricultural practices (Palacios and Barrientos 2014), rendering a wide biodiversity of food and animal species, medicines, perennial species, and forage (Palacios and Barrientos 2011). The (iii) agrosilvicultural systems grow specific crops under trees and/or certain types of bushes.

The biodiversity protection performed by the indigenous communities of the Sibundoy Valley contributes to the delivery of ecosystem services and helps to mitigate ecosystem disservices such as water pollution, odours, health risks, biodiversity loss, nutrient runoff, and other negative impacts (Swinton et al. 2007; Zhang et al. 2007; Garbach et al. 2014).

Within this framework, two questions deserve attention: What are the ecosystem services provided by the biodiversity of the agroforestry systems of the Camëntsá and Inga communities? Is the food security of the households still devoted to agriculture related to the maintenance of biodiversity through agroforestry?

In this vein, the objectives of this inquiry are: (1) to understand the importance of the biodiversity within agroforestry systems, as providers of provisioning, regulating, and cultural ecosystem services to indigenous households and (2) to assess the importance of protecting biodiversity through agroforestry systems to ensure food security.

2. Methodology

2.1. A brief description of the research area

Located in southwest Colombia, on the eastern side of the Andes mountains, the Sibundoy Valley is a transitional zone between the highlands and the jungle. It comprises four municipalities: Santiago, Colon, Sibundoy, and San Francisco, which belong to the province of Putumayo. The flat area covers 8500 ha (Bonilla 2006) and has an altitude between 2000 and 2100 m above the sea level (IGAC 2001). The valley’s temperature fluctuates between 10.3ºC and 21.7ºC, with a yearly humidity of 78–83%, and a precipitation range of 1443–1496 mm (IGAC 1990). The Putumayo river crosses the valley, collecting the waters of many other streams, before leaving it at Balsayaco.

In terms of population, the Inga community has some 15,450 members in Colombia (UNHCR 2011), most of whom (9579) dwell in Putumayo, primarily in the Sibundoy Valley. The Camëntsá community has some 4879 members who also inhabit the valley. There are 270 indigenous households in the area under study, distributed as follows: 55 in Tamabioy, 70 in San Félix (Palacios and Barrientos 2014), 54 in San Silvestre, 48 in La Menta, 20 in Central San Antonio, 12 in San Agustín, and 11 in San José del Chunga (Table 1).

The Inga and the Camëntsá communities are unique cultures with their own worldview and customs, as expressed in their language, folklore, dress, handicrafts, traditional medicine, and agriculture. These cultural manifestations are closely related to the household environment, where people live, but also grow food and medicines, plant trees to use as raw material for artwork or construction, breed animals, and govern their own development. This family household environment comprises the agroforestry systems that protect biodiversity and ensure livelihoods.

2.2. Sampling procedure and data collection

The study was conducted in two villages of the Sibundoy Municipality (Tamabioy and San Félix), and five villages of the San Francisco Municipality (San Silvestre, La Menta, Central San Antonio, San Agustín, and San José del Chunga) (Figure 2). These villages were selected given (i) their number of indigenous households, (ii) their relevant agroforestry systems, as identified through direct observation and key informants, and (iii) the presence of well-known healers and leaders.

The study employed a qualitative research strategy involving ethnography or participant observation and qualitative interviews as the leading methodologies (Fetterman 2010; Bryman 2012). The interviews gathered information to identify: (i) the biodiversity of the agroforestry systems and (ii) the uses given to various species.

Table 1. Population and interviews applied in the seven villages of the Sibundoy Valley in 2015.

| Municipality | Villages             | Population (number of households) | Percentage from total population | Number of respondents | Percentage of population interviewed |
|--------------|----------------------|-----------------------------------|---------------------------------|-----------------------|-------------------------------------|
| Sibundoy     | San Félix<sup>a</sup>| 70                                | 26                              | 3                     | 1                                   |
| San Francisco| Tamabioy<sup>b</sup>| 55                                | 21                              | 6                     | 2.5                                 |
|              | San Silvestre<sup>b</sup> | 54                  | 20                              | 5                     | 2                                   |
|              | La Menta<sup>b</sup> | 48                                | 18                              | 6                     | 2.5                                 |
|              | Central San Antonio<sup>b</sup> | 20              | 7                                | 3                     | 1                                   |
|              | San Agustín<sup>b</sup> | 12                                | 4                               | 4                     | 1.5                                 |
|              | San José del Chunga<sup>b</sup> | 11                  | 4                               | 3                     | 1                                   |
| **Total**    |                      | **270**                           | **100**                         | **30**                | **11.5**                            |

<sup>a</sup>Based on data from 2012 (Palacios and Barrientos 2014); <sup>b</sup>Based on data from this research (2015)
Beyond the interviews, additional data were collected through direct field observation of the agroforestry systems and their species’ scientific names, within transects of the villages and of the household farms. There were, thus, two types of transects: (i) those within the farms, where the household heads showed the species and explained their names and uses, and (ii) those in the villages, where a well-known community healer provided similar information.

The interviews were semi-structured, that is, based on informal talks with the respondents, and thereafter any identified species were checked off against a species list, along with their uses. The enquiry included households living off agriculture, services, and handicrafts. However, the criteria to select the interviewees were: (i) their botanic and healing knowledge and (ii) their remarkably biodiverse agroforestry systems, as reported by other community members.

A non-probability sampling approach was taken into account because the research goal was to approach relevant respondents with suitable knowledge to support in answering the questions regarding ecosystem services involved in biodiversity, along with the linkages between biodiversity maintenance and food security. Therefore, focusing on a fixed purposive sample of criterion and the unit of analysis was the indigenous households of the Caméntsa and Inga in the seven villages. At the outset of the study, the sample included 20 respondents. However, as the study progressed, it evolved to a theoretical saturation of 30 interviews in total in all seven villages (Table 1). This saturation occurred when the information from the interviews yielded no more findings, and therefore, it was reasonable to stop interviewing. In addition, a snowball sampling technique was useful in the respondent selection process (Onwuegbuzie and Collins 2007; Teddlie and Yu 2007; Bryman 2012).

2.3. Data analysis

Based on the literature review, this enquiry used two indicators to ascertain the biodiversity-related ecosystem services and the importance of biodiversity: (i) the uses of biodiversity as reported by the indigenous communities and in the literature and (ii) the number of species in the agrarian systems (Figure 3). The second permitted to compare this study’s agroforestry systems and their biodiversity with other cases described in the literature. As the number of species increase, agroforestry systems become more important to preserve biodiversity.

The biodiversity of the seven Sibundoy Valley villages was partially analysed by comparing it: (i) with the number of species found in a 2015 fieldwork and information gathered in 2008 and 2012; (ii) with agroforestry systems in other communities worldwide as described in the literature; and (iii) with the number of species present in every type of agroforestry system. The qualitative data gathered through observation, transects, and interviews were registered in a field notebook and a species checklist. All the information collected in the field was systematized in Excel and analysed with univariate analysis, focusing on frequency (Bryman 2012).

2.4. Classification of ecosystem services

The classification of ecosystem services was primarily based on the uses given by the households to the species. For instance, the species used as food were classified under provisioning ecosystem...
services. The number of species was another indicator to assess the importance of biodiversity for the provision of ecosystem services. This indicator was also useful to compare the findings of this enquiry with those of studies conducted elsewhere.

2.5. Food security analysis

The number of species indicator was further used to compare the food biodiversity of the several agroforestry systems. The literature review was used in this analysis to identify the nutrients of the food species found in those systems.

