Chapter 12
Hacienda Pinzacuá: An Example of Regenerative Agriculture Amidst a Transformed Landscape in the Colombian Andes

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Abstract The central Andes of Colombia is a region of high biodiversity that has been intensely transformed, mostly by unsustainable agricultural practices, and especially by extensive cattle grazing. Whereas cattle farms are often considered ecological deserts, cattle production can be approached in a different way: by integrating more trees into the pastures, introducing better animal management practices, and restoring protective forests, so that productivity, biodiversity, and the flow of ecosystem services can be positively impacted. In this case study, we describe the agroecological transformation of Hacienda Pinzacuá, a 45-hectare farm that has become an island of regenerative agriculture amidst a highly fragmented landscape. We explain how the farm's land use history led to the severe degradation of its once fertile soils; how key land management decisions were made and gradually implemented through trial and error; and the significant land cover changes that occurred over 20 years of transformation. We also provide data on how these changes have impacted productivity, biodiversity, and ecosystem services to illustrate how conservation and production can work synergistically to transform the land and the people. Today Pinzacuá stands out as an island of vegetation in an otherwise treeless landscape and has become a high-quality matrix that serves as habitat or refuge for a variety of taxa striving to persist in this fragmented landscape. Finally, we reflect on the challenges faced along the process, and the prospects for maintaining Pinzacuá as both an island of biodiversity and an example for other farmers seeking more resilient productive alternatives.

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F. Montagnini (ed.), *Biodiversity Islands: Strategies for Conservation in Human-Dominated Environments*, Topics in Biodiversity and Conservation 20,
https://doi.org/10.1007/978-3-030-92234-4_12

Keywords Agroforestry · Biodiversity conservation · Degraded landscapes · Ecosystem services · Landscape restoration · Silvopastoral systems

12.1 Introduction

The Andean region of Colombia is part of the Northern Andes biodiversity hotspot, an area known for its ecosystem diversity and high levels of endemism, and its significance for global biodiversity (Mittermeier et al. 2011). The region is home to 34% of the country's population—almost 17 million people—and generates 32% of the national Gross Domestic Product (GDP) (Delgado and Pérez 2018). Human activities such as agriculture, cattle ranching, urbanization, infrastructure development, and species introductions have rapidly transformed this landscape, creating enormous pressure on the remaining natural ecosystems, their biodiversity, and the vital services they provide (Kattan and Alvarez-López 1996). Today, only 18–25% of the original forest cover remains, mostly as fragmented remnants embedded in a matrix of agricultural land uses (Etter 1998). As a result, Colombia's Andean ecosystems are among the most threatened in the world (Mittermeier et al. 2011), and the human populations who inhabit them face increasing risks from the impacts of land degradation.

Across Latin America, this pattern of ecosystem transformation has led to a widespread biodiversity crisis that is further compounded by climate change. A variety of nature-based solutions—actions to protect, restore and sustainably manage both natural and transformed landscapes—have been identified that can contribute to preserve biodiversity, combat climate change, and improve human well-being (IUCN 2020). For example, improving the management of agricultural lands to achieve a balance between a sustainably managed matrix, protected ecosystem remnants, and high connectivity is critical to support biodiversity, sustain the flow of ecosystem services, and enhance climate change resilience (Chazdon et al. 2009; Perfecto and Vandermeer 2010; Vílchez et al. 2013; Griscom et al. 2017; Kremen and Merenlender 2018).

Increasing tree cover through practices such as adding live fences, planting, establishing or retaining trees in pastures, and using complex agroforestry and silvopastoral systems can enhance the conservation value of agricultural landscapes without compromising production (Perfecto and Vandermeer 2010; Harvey et al. 2011; Tscharntke et al. 2012; Mendenhall et al. 2014; Prevedello et al. 2018). Although lack of access to technical assistance and financial incentives still limit the widespread adoption of many such practices (Calle et al. 2013; Calle 2020), a growing number of landowners are realizing the need to re-evaluate their conventional practices and test alternative methods to work more closely with nature.

This chapter presents a case study examining the transformation of Pinzacuá, a farm located in the central Andean region of Colombia and whose landowners, having witnessed the degradation of their once fertile lands, decided to change course. We describe the efforts made over 20 years to restore productivity in this 45-hectare farm by increasing tree cover and recovering soil health. We begin by

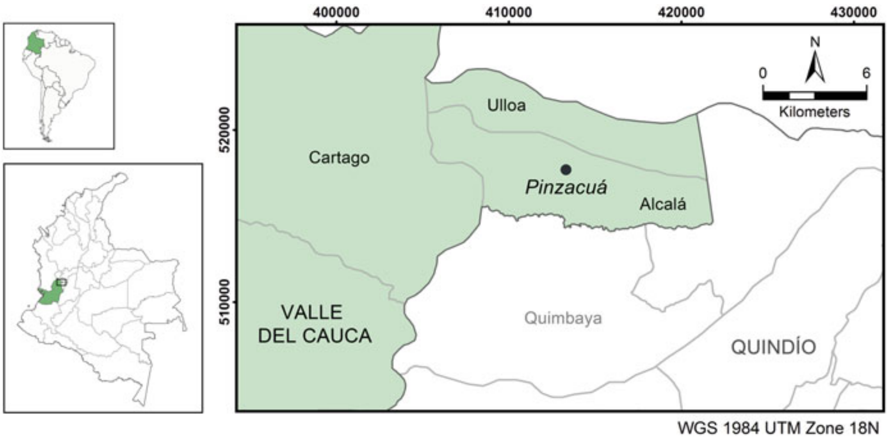

Fig. 12.1 Location of Pinzacuá in the La Vieja River watershed in Colombia's Andean region. Map: Alicia Calle

explaining the landscape context and land use history, then describe how gradual changes were implemented, and the impacts of the process on biodiversity, farm productivity, and ecosystem services. Finally, we reflect on the future of the farm and the challenges and opportunities for others who may decide to tackle such an effort.

12.2 Landscape and Social Context

Hacienda Pinzacuá is located on the western slope of Colombia's Central Cordillera, in the La Vieja river central watershed which marks the limits between the departments of Quindío and Valle del Cauca (Fig. 12.1). The farm is adjacent to Alcalá, a town of 20,000 people located at 1290 m.a.s.l. Annual precipitation averages 1900 mm distributed bimodally from March to May and September to November; average annual temperature is 23.4 °C and relative humidity is 85% (Comisión Conjunta 2008). The area's original vegetation is typical of the transition between premontane and low montane humid forest (Espinal 1977). However, only 11% of the original forest cover remains, mostly in bamboo forests and unconnected fragments <5 hectares (Camargo and Cardona 2005). Soils are Inceptisols and Andisols of quaternary alluvial and volcanic origins respectively, which are young and deep (20–30 m), ranging from sandy to clayey loam in texture, free of rock and acidic (pH 4.5–5.5), and highly productive (Montes Londoño et al. 2017).

While the region has a strong agricultural tradition, the type of agriculture practiced has changed over the past century in response to external drivers. The original forests were first replaced by traditional coffee agroforests, and eventually converted to single-crop coffee plantations of the more productive sun-loving varieties. The collapse of coffee prices in the 1980s and 90s resulted in further conversion, mostly to highly fertilized pastures for cattle ranching (Calle and Piedrahíta 2007), disregarding the fact that the fragile soils and steep slopes are unsuitable for grazing (Sadeghian et al. 2001). Today, the area is an agricultural mosaic of cash crops (e.g., coffee, plantain, citrus) and cattle pastures, which occupy 33% of the land (DANE 2014). Pinzacuá is surrounded by undulating hills covered by a mix of croplands with some isolated trees, monocultures of African grasses with sparse tree cover, some live fences, small fragments of disturbed secondary forests and riparian areas, and small bamboo forest patches.

Historically, this region enjoyed a strong economy and a high quality of life for two main reasons. First, it is located at the center of the so-called “golden triangle” formed by Bogotá, Medellín and Cali, Colombia’s main cities. Second, for most of the twentieth century, this was the country’s prime coffee-growing region, and the majority of its nearly four million inhabitants were dedicated to this activity. High productivity and a strong international coffee market resulted in an economic boom that allowed for the development of excellent infrastructure and services, and the highest quality of life in the country (Toro Zuluaga 2005; Mejía Cubillos 2013). The crash of the coffee markets in the 1990s led to a general economic contraction and the emergence of new problems: unemployment, loss of income, unequal access to essential public services, and increased levels of drug-related violence, all compounded by the arrival of people displaced by the armed conflict that was taking place elsewhere in the country (Toro Zuluaga 2005). Ultimately, the human development index (HDI) stagnated for almost a decade and its gap with respect to the national average widened (UNDP 2004).

The decline of coffee production gave way to new sectors such as telecommunications, services, tourism, construction and commerce that replaced agriculture. Urban centers now concentrate most economic activities and the majority of the population, while less than 15% of the people remain in rural areas (Mejía Cubillos 2013). Moreover, the farmer population is aging; more than 40% are between 40 and 54 years old (DANE 2014). The remaining farms are mostly privately owned, small and medium properties between 5 and 200 hectares (UPRA 2019a, b, c). Smaller farms are usually family-owned and subsistence-oriented, with a mix of cash crops and livestock. Meanwhile, larger farms are largely monoculture-based commercial operations. As farming declines, the price of land in this densely populated region has skyrocketed: the price of an average hectare of cropland in 2014 was $4000 (Becerra et al. 2017a, b, c), but near urban or touristic areas it can be as high as $40,000 (López Murillo 2015). High prices are forcing a land ownership transformation in this landscape where only large developers or consolidated farm owners can afford the land, and the latter tend to stick to the conventional high-input-high-output monoculture model.

12.3 Transforming Pinzacuá: An Incremental Process

12.3.1 History of a Transformation

Pinzacuá is a 45-hectare family-owned and operated business dedicated to raising high-quality female Brangus cattle for breeding and beef production. The farm was acquired in 1985, and its land use history since then can be divided in two distinct periods: before and after 1997. A summary of the main events in the farm's history is provided in Table 12.1.

Before 1997, the farm followed the prevailing high-input, treeless pasture model dictated by the dominant agricultural intensification trend of the 1960s, 70s and 80s. Under this model, a succession of different crops was planted: first coffee, then tobacco, and finally pasture. Despite the high yields, the farm was never profitable because the prices of these commodities could not compensate for the excessive costs of the imported agrochemicals on which production depended. Moreover, as the soils were gradually depleted, higher doses of fertilizers were required every year simply to maintain production. After a decade of struggling to keep the farm afloat, the need to reduce input dependency and keep production costs under control became evident.

In 1997 the decision was made to stop chemical fertilization altogether. This not only required cutting animal load by half, but it also revealed the severity of soil degradation. Finding a strategy to restore soil fertility without applying external inputs thus became the priority. Experience and self-reflection about traditional production systems eventually led to a question: if the soils of coffee systems shaded with nitrogen-fixing *Inga* trees were so rich that they required little fertilization and no pesticides, could the same principles apply to pastures? So, defying the widespread idea that trees and pastures do not mix, in 2002 a 2-hectare trial plot was established with *Inga* spp. trees planted at a density of 100 trees ha^{-1}.

The first 2 years of this trial were difficult: establishing trees in active pastures turned out to be more challenging and expensive than anticipated. Damage by cattle, leaf-cutter ants and humans all contributed to the high mortality rate of the planted seedlings. The idea that trees do not belong in pastures was deeply engrained, and farm workers were reluctant to protect and care for the seedlings which resulted in the need to replant constantly. Protecting the young trees from cattle browsing and trampling was also problematic and required creative solutions (Fig. 12.2). Trees were initially protected with individual bamboo corrals, but eventually a better method was developed by planting lines of trees protected with electrical fence. Fellow cattle ranchers mocked these efforts arguing that intentionally increasing tree cover in the paddocks was nonsense as it would reduce pasture productivity.

In 2002, as the landowner began to question the introduction of *Inga* trees in the pastures, news about the launching of a sustainable ranching project in the region reached him. The Regional Integrated Silvopastoral Ecosystem Management (RISEM) project was providing technical assistance and payments for ecosystem services to promote the adoption of silvopastoral systems, previously unknown in

Table 12.1 Main events in Pinzacuá's land-use history

Year	Event
1985	Pinzacuá is acquired. The farm is a traditional agroforestry plantation with coffee growing under diverse assemblages of shade trees, mainly *Inga*.
1986 (Inspired by the Green Revolution, the National Coffee Federation promoted intensification efforts during these years, paying farmers to eliminate tree cover and replace traditional shade coffee for more productive sun-loving varieties. Tree cover was eliminated in 50% of this territory as a result of both coffee intensification campaigns and a push to replace coffee with pastures in the 1990s (Rodríguez et al. 2004). These changes led to landscape-level degradation and fragmentation of the remaining natural habitats, and in some cases triggered local or regional extinctions (Kattan et al. 2004). Although yields did increase, approximately half of the increased production was lost due to a labor shortage)	Shade coffee is replaced with sun-coffee managed with intensive application of synthetic fertilizers and pesticides, and shade trees are completely eliminated.
1993	Sun coffee is eliminated due to low market prices, and replaced by a monoculture of the African grass *Cynodon plectostachium* without trees, and a monocrop plantation of tobacco.
1994	Tobacco is eliminated and the entire farm is converted to pasture. Pasture management based on intensive application of fertilizers and amendments (1 ton of urea plus 2 tons of dolomite lime ha^{-1} $year^{-1}$) continues in order to sustain a high animal load (10 heads ha^{-1}).
1998	Use of agrochemicals becomes economically unviable and is completely eliminated. As a result, animal loads are reduced and soil degradation becomes evident. Shifting away from grass monoculture to a regenerative system becomes the priority.
2000	A trial plot with *Inga* trees is established with the hope of restoring soil fertility.
2002	Using a farm planning approach, plots are classified according to their potential and limitations. Streams are isolated and riparian areas reforested with native trees and bamboo (*Guadua angustifolia*).
2015	Fodder hedgerows are established within some paddocks.
2016	A small agroforestry plot with shade-loving arabica coffee is established.
2018	A forage bank to feed goats is established.

Fig. 12.2 Methods to plant and protect trees in established active pastures. Individual bamboo and shade cloth corral method (left), and 2 m-wide strips protected with electrical fence (right), an innovation devised in Pinzacuá and later replicated in other farms. Photos: Álvaro Zapata

the region (Pagiola and Ríos 2013). Pinzacuá, along with other 74 farms, joined the project and started working with assistance from the Center for Research on Sustainable Agriculture Production Systems (CIPAV, CIPAV.org.co), whose technical staff advocated increasing tree cover throughout the farm and encouraged the *Inga* trial. Although the project's economic incentive was capped at US $6500 per farm and only covered approximately 30% of the implementation costs incurred, the motivation and support provided by CIPAV were instrumental for Pinzacuá to persevere in its tree-planting efforts.