3. Results

3.1. Agroforestry systems and biodiversity

The seven villages in the research zone have three types of agroforestry systems (Table 2). The silvopastoral system (Figure 4), which takes most of the land of these systems (Table 2), features live fences and woody perennial species spread out in pastures. Livestock is farmed for milk production, which is a stable source of income for the households. Those not breeding cattle usually rent their land to the dairy producers. The trees are a long-term revenue source since they are sold as timber or fuel. The agrosilvopastoral system (Figure 5), which takes the second largest area of these agroecosystems (Table 2), features home gardens that resemble the forest and employ ancestral ways of land management. They bear the highest biodiversity of all agroecosystems in the valley, and their species are mostly used for home consumption. However, production surpluses are traded locally and/or regionally, and it is worth mentioning that barter mechanisms are still common among community members who exchanged goods with neighbours and relatives. Last, there is the agrisilvicultural systems (Figure 6), which takes the smallest area. Currently, it features crops such as beans supported by maize (a first-semester maize crop is followed by a second-semester bean crop that profits from the maize cane to grow), Solanum quitoense, tamarillo, and Passiflora ligularis. These crops are raised for the market and are relevant income sources for the households.

There are 128 species in the biodiversity of these three types of agroforestry systems (silvopastoral, agrosilvopastoral, and agrisilvicultural) (Appendix A1), which are valued for their different uses. Of them, 51% are trees and bushes and 49% are herbaceous, vines, and cane plants. The large number of woody perennial species evidences the agroforestry approach

![Figure 3. Indicators to ascertain the biodiversity-related ecosystem services, and the importance of biodiversity in the research zone of the Sibundoy Valley. Based on: This research 2015; Nafziger (2009); Nair (1993). Source file: CorelDraw/PC](image-url)
Figure 4. Woody perennial species spread out in a pasture in Tamabiroy village, Sibundoy Valley, Colombia.

Figure 5. Home garden in La Menta village, Sibundoy Valley, Colombia.
in which the Camëntsá and Inga communities to preserve biodiversity, for which they have, in all, 21 uses. A longitudinal comparison of biodiversity at the Sibundoy Valley reveals that its number of species has peaked in the most recent period (Table 3) due to exchange of species between Andean and Amazonian indigenous peoples. These species have adapted to the local conditions along with other exotic plants such as sugar cane and plantain.

Two species found in 2008 (Manilkara bidentata and Thevetia peruviana) and 10 identified in 2012 (three forage, two vegetables, two medicinal, two woody perennials, and one flower), were not found in 2015. These species were excluded from the final study. However, as seen in Table 3, four species that were not registered in 2008 or 2012 were identified in 2015 (Acacia sp., Brugmansia aurea, Datura sanguinea cv. Guamuco, and Rubus urticifolius). They were regarded as other identified species maintained in the agroforestry systems. It is worth noting that the three types of agroforestry systems observed in 2015 (silvopastoral, agrosilvopastoral, and agrisilvicultural) already prevailed in the 2008 and 2012 periods of comparison.

Although there were many species not registered in 2012, by 2015, the biodiversity found in the agroforestry systems had increased to 128 species. Of them, 19 species were present in the silvopastoral systems, 105 species lived in the home gardens, and 32 species grew in the agrisilvicultural systems. This reveals that the great biodiversity of all three agroforestry systems, within the research zone, has been maintained in recent years.

3.2. Ecosystem services provided by the agroforestry systems in the Sibundoy Valley

The biodiversity maintained in the three types of agroforestry systems supplies provisioning, regulating, and cultural ecosystem services. In this regard, 109 species (used as food, natural medicines, biochemicals, fuels, and fibres) supply provisioning services, 40 species are associated to regulating services, and 13 species are part of cultural services. This means that almost a third of the overall uses of species is related to regulating and cultural services (Figure 7).

3.2.1. Provisioning services

Overall, a relevant 73% of the biodiversity found in the research zone supplies provisioning ecosystem services to the Inga and Camëntsá communities. Through these services, the communities meet their basic home consumption needs and generate an income from the trade of production surpluses. Both the subsistence and market schemes of the three types of agroforestry systems improve their livelihoods.

The Inga and Camëntsá communities consume seven herb species and use an additional 38 for medicinal purposes (Figure 7). These medicinal species, like certain food plants, have grown out of the local commitment to maintain biodiversity and have therefore adapted to the Andean conditions even though they come from long distances. That is the case of Banisteriopsis caapi, which the healers included in their botanical knowledge and practices. Beyond the healing purposes, herbs replace coffee consumption and are an ingredient in traditional cooking. In addition, 50 species provide nutritious food to the

Figure 6. Agrisilvicultural system with S. quitoense in La Menta village, Sibundoy Valley, Colombia.
Table 3. Agroforestry systems’ biodiversity found in the seven villages of the Sibundoy Valley in the three times analysed (2008, 2012, and 2015).

| Period                  | Biodiversity in the study area | Type of agroforestry systems |
|-------------------------|--------------------------------|------------------------------|
|                         | 2008a                         | 2012b                        | 2015c                        |
| Total number of species found per period | SP AGP AGC SP AGP AGC SP AGP AGC | SP AGP AGC SP AGP AGC |
| Tamabioy                | 27 99 29 22 60 28 28 89 22    | 27 99 29 37 79 27 31 92 21  |
| San Félix               | 37 79 27 31 92 21             | 26 105 30 22 75 30           |
| San Silvestre           | 19 79 26                       | 22 75 30 30                  |
| La Menta                |                                | 39 101 25 27 69 17           |
| Central San Antonio     |                                |                              |
| San Agustín             |                                |                              |
| San José del Chunga     |                                |                              |
| Total per system        | 27 99 29 37 91 30 45 105 32   |                              |
| Total                   | 121                            | 96 128                       |

Species only found in that periods

| 2008a | 2012b | 2015c |
|-------|-------|-------|
| 21    | 0     | 4     |

Number of species missing from total biodiversityc

| 2008a | 2012b | 2015c |
|-------|-------|-------|
| 21    | 46    | 14    |

*a* Data from Tamabioy (Palacios 2008)

*b* Data from Tamabioy and San Félix (Palacios 2012)

*c* Data from the seven villages of this study

SP: Silvopastoral AGP: Agrosilvopastoral AGC: Agrisilvicultural

3.2.2. Regulating services

Of the overall biodiversity of the Sibundoy Valley’s agroforestry systems, 40 species (21%), are related to the provision of regulating ecosystem services. And of those services, crop protection involves the highest number of species. Crop protection refers to the aid received by crops from woody perennial species, which may: (i) act as live fences or windbreaks (in the words of respondents), saving the crops from being blown down in August; and (ii) provide shading. Other uses reported by the interviewees relate to households and the overall region. These species live in all three agroforestry systems and range from fruits to roots, and from native species, varieties, and landraces to exotic species adapted to the local conditions (Figure 8). Moreover, woody perennial, which comprise more than half of the total biodiversity, are employed as fuel by the communities. Of them, 15 species are particularly useful. Other numerous species provide fibres for handicrafts and construction or may be used in the production of dyes and fertilizers (Figure 7).
fluctuations in levels of soil loss, providing habitat for wildlife, and crop protection through the formation of a microclimate (Figure 7).

The indigenous communities’ use and maintenance of species for various ecological purposes reflect their understanding of the benefits of trees and bushes for their livelihoods. For instance, the Camëntsá and Inga identify two species for soil protection (Cestrum ochraceum and Viburnum triphyllum), and one for nitrogen fixation (Alnus jorullensis) (Appendix A1). These trees, therefore, provide the final soil conservation and nutrient cycling services (Figure 7). Beyond the findings of this study, it is worth noting that although the Mexican alder (A. jorullensis) was the only nitrogen fixing species reported by respondents in both communities, four other trees present in the biodiversity have been described in the literature as having the same function (Acacia mearnsii, Acacia melanoxylon, Acacia sp., and Inga edulis) (Ferrari and Wall 2004).

3.2.3. Cultural services
All three types of agroforestry systems provide cultural services to the dwellers of the Sibundoy Valley. Nine species are valued for their aesthetic contribution to the households (Figure 7). Most of them are flower species used to embellish the family home. They are usually grown surrounding it, and the respondents expressed great satisfaction about their gardening. In addition coffee and Yucca elephantipes are woody perennial types that do not need much attention.

Four species are used for ritual purposes (Figure 7) that are directly related to healing practices, a worldview, and myths. Of them, B. caapi (Appendix A1) stands out as a plant that the Inga and Camëntsá communities adapted to the environmental conditions of the Sibundoy Valley. This vine came from the Amazon through the exchange of species with other indigenous peoples such as the Siona and the Cofán.

Maize, besides being a dietary staple for Camëntsá and Inga, has a strong cultural significance to them: it is the fruit of the indigenous force and power. Maize may be consumed dried, or in a traditional fermented beverage taken in everyday life, or as an essential drink during ceremonies, holidays, household celebrations, social meetings, farming labour, and community work. Therefore, this species is linked to the final cultural heritage service through which the elders convey their knowledge of the species to the youth, in an autonomous development of their culture.

3.3 Biodiversity and food security
Attaining food security is at the core of the Camëntsá and Inga communities’ livelihoods strategy. The high number of food species present in all three agroforestry systems, 50 in total, reveals the importance of diet diversification through several foods. There are nine types of food in the research zone’s biodiversity. Of them, the most valued are fruits, which comprise almost half of the species (Figure 8). Nine food species were found to have a stable market, 10 have a local market, 27 have a small market, and 2 have promissory markets: Prunus capuli, domestically, and Physalis peruviana globally (Appendix B1). Those with stable markets, like the bean crop, are the most relevant crops of the valley: they are easily traded, and they provide an income to many households. The species with a local market are seldom commercialized outside the valley. However, their main markets are the capitals.
of the Putumayo and Nariño provinces some 83 and 64 km away, respectively. The species with a small market are grown mostly for home consumption as well as bartering and sharing with neighbours and relatives. Overall, stable and local market species are important for the communities’ food security. Besides their direct consumption by the families all year round, they generate revenues needed for the acquisition of goods and services not produced by the household farm. Both, the small and promissory market species (31 species in all) are highly consumed at the homes, thereby contributing to their nutritional needs.

4. Discussion

The home garden cases shown in Table 4 corroborate this study’s findings about the great biodiversity used and maintained in the agroforestry systems of the Sibundoy Valley. That biodiversity was identified many decades ago by botanist such as R.E. Schultes, who described the valley as unique place in the world, with the highest variety of ethnogenic plants (Davis 1996).

4.1. Provisioning, regulating, and cultural services derived from biodiversity

Provisioning services ensure food, medicines, fuel, and fibre to the Camëntsás and Ingas in all three agroforestry systems of the research zone. Rodríguez (2010) confirmed the relevance of food species for the Sibundoy Valley’s indigenous communities, as he determined that out of 87 medicinal species, 20 are used also as food. Of them, 10 were fruits, four were vegetables, three were spices, and there was one grain. In Latin America, the native groups embrace the principle of diversity to guarantee a continuous flow of goods materials, and energy from the ecosystems (Toledo 2001). Therefore, the communities commit to maintain biodiversity, and on that basis, they select and manage those species relevant to their livelihood. For instance, in a study done at the Bolivian Amazon, Diaz et al. (2015) reported the use of 113 species, 67 as food, 45 as natural medicines, and 23 as handicraft materials.

Biodiversity is also used to meet health needs. Therefore, it has prevailed in home gardens with a high diversity of species (Trinh et al. 2003; Huai and Hamilton 2008), where the households may use them for health purposes (Finerman and Sackett 2003). In the Colombian province of Caquetá, where there are Inga settlements as well, 17 different conditions, such as fever, headaches, nervous breakdowns, kidney ailments, and colic, among the most common, are treated with 20 medicinal plants (Caicedo and Chaparro 2013). In the Sibundoy Valley, the 87 medicinal species reported by Rodríguez (2010) are used to treat 42 health conditions.

Maintaining crop genetic diversity as part of communities’ livelihood strategies (Hajjar et al. 2008) is fundamental to attain food security and well-being. Meeting these challenges depends on the ecological benefits derived from the agrarian systems and their surrounding ecosystems, as those systems provide goods, on the one hand, and regulating services that support the production of those goods, on the other. A wealth of literature on those ecological benefits encourages conservation programmes for agroforestry system and confirms the link between the maintenance of biodiversity and its related ecosystem services. According to Swinton et al. (2007) agriculture, and in this case, agroforestry systems provide a variety of regulating services.

The Sibundoy Valley’s climate conditions, featuring high humidity and precipitation, and temperatures favourable for high and low altitude species, explain the adaptation of foreign species, from the Amazon and elsewhere, to the local environment. The exchange of species between indigenous communities (Trinh et al. 2003) has been reported by several studies, such as that of Ban and Coomes (2004) in the Peruvian Amazonia. That is how, the maintenance of biodiversity within the Camëntsà and Inga territories, through all three types of agroforestry systems, involving the adaptation of exotic species and the conservation of local varieties, has allowed the communities to meet their basic needs and to benefit from the related regulating services.

The woody perennial component of the agroforestry systems has positive effects on the ecological

Table 4. Biodiversity protected in home gardens from several studies, in comparison to the biodiversity protected in the agroforestry systems of the study area in 2015.

| Region and country | Communities | Area covered or sample | Total number of species | Source |
|-------------------|-------------|------------------------|-------------------------|--------|
| Pastaza, Ecuador  | Curary and Mango Uro | 30,000 km² | 53 | Garí (2001) |
| San Regis, Peru   | Peasants | 167 households | 108 | Ban and Coomes (2004) |
| Sucre, Peru       | Peasants | 67 households | 52 | Trinh et al. (2003) |
| Vietnam           | Xinh | 171,433 ha | 242 | Neelamegam et al. (2015) |
| Kanyakumari District, India | - | 128 rural (66) and urban (62) home gardens | 89 | Trinh et al. (2003) |
| Sibundoy Valley, Colombia | Camëntsás and Inga | 30 households | 128 | Own findings 2015 |
process. The trees and bushes help to avoid desertification and degradation caused by runoff and wind. Practices aimed at retaining soil organic matter on the surface layer, by keeping the woody perennials, improve the soil’s capability to sequester carbon (Hajjar et al. 2008). In brief, the maintenance of woody perennial species through the agroforestry systems helps to ensure diverse ecosystem services such as biodiversity conservation, water regulation, and land rehabilitation (Paumgarten et al. 2005).

Ornamental species are frequently planted around the indigenous homes, despite their lack of market value, because they provide aesthetic and cultural benefits, as discussed by Swinton et al. (2007). Other studies have also illustrated how numerous species offer landscaping improvement to their users. Mayori (2009) found 18 ornamental species in the home gardens of Nhema, Zimbabwe. Millow et al. (2010) reported 14 such species, out of a total diversity of 93 plants, in the home gardens of Pahang, Malaysia. Finerman and Sackett (2003) determined that 30 species out of 133 in the home gardens of Saraguro, Ecuador were valued for aesthetic purposes, as were five species reported by Gebauer (2005) in the home gardens of El Obeid, Central Sudan.