From that point on, tree planting became the centerpiece of Pinzacuá's transformation. A land use plan was devised to utilize each plot according to its potential. Trials planting a variety of trees in different spacing arrangements were expanded throughout the farm to identify the optimal combinations. Paddocks were divided with live fences and cattle were rotated in short periods. All streams and water courses were fenced off, and riparian buffer areas were reforested with native tree species and *Guadua angustifolia,* a native giant bamboo. The steepest areas of the farm, which were unsuitable for cattle, were planted with mixed native species. More recently, an agroforestry system with arabica coffee was established and other non-timber forest products such as vanilla and pepper were tested. Fodder hedgerows were planted in some paddocks and a forage bank to feed goats was established.

The changes implemented in Pinzacuá described in the following sections were inspired by a variety of sources. As a former coffee grower, the landowner drew initial ideas for tree planting densities and pruning regimes from technical manuals for shade coffee published by Colombia's Coffee Grower's Federation (federaciondecafeteros.org). Drawing on decades of experience developing silvopastoral systems and management, CIPAV staff offered guidance on tree and fodder species and pasture management, and helped adjust the systems to Pinzacuá's conditions. Visits to demonstration farms, especially to the flagship silvopastoral farm El Hatico Nature Reserve (Calle et al. 2022), enabled farmer-to-farmer learning and inspired many ideas for small scale trials. Ultimately, the landowner's own curiosity and innovative spirit, observation skills, and proclivity to old-fashioned empirical learning were critical for the refinement of techniques that worked for Pinzacuá, some of which went on to become standard silvopastoral practice (Calle 2008).

12.3.2 Trees and Living Soils, the Pillars of Change

Ever since coffee was introduced in Colombia, trees have played a key role in traditional coffee agroforestry systems. Pinzacuá's transformation and its current land use practices are rooted in this traditional knowledge and in the realization that the mechanisms that sustained high natural productivity in shaded coffee systems are largely based on the benefits provided by trees. Today, the entire farm is planted with trees and all land uses—silvopastures, riparian areas, and the homegarden—have some form of tree cover (Fig. 12.3).

The impact of trees on productivity is not direct, but rather mediated by their effect on different components of the production system, from the livestock to the soils. The strength and quality of high-performing soils rest on the interactions between a multitude of beneficial macro and microorganisms that constitute the soil food web. Earthworms, arthropods, nematodes, fungi, protozoa and bacteria consume energy-rich materials (e.g., leaves, roots, root exudates) all of which are directly or indirectly sourced from plants, especially trees, via litterfall and roots. Without plentiful and diverse plant-derived organic inputs, the soil food web cannot thrive (Moebius-Clune et al. 2016). For this reason, and despite the inherent competition between trees and pastures, the main objective of all actions implemented in Pinzacuá since 1997 has been to adequately feed and provide the best conditions for the life belowground. Plants, and especially trees, have been the farm's best allies in restoring soils and making them alive, dynamic, and productive.

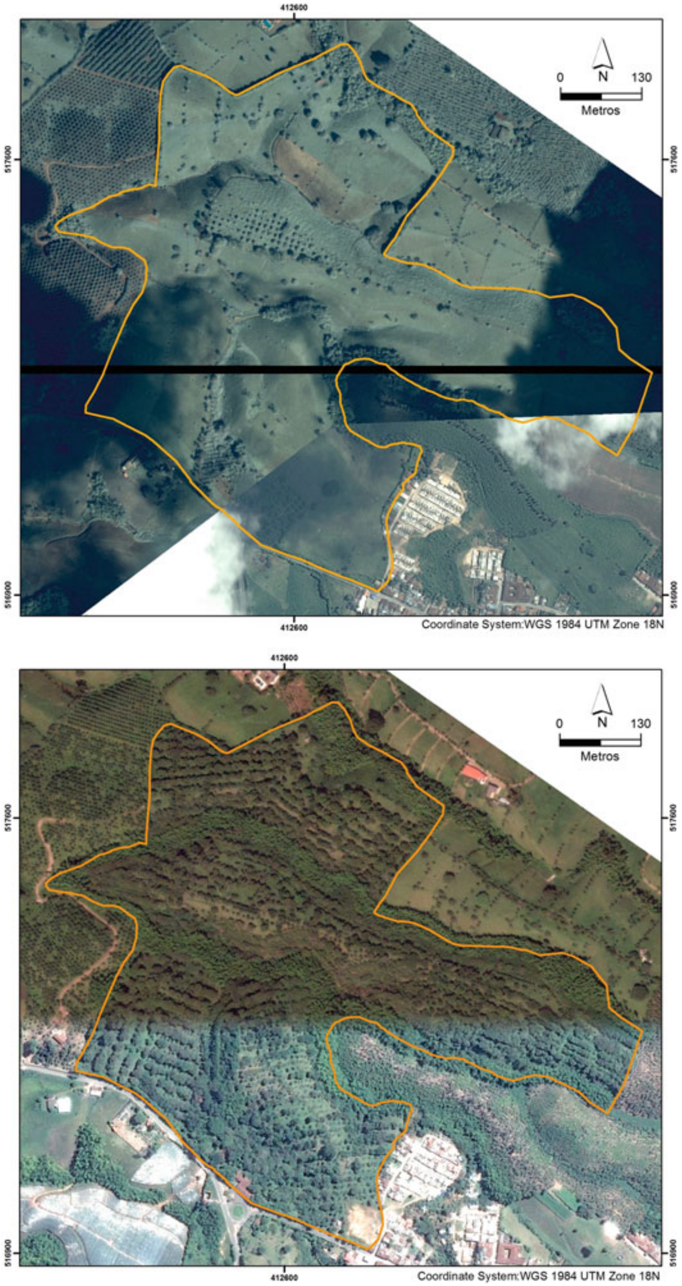

Fig. 12.3 Aerial views of Pinzacuá in 2003 (top) and 2016 (bottom). Main land use in 2003: treeless pasture; in 2016: silvopastoral systems, riparian forests, and homegarden. Land uses in neighboring farms can also be observed. Photos: RISEM Project

12.3.3 Land Use Planning

Today, the level and type of tree cover (i.e., tree density and arrangement) are intentionally managed throughout the farm. As a general rule, soil suitability (e.g., fertility, depth, slope, vulnerability to erosion and compaction) determines the type of land use, which in turn determines tree cover and tree species (Table 12.2). For example, steep hillsides, which are vulnerable to erosion and compaction, are not used for cattle but instead are planted with trees at a high density using a mixed native species forestry model described below. By contrast, the flat areas atop hills, which are more fertile and less prone to erosion, are reserved for cattle production and planted with trees at a lower density to ensure that pastures receive sufficient sunlight.

12.3.4 Tree Species Selection

Pinzacuá's planned tree diversity includes more than 60 different species that have been intentionally incorporated into the different land uses, including some of conservation concern. With the exception of the homegarden, native species are preferred over exotics because they are better adapted to the local climatic and edaphic conditions and provide food and shelter for the organisms above and below ground.

Trees for the silvopastoral systems were selected for specific characteristics including: (i) nitrogen fixation or high production of rapidly decomposing litter (e.g., *Inga edulis*); (ii) hardiness to withstand herbivory, both from cattle and leaf cutter ants (e.g., *Maclura tinctoria*); (iii) rapid growth and vigor to outcompete grasses (e.g., *Gliricidia sepium*); (iv) seeds, fruits and forage production to supplement cattle and horse nutrition (e.g., *Senna spectabilis*); and (v) timber production for farm use or local markets (e.g., *Anacardium excelsum*). Meanwhile, riparian area reforestation favored two fast-growing native species: *Guadua angustifolia*, a giant bamboo with high local economic and cultural value; and *Colubrina* sp., a tree with good timber properties.