Many South American indigenous communities use the species B. caapi in rituals and ceremonies. According to Trujillo et al. (2010), 70 native groups in Ecuador, Peru, Colombia, Bolivia, and Brazil use this ritual plant, besides the Inga and Camëntsá. In Ecuador, for instance, the Pastaza community reported a medicinal and ritual use of this plant, akin to that of the Sibundoy Valley (Gari 2001).

Cultural practices and perceptions affect biodiversity as well as the maintenance of agricultural species. In the agroforestry systems, the protection of biodiversity is associated with the community’s cultural memory and knowledge-transmission practices (Ghosh et al. 2005). In this regard, rituals fundamental for the Camëntsá and Inga convey their traditional wisdom on healing procedures, their worldview, and mythology. Ghosh et al. (2005) suggest that conservation strategies should include the cultural context, because the indigenous knowledge is relevant for the protection of ecosystems, and thus for the well-being of humanity. As the communities use diverse species for medicinal purposes through ritual ceremonies, they remember ancestral healing practices and convey their cultural heritage. The ongoing transmission of such a heritage depends on the preservation and availability of those ritual plants in all three agroforestry systems (Van De Berg et al. 2005).

4.2. Intake of nutritional species to attain food security

Agroforestry systems are known for preserving non-domesticated and semi-domesticated species, landraces of crop species, and wild crop relatives (Toledo 2001). They ensure the availability of nutrients all year around, and lessen the households’ environmental and market risks. Betancourt (2007) highlights the need of prioritizing the subsistence agrarian systems as sources of safe, nutritious, good quality, and fair-priced food.

The Camëntsá and Inga agroforestry systems yield fruits full of nutrients. Of them, lemon guava (Psidium guajava) has the highest vitamin C content (228.3 mg per 100 mg of fruit); avocado (Persea americana) has the highest lipid content (14.66 g per 100 mg of fruit), and P. ligularis has the highest fibre content (10.4 g per 100 mg of fruit) (USDA 2015). As for maize (Zea mays), it is a dietary staple for both communities and has a deep cultural significance to them. At such, it is an important source of nutrients, and it is prepared in a variety of recipes for everyday consumption. The traditional use of maize is widespread among indigenous peoples. The Inga community of the Colombia province of Caquetá uses it to complement the diet of infants as young as five months old (Caicedo and Chaparro 2013), a practice also common among the Nigerian Igbo natives (Marquis et al. 2013).

Another species present in all three agroforestry systems of the Sibundoy Valley is Xanthosoma sagittifolium (L.) Scott & Endl. (Appendix A1). It has been recognized as a nutritious source of carbohydrates (Sama et al. 2012) and income for the households (Agyeman et al. 2004). Its carbohydrate (23.63 g per 100 g of corm) and energy (98 kcal) contents are even higher than those of the potato (17.49 g and 77 kcal per 100 g of tuber, respectively) (USDA 2015). Moreover, some vegetables found in the research zone are rich sources of calcium (Ca) that contribute to the nutritional needs of the indigenous homes. Their supply ranges from 17 mg per 100 g of vegetable in the case of chayote (Sechium edule) to 40 mg in the case of wild cabbage (USDA 2015).

In all three agroforestry systems of the Sibundoy Valley, the household farm production is used for home consumption and market purposes. For instance, in the villages of Tamabioy and San Félix, home gardens satisfy the household’s and basic community needs (Palacios and Barrientos 2014); as home consumption (60%) prevails over the trading of surpluses (40%) (Palacios and Barrientos 2011). Through this model, the families attain both food security and well-being. On the one hand, they obtain food, medicine, fuel, and fibres from the products kept at home. And on the other, the surplus sales allow them to afford further needs such as clothing, education, or additional nutrition. This pattern is observed elsewhere. In Vietnam, the home gardens of Nho Quan produce primarily for home consumption and thereafter, they make a profit from their
market crops (Trinh et al. 2003). Farmers in Bangladesh plant trees to meet various family needs, for example, firewood, and subsequently, raise an income from the trading of surpluses (Das and Das 2005). The Meegahakila farmers of Sri Lanka also meet their subsistence requirements through the home gardens and then commercialize some market crops (Senanayake et al. 2009). In sum, the strategy of combining household consumption and surplus sales enhances the families’ food security and well-being.

Besides combining home consumption and surplus trading, the Camëntsá and Inga enhance their livelihood through the barter of goods and/or services, including labour, as a caring exchange between neighbours and relatives (Palacios and Barrientos 2011). This indigenous idiosyncratic practice, which is broadly used to help families in need or coping with shocks, is commonplace: In Peru’s Cenapa River, the Awajún heads of household share food with their neighbours (Creed-Kanashiro et al. 2013). The Inga settled in the Colombian province of Caquetá share meat, fish, cassava, plantain, onions, tomatoes, fruits, and livestock products with other communities (Caicedo and Chaparro 2013). In the Jabithenan District of North-Western Ethiopia, the natives strengthen community ties by sharing fruits, vegetables, and sugarcane from their home gardens with neighbours and relatives (Linger 2014). And in rural South Africa, it is common for neighbours to barter tree products (Shackleton et al. 2008).

There is a direct relationship between the traditional agrarian systems and food security (Claverías and Quispe 2001; Garcia et al. 2008; Caicedo and Chaparro 2013; Creed-Kanashiro et al. 2013; Egeland and Harrison 2013). A wide variety of food species and types, such as the ones herein identified (Figure 8), provides a balanced diet to the homes, including proteins, calories, lipids, minerals, and other nutrients, thereby ensuring food security at a household and community levels. Another facet of the communities’ well-being is the medicinal use of biodiversity, and all its related knowledge, which permits the treatment of many conditions at home, employing the very species cultivated in the household farms. In addition, biodiversity is a rich source of fibres useful for construction, manufacturing, or energy purposes. It is, thus, clear that preserving all three agroforestry systems is crucial for (i) the use and maintenance of biodiversity, (ii) the provision of ecosystem services, and (iii) the enhancement of food security and well-being within the region.

5. Conclusions and recommendations

The Inga and Camëntsá communities of the Sibundoy Valley in the Colombian province of Putumayo develop three types of agroforestry systems (silvopastoral, agrosilvopastoral, and agrisilvicultural) that altogether yield 128 species for which there are 21 uses. This biodiversity provides three types of ecosystem services, namely: provisioning, regulating, and cultural. Most community members benefit from provisioning services, which are related to the food, medicine, fuel, and fibre derived from 109 species. There are 14 uses given to those species, which represent 73% of all biodiversity uses. The regulating services involve 40 species for which there are five uses, or 21% of them. And the cultural services employ 13 species for which there are two uses, or 6% of them (Table 5 and Figure 7).

There are 45 species in the silvopastoral system, 32 species in the agrosilvicultural system of growing crops under trees, and 105 species in the home gardens of the agrosilvopastoral system. All three systems are, thus, important for conserving the genetic diversity necessary for the future delivery of ecosystem services. Consequently, they must be preserved.

From their earliest history, the Camëntsá and Inga have used their rich biodiversity for their livelihood and cultural development. This biodiversity has evolved over time through exchange of numerous species that both communities have held with native peoples from the Amazon region and elsewhere. Both communities have, thus, worked hard at collecting planting materials, choosing the best individuals, sowing them in their agrarian systems, and adapting them to the local conditions ever since pre-Columbian times. And from their efforts, both have reaped the benefits of food security, health, and well-being. Today, the indigenous healers’ wisdom and services have extended beyond local boundaries to urban Colombia, and overseas, where patients in search of alternative treatments demand them. The communities’ huts, homes, barns, fences, bridges are built with native and exotic-tree materials, which are also used to create handicrafts and further agricultural inputs such as sticks for climbing species. Moreover, these materials may be fuel for cooking and other purposes. Biodiversity maintenance is therefore essential for the well-being, food security, and overall livelihood of both the Inga and the Camëntsá.

The agroforestry systems discussed herein are crucial to preserve the genetic diversity indispensable for the future delivery of ecosystem services at local, regional, and global levels. As they contribute to the stabilization of ecosystems in the long term and support the livelihood and food security of indigenous communities, they should be both promoted and protected by the State. Consequently, an official policy framework should be developed so that both the communities and their ecosystems receive adequate attention, protection, and support to continue delivering sustainable goods and services.
Nevertheless, as globalization reaches remote indigenous territories, introducing needs for goods and services, agroforestry systems may seem to be limited to the household needs and revenues, whereas monoculture may start looking like a viable option. Based on its findings, this enquiry stresses the need to maintain and use biodiversity, through agroforestry systems, for the ongoing delivery of provisioning, regulating, and cultural ecosystem services, and to ensure the livelihood and food security of many.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Agbogidi O, Adolor E. 2013. Home garden in the maintenance of biological diversity. Appli Sci Rep. 1(1):19–25.
Agyeman S, Larney S, Markwe C. 2004. Agro-morphological and sensory characterization of cocoyam (Xanthosoma sagittifolium (L) Schott) germplasm in Ghana. Ghana Jnl Agric Sci. 37:23–31.
Alao J, Shuaibu R. 2013. Agroforestry practices and concepts in sustainable land use systems in Nigeria. J Hortic and For. 5(10):156–159.
Ban N, Coomes O. 2004. Home garden in Amazon Peru: diversity and exchange of planting material. Geograph Rev. 94(3):348–367.
Bateman I, Mace G, Fezzi C, Atkinson G, Turner K. 2011. Economic analysis for ecosystem services assessment. Environ Res Econ. 48:177–218.
Beetz A. 2011. Agroforestry: an overview. National Sustainable Agriculture Information Service ATTRA, http://www.ncat.org.
Betancourt M. 2007. La seguridad alimentaria nutricional – SAN- Un acercamiento a la política pública [A public policy approach to food and nutrition security]. Cuader Admin/Univ Valle. 36–37:392–439.
Bonilla V. 2006. Siervos de dios amos de indios [Servants of god and masters of Indians]. Colombia: Editorial Universidad del Cauca, Universidad del Valle.
Bryman A. 2012. Social research methods. United States: Oxford University Press.
Caicedo S, Chaparro M. 2013. Inga food and medicine systems to promote community health. In: Kuhnlein H, Erasmus B, Spigelski D, Burlingame B, editors. Indigenous peoples’ food systems and well-being interventions and policies for healthy communities. Canada: FAO; p. 121–139.
Ch. S, Paumgarten F, Cocks M. 2008. Household attributes promote diversity of tree holdings in rural areas, South Africa. Agrof Sys. 72:221–230.
Claverías R, Quispe C. 2001. Biodiversidad cultivada: una estrategia campesina para superar la pobreza y relacionarse con el Mercado [Agricultural biodiversity: a peasant strategy for overcoming poverty and entering the markets]. In: SEPIA, editor. Peru: el problema agrario en debate SEPIA IX. Lima, Peru: SEPIA; p. 180–204.
Creed-Kanashiro H, Carrasco M, Abad M, Tuesta I. 2013. Promotion of traditional foods to improve the nutrition and health of the Awajun of the Cenepa River in Peru. In: Kuhnlein H, Erasmus B, Spigelski D, Burlingame B, editors. Indigenous peoples’ food systems and well-being interventions and policies for healthy communities. Canada: FAO; p. 53–74.
Das T, Das A. 2005. Inventory plant biodiversity in home-gardens: A case study in Barak Valley, Assam, North East India. Curre Sci. 89(1):155–163.

Table 5. Final services, related uses, the number of related species per uses, the number of species per agroforestry systems, and the number of uses per type of ecosystem services in the seven villages of the Sibundoy Valley in 2015.

| Final services | Uses | Number of species per use | Number of species per agroforestry system |
|---------------|------|---------------------------|------------------------------------------|
|               |      | Silvopastoral | Agrosilvopastoral | Agrisilvicultural |
| Provisioning  |      | | | |
| Food          | 1. Food | 50            | 14            | 44            | 15 |
| Natural medicines | 2. Medicine | 38            | 9             | 35            | 5  |
| /biochemical  | 3. Herbal | 7             | 1             | 7             |    |
|               | 4. Poison | 1             | 1             |               |    |
| Fuel          | 5. Fuel | 15            | 13            | 11            | 6  |
| Fibre         | 6. Handicrafts | 13            | 8             | 11            | 8  |
|               | 7. Wood | 12            | 10            | 8             | 7  |
|               | 8. Construction material | 4             | 3             | 4             | 4  |
|               | 9. Food packaging | 2             | 2             |               |    |
|               | 10. Compost | 1             | 1             | 1             | 1  |
|               | 11. Supporting form climbing plants | 1             | 1             |               |    |
|               | 12. Input for bean crop | 1             | 1             |               |    |
|               | 13. Forage | 1             | 1             |               |    |
|               | 14. Ink | 1             | 1             |               |    |
| Regulating    |      | | | |
| Crop protection | 1. Live fence | 32            | 26            | 22            | 13 |
|               | 2. Shade for crops | 4             | 2             | 4             | 1  |
| Habitat       | 3. Parrot or bird food | 3             | 1             | 1             | 1  |
| Soil conservation | 4. Soil protection | 2             | 2             | 2             |    |
| Nutrient cycling | 5. Nitrogen fixation | 1             | 1             | 1             | 1  |
| Cultural      |      | | | |
| Aesthetic landscapes | 1. Aesthetic | 9             | 6             | 2             |    |
| Cultural heritage | 2. Ritual | 4             | 1             | 4             | 1  |
Dash S, Misra M. 2001. Studies on hill agro-ecosystems of three tribal villages on the Eastern Ghats of Orissa, India. Agricul Ecos Env. 86:287–302.

Davis W. 1996. One river: explorations and discoveries in the Amazon rain forest. United States: Simon & Schuster Paperbacks.

Díaz I, González L, Fernández A, Howard P, Molina J, Reyes V. 2015. Social organization influences the exchange and species richness of medicinal plants in Amazonian homegardens. Ecol Socie. 21(1):1–14.

Egeland G, Harrison G. 2013. Health disparities: promoting indigenous peoples’ health through traditional food systems and self-determination. In: Kuhnein H, Erasmus B, Spigelskli D, Burlingame B, editors. Indigenous peoples’ food systems and well-being interventions and policies for healthy communities. Canada: FAO; p. 9–22.

Ferrari A, Wall L. 2004. The use of nitrogen fixing trees for reeled soil restoration. Rev Fac Agro La Plata. 105(2):63–87.

Fetterman D. 2010. Ethnography step-by-step: applied social research methods series. United States, UK, India, Singapore: SAGE.

Finaner R, Sackett R. 2003. Using home gardens to deci-pheer health and healing in the Andes. Medic Anthrop Quart. 17(4):459–482.

Gari J. 2001. Biodiversity and indigenous agroecology in Amazonia: the indigenous peoples of Pastaza. Etnoecológica. 5(7):21–37.

Garbach K, Milker J, Montenegro M, Karp D, DeClerck F. 2014. Biodiversity and ecosystem services in agroecosystems. Encyclopaedia Agr Food Sys. 2:1–40.

García E, Toledo M, Martínez J. 2008. Apropiación de la naturaleza por una comunidad Maya Yucateca: el análisis económico-ecológico [The conscious ownership of nature by a Maya-Yucatecan community: an economic-ecological analysis]. Rev Ibero Econ Ecol. 7:27–42.