The homegarden includes a mix of native and exotic species of cash crops (e.g., *Vanilla planifolia*), medicinal plants (e.g., *Sechium edule*), and ornamentals (e.g., *Anthurium* sp.), as well as timber trees (e.g., *Swietenia macrophylla*), fruit trees (e.g., *Garcinia madruno*), multipurpose trees (e.g., *Inga edulis*) and palms (e.g., *Aiphanes caryotifolia*).

For the forestry plantations, dinde (*Maclura tinctoria* (L.) D. Don *ex* Steud) was the main species selected because of its timber quality, high survivorship relative to other native species, and ability to provide fruit and habitat for birds and other wildlife (Martins and Setz 2000; Chízmar-Fernández 2009; Suárez et al. 2012; Montes-Londoño et al. 2017). Also known as old fustic or Argentine osage orange, dinde is valued for heavy construction, flooring, furniture, turnery, fence posts and

Table 12.2 Current land uses and their extension, relief, and species planted

Land use and area	Relief type	Tree density (trees ha^{-1})	Plant species
Silvopastoral system 15 ha	Hilltops	100–150	*Albizia guachapele, Anacardium excelsum, Anadenanthera peregrina, Brachiaria* sp., *Cassia grandis, Cynodon plectostachyus, Enterolobium cyclocarpum, Gliricidia sepium, Hymenaea courbaril, Inga edulis, Leucaena leucocephala, Pennisetum* sp., *Psidium guajava, Samanea saman, Senna spectabilis, Syagrus sancona*
Mixed planted forest 15 ha	Hillsides	Initial density: 1100;	
Final density: 250.	*Anacardium excelsum, Aniba perutilis, Cedrela odorata, Lafoensia acuminata, Maclura tinctoria, Magnolia hernandezii, Ocotea helicterifolia, Swietenia macrophylla, Vachellia macracantha*		
Riparian areas 5 ha	Depressions	>900	*Anacardium excelsum, Guadua angustifolia*
Shaded coffee 1 ha	Hillside	500 shade trees, 2000 coffee shrubs	*Albizia carbonaria, Anacardium excelsum, Caesalpinia ebano* (threatened in Colombia), *Citrus* sp., *Inga edulis, Jacaranda mimosifolia, Pourouma cecropiifolia, Pouteria caimito, Quararibea cordata, Swietenia macrophylla*
Natural regeneration and enriched secondary forest 1 ha	Hillside/ depression	500–900	*Cedrela odorata, Colubrina* sp., *Erythina fusca, Erythrina poeppigiana, Juglans neotropica, Magnolia hernandezzi, Montanoa quadrangularis*
Homegarden 0.24 ha	Hilltop	500	*Acca sellowiana, Aiphanes caryotifolia, Anthurium* sp., *Arachis pintoi, Bactris gasipaes, Bismarckia nobilis, Brownea ariza, Bougainvillea*

(continued)

Table 12.2 (continued)

Land use and area	Relief type	Tree density (trees ha^{-1})	Plant species
			sp., *Cassia grandis, Ceiba pentandra, Citrus* sp., *Codiaeum variegatum, Crescentia cujete, Diospyros* sp., *Eugenia stipitata, Euphorbia pulcherrima, Garcinia madruno, Garcinia mangostana, Inga edulis, Juglans neotropica, Myrciaria cauliflora, Passiflora edulis, Passiflora ligularis, Persea americana, Piper nigrum, Sechium edule, Selenicereus megalanthus, Senna spectabilis, Swietenia macrophylla, Tamarindus indica, Vanilla planifolia*
Forage/protein bank 0.5 ha	Hillside	3000–4000	*Alocasia macrorrhiza, Boehmeria nívea, Guazuma ulmifolia, Pennisetum* sp., *Tithonia diversifolia, Trichanthera gigantea.*

railroad crossties, and specialty wood items, and is culturally and economically important throughout Latin America. Dinde is the source of fustic, a yellow pigment used as dye for khaki and other color textiles (Rangel 1949; Roig 1974). The leaves, sap and wood have been used in traditional medicine, and have potential for extraction of a non-toxic broad-spectrum antioxidant (Cioffi et al. 2003). Once common in La Vieja river watershed, dinde populations have been decimated; today it is rarely found in the forests or in the markets, although it is considered a species of least concern (LC) for conservation (Rivers et al. 2017).

12.3.5 Tree Density and Shade Management

12.3.5.1 Silvopastures

The main factor affecting pasture productivity in silvopastures is shade, which in turn depends on the level of canopy cover and the characteristics of the tree canopy. Thus, identifying the level of shade that maximizes pasture productivity is key to successful silvopasture management. In Pinzacuá, informal trials manipulating shade with different planting densities and pruning intensities have shown that the pasture of choice, star grass (*Cynodon plestostachys*), performs best with <50% shade.

Fig. 12.4 Final tree spacing arrangement in the silvopastoral system. Trees are planted in an east-west direction to allow maximum light penetration to the understory. Photo: Fernando Uribe, 2018

Three different spatial arrangements identified through empirical observation were tested to determine the optimal tree density to both restore the soils and allow enough light into the understory: (i) a 10 × 10 m grid (100 trees ha^{-1}); (ii) rows planted every 20 m with 5 m between trees (100 trees ha^{-1}); and (iii) rows planted every 15 m with 5 m between trees (133 trees ha^{-1}). The latter design has worked best as the initial planting arrangement, and is then gradually reduced to a final density of approximately 100 trees ha^{-1} to avoid canopy closure (Montes Londoño unpublished data) (Fig. 12.4).

The optimal level of shade at this tree density is maintained by pruning three fourths of the tree crown every 2 years. Branches growing in east-west direction are retained while those growing north-south and directly shading the pasture corridors are removed (Fig. 12.5). While pruning is labor intensive, the residue is used to make artisanal charcoal and sold to cover the labor costs and to get some additional revenue (Fig. 12.5). Furthermore, the residue from the charcoal heaps is used as a high-quality biochar amendment to improve soil fertility throughout the farm.

12.3.5.2 Forestry Plantations

The forestry plantations were established with a mix of native timber trees planted in a 3 × 3 m spacing arrangement. The grid pattern spreads trees out to minimize competition, and the high initial density prevents early branching and promotes self-thinning, reducing the need for frequent pruning. Because dinde is good at self-thinning, plantations require less intensive management than silvopastures.

Fig. 12.5 Pruning of *Inga* trees (left) and artisanal charcoal production from the pruning material (right). Photos: Álvaro Zapata

Thinning is performed according to a specific guideline developed for dinde (Montes-Londoño et al. 2017).[1]

12.4 Impact on Land Cover and Biodiversity

12.4.1 Land Cover Change

Although Pinzacuá's transformation has been slow and gradual, 20 years into the process the accumulated changes in land use and tree cover are substantial. A spatio-temporal analysis based on high resolution satellite images revealed that between 2003 and 2016 land uses with high tree cover (i.e., forests, silvopastures and live fences) increased by 74.9% at the expense of uses with low tree cover (i.e., treeless pastures and croplands) (Table 12.3, Fig. 12.6) (Alicia Calle 2018, unpublished data). Forests included both reforestation and forestry plantations with a closed canopy and natural regeneration, and silvopastures were all areas of pasture with intermediate or high tree density. The most important changes during this period occurred in forests, which increased by 14.4% (6.3 ha); pastures with tree cover, which increased by 62.9% (27.6 ha); and pastures without trees, which initially

[1]Given the lack of information on growth and silvicultural management for dinde, research was conducted on 12 farms of the region to develop preliminary spacing and thinning guidelines (see Montes et al. 2017). Dinde performed similar to other trees used for reforestation in the humid American tropics, with a Mean Annual Increment in Diameter at Breast Height (MAIDBH) of 2.56 cm $year^{-1}$, a growth rate which is higher than it has been reported for sites in Honduras and Cuba (Cordero and Boshier 2003) but lies on the lower end of fast-growing native and exotic species in Central America. This growth rate stands overall within the range that has been reported for other native species in tropical humid regions elsewhere in Latin America (Piotto et al. 2004; Wishnie et al. 2007; van Breugel et al. 2011).