Gebauer J. 2005. Plant species diversity of home gardens in El Obeid, Central Sudan. J Agric Res Devel Trop Sub. 106(2):97–103.

Ghosh A, Travers M, De Castro F, Morsello C, Siqueira A. 2005. Cultural services. In: Millennium Ecosystem Assessment, editor. Ecosystems and human well-being: policy responses. Washington, DC: Island Press; p. 401–422.

Hajjar R, Jarvis D, Gemmill-Herren B. 2008. The utility of crop genetic diversity in maintaining ecosystem services. Agric Ecos Environ. 123:261–270.

Huai H, Hamilton A. 2008. Characteristics and functions of traditional homegardens: a review. Front Biol China. 4(2):151–157.

Huxley P. 1999. Tropical agroforestry. USA-Canada-Australia: Blackwell Science Ltd.

IGAC Instituto Geográfico Agustín Codazzi. 1990. Estudio general de suelos de algunos municipios del Putumayo [A general soil survey of some Putumayo municipalities]. Bogotá (Colombia): IGAC.

IGAC Instituto Geográfico Agustín Codazzi. 2001. Carta general III – B –1,2,3,4 [maps]. Colombia: IGAC Instituto Geográfico Agustín Codazzi. 4 sheet: 1:10,000; black and white.

Jacanamijoy J. Unpublished. Diccionario bilingüe Camsá-Español Español-Camsá. p. 266.

Jammaddass R, Place F, Torquebiau E, Malézieux E, Liyama M, Sileshi G, Kehlenbeck K, Masters E, McMullin S, Weber J, et al. 2013. Agroforestry, food and nutritional security. Nairobi, Kenya: World Agroforestry Centre.

Linger E. 2014. Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabiithen District, North-Western Ethiopia: implication for climate change adaptation. SpringerPlus. 3(1):154–159.

Marquis G, Juteau S, Creed-Kanashiro H, Roche M. 2013. Infant and young child complementary feeding among indigenous peoples. In: Kuhnein H, Erasmus B, Spigelski D, Burlingame B, editors. Indigenous peoples’ food systems and well-being interventions and policies for healthy communities. Canada: FAO; p. 39–50.

Morevic A. 2009. Traditional home gardens and rural livelihoods in Nhema, Zimbabwe: a sustainable agroforestry system. In J Sust Devel Worl Ecol. 16(1):1–8.

Millennium Ecosystem Assessment. 2003. Ecosystems and human well-being: a framework for assessment. USA: Island Press.

Millow P, Ramli M, Chooi O. 2010. Preliminary survey on plants in home gardens in Pahang, Malaysia. J Biod. 1(1):19–25.

Nafziger E. 2009. Cropping systems. In: Nafziger E, editor. Illinois Agronomy Handbook. USA: University of Illinois; p. 49–63.

Nair R. 1993. An introduction to agroforestry. Netherlands: Kluwer Academic Publishers.

Neelamgaram R, Pillai V, Anishal A, Reselin S. 2015. Status and composition of home garden plants in rural and urban areas in Kanyakumari District, Tamil Nadu, India. Sch. Acad. J. Biosci. 8(3):656–667.

Onwuegbuzie A, Collins K. 2007. A typology of mixed methods sampling designs in social science research. Qualit Rep. 12(2):281–316.

Palacios V. 2008. Identificación y caracterización de sistemas agroforestales tradicionales en la comunidad Caméntas resguardo Tamabioy municipio de Sibundoy, Putumayo [dissertation]. Colombia: Universidad de Nariño.

Palacios V. 2012. Análisis socioeconómico de los sistemas de producción agraria en los resguardos indígenas Tamabiyo y San Félix de Sibundoy, Putumayo [dissertation]. Colombia: Universidad Nacional de Colombia.

Palacios V, Barrientos J. 2011. Importancia del huerto casero en la seguridad alimentaria. Caso de la comunidad indígena Caméntas del Valle de Sibundoy, Colombia [Importance of the home garden for food security. Case of the indigenous community Sibundoy Valley, Colombia]. CienciAgro. 2(2):313–318.

Palacios V, Barrientos J. 2014. Caracterización técnica y económica de los agrosistemas de producción en dos resguardos indígenas del Putumayo [The farm systems in two indigenous territories of Putumayo (Colombia), a technical economic comparative assessment. Acta Agron. 63(2):1–15.

PAR Platform for Agrobiodiversity Research. 2010. The use of agrobiodiversity by indigenous and traditional agricultural communities in: adapting to climate change. Italy: PAR.

Paumgarten F, Shackleton C, Cocks M. 2005. Growing of trees in home-gardens by rural households in the Eastern Cape and Limpopo provinces, South Africa. Int J Sust Devel Worl Ecol. 12:365–383.

Pimbert M. 2009. Towards food sovereignty. Gatekeeper. 141:1–20.

Rodríguez J. 2010. Uso y manejo tradicional de plantas medicinales y mágicas en el Valle de Sibundoy, alto Putumayo, y su relación con procesos locales de construcción ambiental [Traditional use of medicinal
plants in the Sibundoy Valley, Putumayo – The linkages to building local environmental processes]. Rev Acad Col Cienc Exac Fis Nat. 34(132):309–326.
Sama A, Hughes H, Abbas M, Shahha M. 2012. An efficient in vitro propagation protocol of cocoyam [Xanthosoma sagittifolium (L) Schott]. Scie Wotr J. 2012:1–10.
Schroth G, Souza M, Hills T, Soto L, Wijayanto I, Arief C, Zepeda Y. 2011. Linking carbon, biodiversity and livelihoods near forest margins: the role of agroforestry. In: Kumar M, Nair P, editors. Carbon sequestration potential of agroforestry systems. Opportunities and challenges. London-New York: Springer; p. 179–200.
Senanayake R, Sangakkara U, Pushpakumara D, Stamp P. 2009. Vegetation composition and ecological benefits of home gardens in the Meegahakuli region of Sri Lanka. Trop Agric Res. 21(1):1–9.
Swinton S, Lupi F, Robertson G, Hamilton S. 2007. Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecol Econ. 64:245–252.
Teddlie C, Yu F. 2007. Mixed methods sampling. A typology with examples. J Mix Meth Resea. 1(1):77–100.
Toledo V. 2001. Indigenous peoples and biodiversity. Encyclop Biodiv. 3:451–463.
Trinh L, Watson J, Hue N, De N, Minh N, Chu P, Shapat B, Eyzaguirre P. 2003. Agrobiodiversity conservation and development in Vietnamese home gardens. Agriculture, Ecosys Enviro. 97:317–344.
Trujillo E, Frausin G, Correa M, Trujillo W. 2010. El uso de la ayahuasca en la Amazonia [Ayahuasca use in the Amazon]. Ingen Amazon. 3(2):151–163.
Turner N, Plotkin M, Kuhnlein H. 2013. Global environmental challenges to the integrity of indigenous peoples’ food systems. In: Kuhnlein H, Erasmus B, Spigelski D, Burlingame B, editors. Indigenous peoples’ food systems and well-being interventions and policies for healthy communities. Canada: FAO; p. 23–38.
UNHCR United Nations High Commissioner for Refugees. 2011. Informe comunidades indígenas [Human rights report indigenous communities]. Colombia: UNHCR United Nations High Commissioner for Refugees.
United States Department of Agriculture. 2015. USDA food composition database. USDA Nutrient Data Laboratory - Food and Nutrition Information Center and Information System Division of the National Agricultural Library. Available at https://ndb.nal.usda.gov/ndb/
Van De Berg A, Kulenthran T, Muller S, Pitt D, Wascher D, Wijesuriya G, Amelung B, Eliezer N, Gopal A, Rössler M. 2005. Cultural and amenity services. In: Hassan R, Scholes R, Ash N, editors. Ecosystems and human well-being: current state and trends. Washington, DC: Island Press; p. 455–476.
Young A. 1997. Agroforestry for soil management. UK: ICRAF.
Zhang W, Ricketts T, Kremen C, Carney K, Swinton S. 2007. Ecosystem services and dis-services to agriculture. Ecol Econ. 64:253–260.
### Appendix A1. Woody perennial, herbaceous, vines, and cane plants in the rural agrarian systems of Sibundoy Valley.