Table 12.3 Land cover change in Pinzacuá and the surrounding landscape from 2003 to 2016 (Alicia Calle, 2018, unpublished data)

	Pinzacuá				Surrounding landscape
	2003 Area (ha)	2016 Area (ha)	Change (ha)	% Change	% Change
Forests	2.85	9.18	6.33	14.44	2.82
Silvopastures	1.75	29.31	27.56	62.86	0.80
Live fences	1.23	0.17	−1.06	−2.43	0.62
Pasture no tree cover	34.74	2.82	−31.92	−72.81	−15.85
Cropland (no trees)	1.21	0.05	−1.16	−2.64	10.92
Other/No information	2.06	2.32	0.25	0.58	1.38
Total	43.84	43.84			

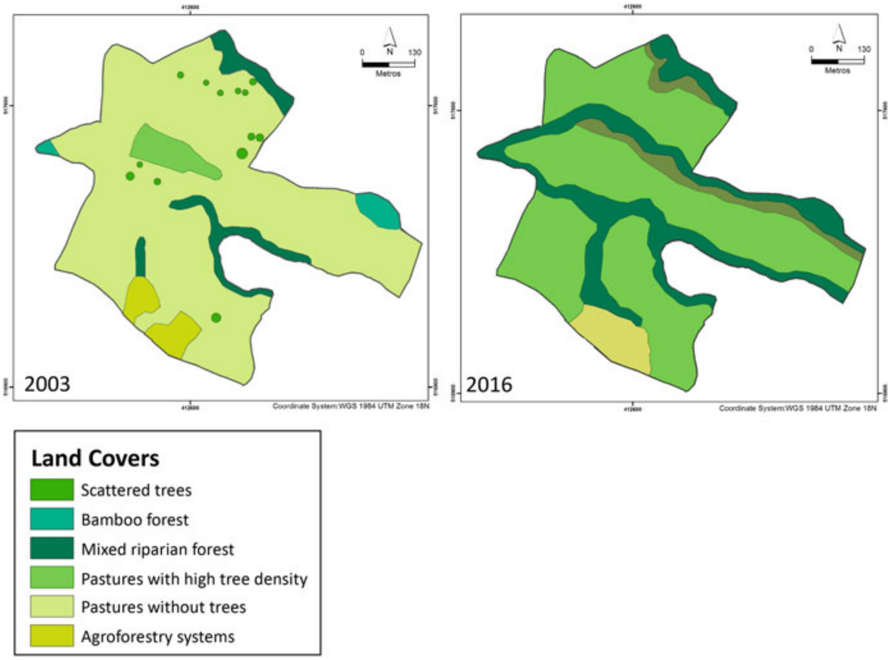

Fig. 12.6 Land cover in Pinzacuá, 2003 and 2016. Maps: Alicia Calle

comprised most of the farm but decreased by 72.8% (31.9 ha) (Calle unpublished data). Given the small size of the property, the decision to release areas for forest restoration and convert all treeless pastures to silvopastures underscores the landowners' appreciation for both the direct and indirect benefits of trees.

The magnitude of changes implemented in Pinzacuá, however, is perhaps best appreciated in the context of the surrounding landscape. During the same 13-year period, land cover change in a total of 557.4 hectares covered by farms surrounding Pinzacuá followed a different trend. Forest cover increased modestly (2.8%) and treeless pastures decreased by 15.9%, mostly to accommodate cropland expansion (10.9%) with only marginal improvements in pasture tree cover (1.4%) (Calle 2020) (Table 12.3, Fig. 12.6). The neighboring farms, which were not part of the RISEM project, had no access to payments for ecosystem services or technical assistance to improve their pasture areas. Instead, they appear to have planted cash crops in response to short-term spikes in market prices. Although spillover of silvopastoral systems onto neighboring farms did happen in other project farms, Pinzacuá's neighbors were not interested. Location adjacent to a large town and a main road connecting to markets may partly explain why other farmers opted for high-value cash crops.

12.4.2 Biodiversity

Since the transformation began, Pinzacuá has been the site of numerous biodiversity studies. While the lack of baseline assessments does not allow for direct comparisons, the minimal vegetation cover and severe land degradation evident in the 2003 satellite image (Fig. 12.6) suggest low levels of biodiversity at the baseline. The studies and species documented on the farm are summarized in Table 12.4.

12.4.2.1 Trees

Pinzacuá's transformation has relied heavily on planting trees and managing woody natural regeneration on degraded pastures for different purposes. Riparian forests were established to improve and protect the water supply; forestry plantations were established in the steepest parts of the farm that were not apt for grazing; and different silvopastoral arrangements were implemented to reduce cattle heat stress and improve productivity. As a result, overall tree diversity has increased dramatically over time. The farm also propagates several tree species and shares seedlings with others interested in improving on-farm tree cover.

To date, studies of tree diversity on the farm have identified 45 different tree species as adults or seedlings across the different land uses (Table 12.4). Thirty-six woody species have been identified across the different forest fragments, 17 as adult trees and 28 as regenerating seedlings. Eight tree species were also recorded in the mixed plantation (Calle and Méndez 2017, unpublished data, Giraldo et al. 2019), and 16 additional tree species have been recorded in the silvopastures.

A survey of woody vegetation structure and composition in 20 recovering forests protected during the RISEM project included two young riparian forests in Pinzacuá. The study found five species in the canopy and 25 species regenerating in the farm's

Table 12.4 Biodiversity studies and species reported in Pinzacuá

Woody plants		Author and methods
11 species 219 individuals	*Cedrela odorata, Cestrum* sp.*, Cordia alliodora, Gliricidia sepium, Inga edulis, Leucaena leucocephala, Maclura tinctoria, Psidium guajava, Senna spectabilis, Vachellia macracantha, Vernonanthura patens* *Anacardium excelsum, Erythrina poeppigiana, Syagrus sancona* (recorded outside the plots)	1000 m^2 transects (Calle and Méndez 2017, unpublished data)
16 species 64 individuals	*Anacardium excelsum, Bauhinia picta, Cecropia angustifolia, Cedrela odorata, Cordia alliodora, Cupania americana, Erythrina fusca, Erythrina poeppigiana, Gliricidia sepium, Juglans neotropica, Montanoa quadrangularis, Nectandra turbacensis, Psidium guajava, Samanea saman, Solanum aphyodendron*	1000 m^2 transects (Giraldo et al. 2019, unpublished data)
Woody regeneration		
28 species 834 individuals	*Anacardium excelsum, Bauhinia picta, Cecropia angustifolia, Celtis schippii, Cinnamomum triplinerve, Citrus sinensis, Cordia alliodora, Cupania americana, Erythrina poeppigiana, Eugenia sp, Ficus insipida, Ficus tonduzii, Hymenaea courbaril, Inga edulis, Maclura tinctoria, Myrcia sp, Nectandra lineata, Nectandra turbacencis, Ocotea macropoda, Oroepanax cecropifolium, Persea americana, Sapium laurifolium, Senna spectablis, Sorocea trophoides, Tetrochidium rubrinervium, Trichilia pallida, Zanthoxylum rhoifolium*	1000 m^2 transects (Calle and Méndez 2017, unpublished data)
Dung beetles		
11 species 97 individuals	*Canthidium* sp.*, Delthochilum* sp.*, Dichotumius alyattes, Dichotomius* sp.*, Eurysternuspp; —mexicanus, Eurysternus plebejus, Ontherus azteca, Onthophagus acuminatus, Onthophagus nasutus, Onthophagus* sp.*, Oxysternon conspicillatum*	Pitfall traps (Giraldo et al. 2019, unpublished data)
Birds		
34 species 104 individuals	*Amazilia tzacatl, Amazona ochrocephala, Anthracothorax nigricollis, Ara severus, Bubulcus ibis, Coccyzus pumilus, Coereba flaveola, Columbina talpacoti, Dendroplex picus, Icterus nigrogularis, Lepidocolaptes souleyetii, Melanerpes formicivorus, Melanerpes rubricapillus, Myiarchus apicalis*[a]*, Myiodynastes maculatus,*	Point counts (Giraldo et al. 2019, unpublished data)

(continued)

Table 12.4 (continued)

Woody plants		Author and methods
	Myiopagis viridicata, Picumnus granadensis[a], *Pionus chalcopterus, Pionus menstruus, Piranga rubra*[b], *Pitangus sulphuratus, Polioptila plúmbea, Pyrocephalus rubinus*[b], *Setophaga petechia*[b], *Sicalis flaveola, Synallaxis azarae, Thamnophilus multistriatus, Thraupis episcopus, Thraupis palmarum, Tiaris olivaceus, Todirostrum cinereum, Troglodytes aedon, Tyrannus melancholicus, Zimmerius chrysops*	
89 species 28 families 1069 individuals	*Bubulcus ibis, Camptostoma obsolete, Columbina talpacoti, Columbina minuta, Dendroica petechia, Egretta thula, Eucometis penicillate, Leptopogon superciliaris, Myiodynastes maculatus, Phaeothlypis fulvicauda, Pachyramphus rufus, Pygochelidon cyanoleuca, Pyrocephalus rubinus, Sporophila schistacea, Thraupis episcopus, Tyrannulus elatus, Tyrannus melancholicus, Vireo olivaceus, Xiphorhynchus susurrans,* among others	Point counts (Sánchez and Camargo 2015)
Butterflies		
16 species	*Actinote ozomene, Anartia amathea, Anthanassa Drusilla, Caligo eurilochus, Ceratinia tutia, Cissia pompilia, Dryas iulia, Eurema daira, Heliconius charitonia, Heliconius erato, Papilio thoas, Pteronymia artena, Pteronymia picta, Siproeta stelenes, Timolus echion, Urbanus proteus*	Visual encounter surveying (VES) (Montes-Londoño 2019, unpublished data)
Mammals		
8 species	*Sciurus granatensis, Didelphis marsupialis, Dasyprocta spp., Dasypus novemcinctus, Cerdocyon thous, Puma yagouaroundi, Cuniculus paca, Leopardus pardalis*	Observations by managers and workers
Reptiles		
6 species	*Chironius monticola, Bothriechis schlegelii, Micrurus mipartitus, Oxybelis fulgidus, Oxyrhopus petola, Spilotes pullatus*	Observations by managers and workers

[a]Endemic species
[b]Migratory species

bamboo forest, and another 11 species in the canopy and 11 species regenerating in the mixed planted forest (Calle and Méndez 2017, unpublished data) (Table 12.4). Pinzacuá's bamboo forest had the highest abundance of woody regeneration with 785 seedlings, including many species that are not currently represented in its forest canopy. The study suggests that these riparian sites that were retired from cattle production over a decade ago are slowly recovering, and the total number of woody species will likely increase over time (Calle and Holl 2019).

12.4.2.2 Birds

Birds play a number of important roles in both natural and agricultural ecosystems: they contribute to natural pest control by consuming pest insects and organisms; they pollinate flowers helping with fruit production; they disperse seeds facilitating natural regeneration; and they add aesthetic and cultural value to landscapes (Giraldo et al. 2019).

Two different bird studies have been conducted in Pinzacuá. Sánchez and Camargo (2015) examined the relationships between bird diversity and landscape structure in four farms with different land uses (i.e., conventional treeless pastures, silvopastoral systems and agroforestry systems) connected to bamboo forests. The highest bird diversity and abundance were recorded in Pinzacuá, where 1069 individuals belonging to 89 species and 28 families, including 3 migratory and 3 endemic species (Table 12.4), were sighted in the silvopastoral systems connected to bamboo forests. The structural and functional attributes of these systems create connectivity to the forest edges, effectively providing food and habitat resources needed for the permanence of bird species, both local and migratory.

The abundance of birds in the Tyrannidae family (180 species) suggests that silvopastoral systems offer optimal conditions for insectivorous species. These birds are known to reduce insect pest outbreaks and herbivory in multi-strata cocoa and coffee agroforestry systems (De Beenhouwer et al. 2013; Maas et al. 2013; Peters and Greenberg 2013; Poch and Simonetti 2013). Although the same could be true in silvopastoral systems, where the main pests are ticks and flies, the role of insectivorous birds in controlling pests in these systems has not been studied.

Another study comparing bird diversity across three different land uses in Pinzacuá (i.e., forest, silvopastoral systems, and fodder hedges) recorded 104 individuals belonging to 34 species (Giraldo et al. 2019) (Table 12.4). Most species were open area generalists but at least four were forest dwellers; three species were migratory and three others were endemic. Silvopastoral systems with scattered trees had the highest bird diversity, followed closely by the forest; they also hosted a variety of common generalists that have been displaced by the elimination of coffee shade and overall tree cover across the region.

The presence of birds with a wide range of habitat preferences in Pinzacuá suggests that the complex and perennial habitat diversity that was intentionally created in the farm facilitates bird movement in fragmented agroecosystems and can provide important habitat for farmland species and migratory birds (Philpott and Bichier 2012; Vílchez et al. 2013).

12.4.2.3 Dung Beetles

Dung beetle communities are shaped by both dung availability and vegetation structure. Because beetle assemblages can be severely modified by farming intensification practices and the elimination of tree cover, dung beetles are useful indicators of land use change and pasture health (Davis et al. 2004; Giraldo et al. 2011). In grazing landscapes, dung beetles mediate important ecosystem functions: they rapidly remove dung piles from the pasture surface by incorporating them into the soil and improving its fertility; they reduce soil compaction and improve soil structure; and they interrupt the life cycles of flies and parasites that lay their eggs on dung piles and affect cattle health (Giraldo et al. 2019).

A study comparing dung beetle diversity across three land uses in Pinzacuá found 97 individuals of 11 species, of which 24 individuals of five species were in the pastures with scattered trees (silvopastures); 20 individuals of seven species were in the fodder hedges; and 53 individuals of eight species were in the planted forest (Table 12.4). Species diversity was twice as high in the forest than in the silvopastures, and similar in silvopastures and fodder hedges (Giraldo et al. 2019). Structural complexity, high canopy cover, and the presence of a leaf litter layer that retains moisture explain the higher abundance and richness in the forests, as well as the diverse assemblage in the pastures with high tree density.

12.4.2.4 Other Species

No formal studies of mammals or reptiles have been conducted to date on Pinzacuá. However, squirrels, opossums, agoutis, and armadillos are common on the farm, crab eating fox (*Cerdocyon thous*) and jaguarundi (*Puma yagouaroundi*) have been occasionally seen, and lowland pacas (*Cuniculus paca*) and ocelots (*Leopardus pardalis*) are likely present as they have been spotted in neighboring farms. In addition, three species of snakes including the false coral (*Oxyrhopus petolarius*), the green vine snake (*Oxybelis fulgidus*), and the yellow rat snake (*Spilotes pullatus*) are also on site.