| #  | Scientific name                          | Name                             | English or Spanish (S) | Family | Use                  |
|----|-----------------------------------------|----------------------------------|------------------------|--------|----------------------|
| 1  | A. mearnsii                             | Acacia                           | Fabaceae               | W, G, H, L |
| 2  | A. melanoxylon R. Brown.               | Acacia                           | Fabaceae               | G, L   |
| 3  | Acacia sp                               | Acacia arizonica (S)             | Fabaceae               | W, G, H, L |
| 4  | A. jorullensis                          | Chamaecyparis thyoides (S)       | Fabaceae               | G, L   |
| 5  | Ambrosia sp                             | Tseta                            | Fabaceae               | F      |
| 6  | Baccharis latifolia                     | Chila                            | Fabaceae               | C, L   |
| 7  | Baccharis sp                            | Chila blanca (S)                 | Fabaceae               | C, L   |
| 8  | Brugmansia arborescens (Linnaeus)      | Golden angel's trumpet tree      | Solanaceae             | M      |
| 9  | B. aurea Lagerheim                      | Golden angel's trumpet tree      | Solanaceae             | M      |
| 10 | Brugmansia x candida f. Culebra     | Mestcuay borrachero              | Solanaceae             | M      |
| 11 | Brugmansia x candida Persson           | Borrachero (S)                   | Solanaceae             | M, L   |
| 12 | Brugmansia sp                           | Andaquí borrachero (S)           | Solanaceae             | M      |
| 13 | Micromelanum sp                        | Chili                            | Solanaceae             | F      |
| 14 | C. ochraceum                           | Syangish                         | Solanaceae             | M, I, S, B, G |
| 15 | Ceuster sp                             | Fchentangtly                     | Solanaceae             | H, B   |
| 16 | Coffea arabica L.                      | Coffee                           | Rubiaceae              | A      |
| 17 | Croton magdelenensis Müll. Arg.        | Sangregano (S)                   | Euphorbiaceae          |        |
| 18 | Cupressus sempervirens                 | Cypress                          | Cupresaceae            | W, G, L|
| 19 | Cyathea incana                         | Bongueity, bongé                 | Cyathaceae             | C, L   |
| 20 | Cyphomandra betacea                    | Chémalbity, chémalbá             | Solanaceae             | F      |
| 21 | Datura candida cv. Quinde              | Quinde borrachero (S)            | Solanaceae             | M      |
| 22 | Ficus carica cv. Guanuco               | Guanuco                          | Solanaceae             | M      |
| 23 | Delostoma integrifolium D. Don         | Nacedero (S)                     | Bignoniaceae           | L      |
| 24 | Erythrina edulis                       | Tsémbesty                        | Fabaceae               | F      |
| 25 | Eucalyptus citriodora Hook.            | Lemon eucalyptus                 | Myrtaceae              | W, G, H, L |
| 26 | Eucalyptus globulus                    | Blue gum                         | Myrtaceae              | W, G, H, L |
| 27 | Ficus carica L                         | Common fig                       | Moraceae               | F      |
| 28 | Fraxinus chinensis                     | Urápán (S)                       | Oleaceae               | W, G, H, L |
| 29 | Fuchsia boliviana Carriere             | Fucia arbutiva (S)               | Onagraceae             | L      |
| 30 | Hieronyma colombiana                   | Motián (S)                       | Phyllanthaceae         | F, L   |
| 31 | I. edulis                              | Ice-cream-bean                   | Fabaceae               | F, L   |
| 32 | Iochroma fuchsioides                   | Quinde chupa (S)                 | Solanaceae             | M, L   |
| 33 | Juglas neotropica                      | Andean walnut                    | Juglandaceae           | W, G   |
| 34 | Lapiensia acuminata (Ruiz y Pav.) DC. | Guayacán (S)                     | Lythraceae             | L      |
| 35 | Lippia citriodora (Lam.) Kunth.        | Lemon verbena                    | Verbeneaceae           | M, E   |
| 36 | Malus domestica                        | Apple                            | Rosaceae               | F      |
| 37 | Malus sp                               | Morichillo (S)                   | Melastomateaceae       | L      |
| 38 | Musa paradisiaca                      | Plantain                         | Musaceae               | F      |
| 39 | Myrica pubescens                       | Laurel (S)                       | Myricaceae             | G      |
| 40 | Nicotiana tabacum                      | Tobacco                          | Solanaceae             | M      |
| 41 | Ocotea sp                              | Medio comino (S)                 | Lauraceae              | L      |
| 42 | P. americana                           | Avocado                          | Lauraceae              | F      |
| 43 | Pinus patula                           | Pine                             | Pinaceae               | W, G, H, L |
| 44 | Piper bogotense C. DC.                 | Arco iris (S)                    | Piperaceae             | L      |
| 45 | Pouteria leuca                       | Macý, macbé                      | Sapotaceae             | F, B, Q|
| 46 | Pouteria sp                            | Palto Joro (S)                   | Sapotaceae             | K      |
| 47 | Prestoea acuminata                    | Bétsajeshá                      | Araceae                | F, H   |
| 48 | P. capuli                              | Mountain black cherry            | Rosaceae               | F, L   |
| 49 | Prunus domestica                       | Tsabettly                        | Rosaceae               | F      |
| 50 | Prunus persica                         | Peach                            | Rosaceae               | F      |
| 51 | P. guajava L                          | Lemon guava                      | Myrtaceae              | F      |
| 52 | Pynus communis                         | Peer                             | Rosaceae               | F      |
| 53 | Rosmarinus officinalis L.              | Rosemary                         | Lamiaceae              | F      |
| 54 | Salix humboldtiana                     | Willow                           | Salicaceae             | W, G, H, L |
| 55 | Sambucus nigra                         | Elderberry                       | Adoxaceae              | M, L   |
| 56 | Sapium sp                              | Cauchillo (S)                    | Euphorbiaceae          | L      |
| 57 | Saurauia scabra (Kunth) (D. Dietr.     | Nyinty                          | Actinidaceae           | L, W, G|
| 58 | Smallanthus pyramidalis (Triana) (H. Rob. | Macoya (S)                     | Asteraeae              | O, L   |
| 59 | Swinga glotinosa (Blanco) Merr.        | Lemon                            | Rutaceae               | F      |
| 60 | Tomentosa fuliginea                    | Buendénty                       | Boraginaceae           | M, K   |
| 61 | Trichocereus pachonii                 | San Pedro (S)                    | Cactaceae              | M      |
| 62 | Vascuncellea pubescens                | Titeyes, tityies                | Caricaceae             | F, M, L|
| 63 | V. tripolygium Bentahm                | Ndtétembetty                     | Adoxaceae              | V, B, G|
| 64 | Weinmannia pubescens                  | Encino (S)                       | Cunoniaceae            | W      |
| 65 | Y. elephantipes Regel                 | Palma de yucca (S)               | Agavaceae              | A      |