Overall, Pinzacuá's efforts to increase vegetation cover and complexity by planting and protecting a variety of tree species have not only increased tree diversity, but they have provided adequate resources for other wildlife species, thereby transforming this previously degraded farm into an island of biodiversity amidst an otherwise impoverished landscape. Furthermore, Pinzacuá has become a site for biodiversity research and has contributed to our understanding of how the incorporation of trees can aid in the recovery of degraded farmlands.

Table 12.5 Productivity indicators for two intensive cattle ranching systems in Colombia

Productivity indicators	High input treeless pastures, Cimitarra, Santander[a]	Silvopastoral system, Pinzacuá
Stocking rate (animal units[b] ha^{-1})	7	5.5
Meat production (gr $animal^{-1}$ day^{-1})	600	600
Conception rate (excluding first time pregnancies)	80%	95%
Veterinary care costs (vet, pest control, vitamins, etc.)	4% of total input cost	0.5% of total input cost
Calf mortality rate	5%	3%

[a]Personal communication with Antonio José Uribe, CIPAV
[b]1 animal unit = 450 Kg

12.4.3 Impact on Productivity

In terms of productivity, the silvopastoral systems implemented over the past 20 years have allowed the farm to support cattle stocking rates similar to those seen in high-input cattle grazing systems, while also eliminating the use of chemical fertilizers completely. During this period fodder biomass production in the pastures has increased from two tons ha^{-1} in 1997 when fertilization ceased, to 11 tons ha^{-1} in the silvopastoral systems. Compared to high-input grazing systems, Pinzacuá's calf mortality rate is 2% lower and the birth rate is 10% higher, with a calving interval of 13 months (Table 12.5) (Reyes et al. 2017). In addition, the shade provided by trees has reduced the risk of heat stress, creating a more comfortable environment in which animals stay hydrated and maintain their normal feeding behavior (Broom et al. 2013). Shade also provides habitat for predators that control ticks, flies, and other common cattle pests, thereby reducing the incidence of disease. These improvements in livestock's' bodily condition reduce costs in veterinary care and medications. Overall, the direct and indirect benefits provided by trees are reflected in better animal welfare and higher productivity.

12.4.4 Impact on Ecosystem Services

12.4.4.1 Water Quality and Quantity in Restored Streams

The re-establishment of riparian corridors in the farm's previously unprotected steams has also impacted water quality. The upstream town of Alcalá discharges raw sewage from approximately 1400 people into the main stream that flows through Pinzacuá at a rate of 10.6 L s^{-1}. An evaluation of the stream's self-purification capacity was conducted in 2010, approximately 10 years after 5 to 10-meter-wide strips were fenced off and reforested with guadua (*Guadua angustifolia*) on both streambanks. Analyses of three composite water samples taken at 400-m intervals showed the following removal efficiencies for five pollutants along the 800-m stretch: 52% for nitrogen, 49% for phosphorus, 88% for chemical oxygen demand (COD), 92% for total coliforms and 97% for fecal coliforms (Montes Londoño and Rodríguez Susa 2011). Compared to similar studies, the stream appears to retain its self-purification capacity thanks in part to resemblance of the restored forests to the basin's historical guadua forest cover. Despite the lack of baseline data, workers and landowners report substantial changes in water quality parameters such as color, odor, turbidity and the presence of foam. Thus, riparian restoration appears to have had a positive effect on the water, underscoring the links between riparian area protection, land management practices, and water quality.

12.4.4.2 Climate Change Mitigation

Whereas greenhouse gas (GHG) emissions, carbon stocks and carbon sequestration have not been directly measured at Pinzacuá, numerous studies from tropical and sub-tropical Latin America highlight the potential of tree-based grazing systems for climate mitigation. Silvopastoral systems can contribute in two important ways: via carbon sequestration in both the woody biomass and the soils, and via an improved animal diet that reduces emissions from enteric fermentation (Ibrahim et al. 2007; Arias Giraldo et al. 2009; Mesa Arboleda 2009; Amézquita et al. 2010; Naranjo et al. 2012; Montagnini et al. 2013; Aynekulu et al. 2019).

Silvopastoral systems store more carbon than grass-only systems because of their higher amount of above and belowground biomass. A study conducted in the RISEM project farms estimated a total carbon storage of 153 Mg C in 1 ha of silvopasture consisting of improved grass planted with 83 native trees (Arias Giraldo et al. 2009). Silvopastures also perform better in their total GHG balance, as shown in a study comparing four different types of pasture systems in Colombia. The two conventional systems—degraded treeless pastures and improved treeless pastures—were net GHG sources, emitting 3.2 and 3.3 tons CO_2e ha^{-1} $year^{-1}$ respectively. Meanwhile, the two silvopastoral systems—one combining improved grasses with *Leucaena leucocephala* (60,000 shrubs ha^{-1}) and a similar one that also had mixed species of timber trees—were net sinks, respectively removing 8.8 and 26.6 ton CO_2e ha^{-1} $year^{-1}$ (Naranjo et al. 2012).

Sequestration potential varies with factors such as soil type, tree species, stand age, and management (Nair et al. 2010). However, these studies suggest that given the farm's baseline condition of mostly degraded soils and treeless pastures, and the significant increase in tree cover over the past two decades, Pinzacuá has become a provider of climate mitigation services.

12.5 Discussion and Conclusions

12.5.1 *Pinzacuá as an Island of Biodiversity*

Twenty years ago, Pinzacuá began a gradual transformation of its land use and management practices with the goal of improving productivity and ensuring economic viability. The results are evident.

Increasing farm productivity was the key first step that allowed the farm to reduce the production area to accommodate more areas for conservation. Pasture monocultures were replaced with live fences, silvopastures, riparian buffers, and connectivity corridors, transforming the farm into a mosaic of vegetation structures associated to different land uses. Today, the added diversity and complexity provides refuge for birds, bats, and other mammals; native flowering trees offer resources for wildlife and a variety of beneficial insects; canopy cover creates favorable conditions for ground-dwelling ants and dung beetles that require moisture and tree litter to move through the pasture; trees support the web of underground biodiversity that underpins soil fertility; and riparian corridors and high tree cover provide connectivity throughout the farm. In short, Pinzacuá has become a high-quality matrix that serves as permanent habitat or temporary refuge for a variety of taxa that strive to persist in this highly fragmented landscape. As seen in the satellite images, Pinzacuá stands out, literally, as an island of vegetation in an otherwise treeless landscape (Calle 2020).

Beyond the physical transformation, Pinzacuá's process is the expression of a deep cultural change that began at a personal level and eventually became a family project. However, Pinzacuá alone is not enough, and its impact will be limited unless other farms make similar management decisions and intentional efforts to integrate more trees and change harmful practices.

12.5.2 *Challenges and Setbacks*

While transitioning from input-based conventional systems to agroecological-based systems can entail a productivity trade-off, silvopastoral systems may be a notable exception. The extensive cattle production model currently used across Latin America is known for its low productivity (0.6 animal units ha^{-1} (FAO 2006) and high environmental impact. By contrast, the higher productivity of silvopastoral systems is rooted precisely in their environmental benefits, and both cannot be decoupled (Murgueitio et al. 2011; Chará et al. 2019). The question then is, if the systems is so good why are more cattle ranchers not adopting it? The answer is simple: silvopastoral systems are knowledge and management intensive, and they require a significant up-front investment that takes time to recover. Whereas Pinzacuá's owner was able to keep the farm afloat during the transition period by drawing from another business, many farmers are not in a position to do the same. Unfortunately, the structures needed to overcome these entry barriers are currently not in place in most countries. In recent years, however, the RISEM and other projects have shown that economic incentives and technical assistance can effectively address these barriers and deliver lasting impacts (Calle 2020; Pagiola et al. 2020).

Pinzacuá's transformation clearly illustrates the potential to increase productivity while restoring and conserving the natural capital, a process known as ecological intensification (Gaba et al. 2014). However, this transformation requires a radical shift in mindset, from one of controlling nature to one of learning from nature, as well as perseverance in facing challenges. Below we describe some of the failed trials and unexpected setbacks faced at Pinzacuá, as well as some of the emerging challenges.

One of the earliest failures was the implementation of an intensive system with *Leucaena leucocephala*, a nutritious nitrogen-fixing fodder tree/shrub (Murgueitio et al. 2011). Although expensive to implement, the system's high productivity can quickly offset the investment. However, Pinzacuá's soils proved to be too acidic for *Leucaena*, and the time and resources invested were lost. A number of failures were related to tree-planting. For example, different versions of corrals built with barb wire or bamboo and efforts to spray cattle dung and other substances to deter herbivores failed to keep leaf-cutter ants and cattle at bay. Eventually better protection methods were developed through trial and error. The high mortality of healthy-looking tree seedlings, also frustrating early on, was later attributed to roots coiling in the small bags used by commercial nurseries. Careful sourcing of plant material and direct seeding techniques eventually helped overcome the problem. Pinzacuá even faced challenges with the propagation of *Gliricidia sepium* live fences, which is commonly done using plant stakes. After strong winds repeatedly unrooted the new fences, the farm modified its propagation approach planting *Gliricidia* directly from seed to obtain stronger roots.

Besides tree-planting, other setbacks are related to human factors. After transitioning to agroecological methods, the use of chemical inputs –even fertilizers to facilitate tree growth– has become a difficult choice to make. Although this has led to creative workarounds like the use of charcoal residue as biochar for the soils, developing and perfecting new methods has been time consuming. Perhaps one of the most recurring and persisting frustrations is related to training and retaining of farm workers. Silvopastoral systems represent a radical departure from conventional ranching and requires a completely different mindset. Training a new worker to do things differently requires an investment of time and resources, and losing a trained worker represents a huge setback. To alleviate labor, Pinzacuá has also experimented with agri-voluntourism but so far volunteers have been ill-prepared for the difficult field tasks, and often just interested in how the experience looks on their resume and on social media.

Over the past 20 years, Pinzacuá has faced a number of setbacks and learned many important lessons. Moving forward, the main challenges appear to be less related to increasing or maintaining productivity, and more to the numerous local socio-economic factors that threaten the farm's long-term sustainability. Today, the most significant production cost in the farm is labor. Compared to conventional extensive production, silvopastoral systems require more labor for activities such as herd rotation and tree maintenance. Production costs can be diluted either by increasing productivity per unit area or by increasing the size of the herd (Holmann et al. 2003). Although higher productivity in silvopastoral systems allows for higher stocking rates and lower costs, labor costs are barely covered at the current herd size and herd expansion is limited by the size of the farm.

Pinzacuá's proximity to an urban center raises other cost-related concerns. As land prices increase, so does the opportunity cost of using the property for conservation-friendly farming, and the pressure to plant cash crops or sell to developers increases. Proximity to town also exacerbates the labor shortage as younger generations increasingly reject farming in favor of urban employment (Calle 2020). Here, as elsewhere in the world, rural life has been downgraded and youth are concerned with the lack of future and opportunities in the agricultural sector.

The potential to diversify production and increase farm revenue through the integration of high-value timber and non-timber products is often highlighted as one of the benefits of silvopastoral systems (Somarriba 1997; Pezo and Ibrahim 1998). However, Pinzacuá has faced a different reality. While sales of bamboo posts alone can be up to ten times more profitable than cattle breeding, the excessive paperwork and bureaucracy required for harvesting and transporting planted timber make it difficult to realize these diversified revenue streams. The lack of developed value chains and local markets for both planted native hardwoods and non-timber forest products currently limits access to these other sources of revenue that could potentially complement income from livestock. Thus, although ongoing trials with vanilla, pepper, and dinde show promise, their future will depend on the development of local markets.

Being an island of biodiversity in a degraded landscape is certainly reason for pride, but at times it also feels like an uphill battle. The farm has suffered the spillover effects from unsustainable practices used in the surroundings. For example, in only 2 years the apiary, which provides additional revenue, has lost 30% of the beehives due to agrochemical drift from neighboring farms. In addition, the use of unconventional methods elicits mockery by other farmers, increasing the sense of isolation in an already lonely occupation.

Finally, Pinzacuá faces challenges related to monitoring of both productive and ecological indicators. Basic farm data are essential for sound decision making, especially in agroecological systems where management—not inputs—determines productivity, and introducing timely changes is essential. Simple tasks such as recordkeeping, measuring pasture capacity or tree growth, testing for diet deficiencies, and other forms of data collection remains challenging as the farm lacks the technological and human capacity to systematically compile and analyze this information.

Likewise, monitoring ecological data in a simple and cost-effective way poses a challenge moving forward. The studies conducted to date, mostly through collaborations with individual researchers, have sparked the landowners' interest in understanding the underlying ecological processes. Implementing simple protocols to consistently monitor key ecological indicators in the long-term would therefore be desirable. For example, understanding soil dynamics and the impact of organic management on sensitive groups such as butterflies and amphibians, is of particular interest. Thus, the challenge will be to build long-term partnerships with universities or research institutions in order to develop a structured long-term research plan.

12.5.3 Opportunities

Despite these challenges, the farm continues to seek new opportunities to remain competitive while respecting its commitment to biodiversity-friendly production. For example, Pinzacuá has already positioned itself as a demonstration farm and hosts 400+ visitors every year, including local and international groups of school and university students, farmers, researchers, as well as NGO and government workers. Aside from providing additional income, these visits foster opportunities to exchange knowledge and ideas, strengthen networks, and contribute to scale-up sustainable land use practices across the region (Calle et al. 2013).

Pinzacuá is located within a larger region known as the Coffee Cultural Landscape of Colombia, an UNESCO World Heritage site and the country's second most popular tourist destination with approximately 100,000 visitors every year (La Patria 2019). Agritourism is already one of the main sources of income across the region, and the farm could potentially combine nature-based tourism with biodiversity-friendly farming. Furthermore, ecotourism and proximity to urban centers are potential new markets for organic produce, which the farm already grows, and direct marketing of specialty crops such as mushrooms or underutilized species such as natural dyes or medicinal plants. But this will require efforts to identify short value chains supplied by many small producers, and to market the services.

Finally, agri-voluntourism and scientific tourism could potentially offer an alternative to facilitate the collection and analysis of both productivity and ecological data. A careful selection process to identify volunteers with the right skills set will be required to realize this opportunity.

12.6 Conclusion

Pinzacuá's efforts to increase vegetation cover and complexity by planting and protecting a variety of trees have not only improved the farms' productivity but have also increased its biodiversity. By providing adequate resources for wildlife species, this previously degraded farm has been transformed into an island of biodiversity amidst an otherwise impoverished landscape. Furthermore, Pinzacuá has become a farm that serves as an example for others interested in restorative agriculture, and a site for biodiversity research that has contributed to our understanding of how agroforestry and sustainable management can aid in the recovery of degraded farmlands. Today, Pinzacuá stands as living proof that by mimicking natural ecosystems, the ecological interactions and synergies among the components of the agroecosystem can be re-established, and land degradation can be reversed to restore soil productivity, support biodiversity, and recover important ecosystem services. The process has been long and not without setbacks, but the results have led to an undeniable transformation of both the land and its people. As new challenges continue to emerge, Pinzacuá will draw on the lessons learned to continue applying agroecological principles, and perhaps more importantly, to remain open to experimenting with new ideas.

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