### Herbaceous, vines, and cane

| #  | Scientific name                          | Name                             | English or Spanish (S) | Family | Use                  |
|----|-----------------------------------------|----------------------------------|------------------------|--------|----------------------|
| 66 | Abutilon insignis Planch.              | Campanita (S)                    | Malvaceae              | L      |
| 67 | Allium fistulosum                      | Onion                            | Amaryllidaceae         | F      |
| 68 | Aloe vera                              | Aloe                             | Xanthorrhoeaceae       | M      |
| 69 | Alstroemeria aurantica                 | Alstroemia (S)                   | Alstromeriaceae        | A      |
| 70 | Alternanthera Mexican                  | Descancel (S)                    | Aamaranthaceae         | M      |
| 71 | Amica montana                          | Mountain aura                    | Asteraeae              | M      |
| 72 | Arracacia xanthorrhiza                 | Ingóshá, Ingó                    | Apiaceae               | F      |
| 73 | Artemisia absinthium                   | Wormwood                         | Asteraeae              | M      |
| 74 | Arundo donax                           | Juinjyanéséjá                    | Poaceae                | C, H, Q, L |

(Continued)
| No. | Scientific name | Name | Family | Use |
|-----|-----------------|------|--------|-----|
| 75  | Axonopus scoparius | Pasto imperial (S) | Poaceae | T |
| 76  | B. caapi | Ayahuasca (From Quichua language) | Malpighiaceae | M, R |
| 77  | Brassica oleracea | Beshá, beshentsá | Wild cabbage | Brassicaceae | F |
| 78  | C. gigantea | Pot marigold | Asteraceae | M, A |
| 79  | Canna indica | Bebíá | Achira (S) | Cannaceae | F, U, H, M |
| 80  | Canna sp. | Buángan bebíá | Achira morada (S) | Cannaceae | F, U, H |
| 81  | Cannabis sativa | Cannabis | Cannabaceae | M |
| 82  | Chenopodium ambrosioides | Paico (S) | Amañantchéaceae | M |
| 83  | C. and xanthosoma sp. | Jomésá | Barbacoano (S) | Araceae |
| 84  | Cucurbita ficifolia | Quelbásëjuá | Pumpkin | Cucurbitaceae | F |
| 85  | C. maxima | Squash | Cucurbitaceae | F |
| 86  | Cymbopogon citratus | Limoncillo (S) | Poaceae | M, E |
| 87  | Cyperus ferax | Chonduro (I) | Chonduro (S) | Cyperaceae |
| 88  | Cyperus sp. | Chonduro Colorado (S) | Cyperaceae |
| 89  | Dalia sp. | Dalia (S) | Asteraceae | A |
| 90  | Fragaria vesca | Strawberry | Rosaceae | F |
| 91  | Furcraea andina | Cabuya (S) | Agavaceae | L |
| 92  | Geranium sp. | Cranesbill | Geraniaceae | A |
| 93  | H. bimittata | Cuyanguillo (S) | Acanthaceae | M |
| 94  | Hydrangea arborescens | Smooth hydrangea | Hydrangeaceae | A |
| 95  | Manihot dulcis | Cassava | Euphorbiaceae | F |
| 96  | Matricaria chamomilla | Chamomile | Asteraceae | M, E |
| 97  | Melissa officinalis | Balm mint | Lamiaceae | M, E |
| 98  | Mentha arvensis | Wild mint | Lamiaceae | E |
| 99  | Mentha spicata | Spearmint | Lamiaceae | E |
| 100 | Ocimum basilicum | Sweet basil | Lamiaceae | E |
| 101 | O. vulgare | Oregano | Lamiaceae | F |
| 102 | P. ligularis | Matingajëshá | Passifloraceae |
| 103 | Passiflora mixta L. | Curuba, tavo (S) | Passifloraceae |
| 104 | Pelargonium sp. | Malva alta | Malvaceae | A |
| 105 | Peperonia sp. | Boteshá, uaboteshá | Piperaceae | R |
| 106 | Petrocallis crispum L. | Parsley | Apiaceae | F |
| 107 | Pisum sativum | Pea | Fabaceae | F |
| 108 | Phaseolus coccineus | Frijol tranca (S) | Fabaceae | F |
| 109 | Phaseolus vulgaris | Tsëmbé | Bean | Fabaceae | F |
| 110 | P. peruviana | Physalis | Solanaceae | F |
| 111 | Rosa centifolia | Rose | Rosaceae | A |
| 112 | Rubus glaucus | Blackberry | Rosaceae | F |
| 113 | R. ursinus | Blackberry | Rosaceae | F, K |
| 114 | Ruta graveolens | Rue | Rutaceae | M |
| 115 | Saccharum officinarum | Sugarcane | Poaceae | F |
| 116 | Satureja brownii | Poleo (S) | Lamiaceae | M |
| 117 | S. edule | Chayote | Cucurbitaceae | F, M |
| 118 | S. quitensis | Mashactiy | Lulo (S) | Solanaceae | F |
| 119 | Solanum sp. | Naranjuala (S) | Solanaceae | F |
| 120 | Solanum tuberosum | Potato | Solanaceae | F |
| 121 | Taraxacum officinale | Dandelion | Asteraceae | M |
| 122 | Triglochin maritima | Watsimba (S) | Iridaceae | F |
| 123 | Urtica urens | Ushbojëshá | Urticaceae | M |
| 124 | Verbena officinalis | Verbena | Verbenaceae | M, R |
| 125 | Vicia faba | Broad bean | Fabaceae | F |
| 126 | X. sagittifolium (L.) Scott & Endl. | Tumaqueño (S) | Araceae | F |
| 127 | Xanthosoma sp. | Sandona (S) | Araceae | F |
| 128 | Z. mays | Sbuachán | Maize | Poaceae | F, R |

A: aesthetic; B: shade for crops; C: construction material; D: compost; E: herbal; F: food; G: fuel; H: handicrafts; I: natural ink; K: parrot or bird food; L: live fence; M: medicinal; N: nitrogen fixation; O: poison; Q: support for bean plants; R: ritual; S: soil protection; T: forage; U: food packaging; V: soil retention; W: wood.
Appendix B1. Food species biodiversity identified with a stable, a local, a small, and a promissory market.

| Stable market | Food species |
|---------------|--------------|
| 1. C. betacea | 2. F. vesca L. |
| 3. P. ligularis | 4. P. vulgaris |
| 5. P. sativum | 6. R. glaucus |
| 7. S. quitense | 8. S. tuberosum |
| 9. Z. mays |  |

| Local market | Food species |
|--------------|--------------|
| 1. A. fistulosum | 2. Colocasia and xanthosoma sp. |
| 3. P. morta L. f. | 4. P. americana |
| 5. Phaseolus coccineous | 6. S. officinarum |
| 7. S. edule | 8. V. pubescens |
| 9. V. faba |  |
| 10. Xanthosoma sagitifolium |  |

| Small market | Food species |
|--------------|--------------|
| 1. Capsicum annum | 2. E. edulis |
| 3. F. carica L. | 4. H. colombiana |
| 5. F. edulis | 6. M. domestica |
| 7. M. paradisiaca | 8. P. lucuma |
| 9. Prestoea acuminata | 10. P. domestica |
| 11. P. persica | 12. P. guajava L. |
| 13. P. communis | 14. Rosmarinus officinalis L. |
| 15. S. scabra (Kunth) D. Dietr. | 16. S. glutinosa (Blanco) Mer. |
| 17. A. xanthorrhiza | 18. B. olaraceae |
| 19. C. indica | 20. Canna sp. |
| 21. Cucurbita ficifolia | 22. Cucurbita mexicana |
| 23. M. dulcis | 24. O. vulgare |
| 25. P. crispum L. | 26. Rubus utricellulosus |
| 27. Solanum sp. |  |

| Promissory market | Food species |
|-------------------|--------------|
| 1. P. peruviana | 2. P. capuli |