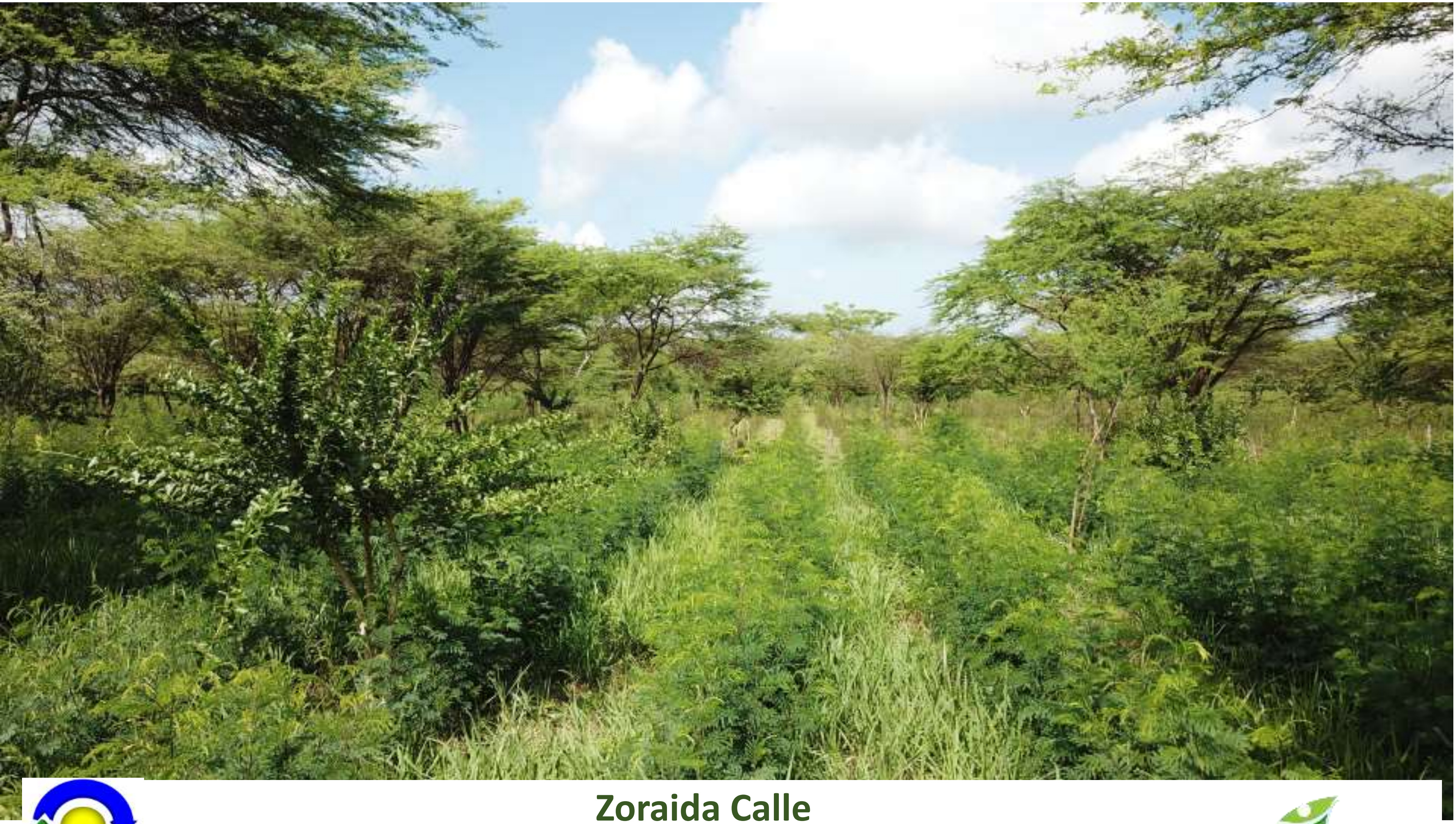
Silvopastoral Systems:
An Agroecological Approach to Sustainable Cattle Ranching



Zoraida Calle

Coordinator, ELTI Colombia Program & CIPAV Restoration Group

Addressing the real complexity of cattle ranching involves considering a variety of ecological, economic and social factors at play.

Conventional cattle ranching, practiced in extensive grass monocultures

The livestock sector: a leading driver of deforestation, land degradation, pollution, climate change, the sedimentation of coastal areas and invasions by alien species (FAO and LEAD, 2006).

Photo: Mauricio Carvajal


Should these more than 600 million hectares be
condemned to low productivity and degradation?

What happens if we add efficient N-fixing shrubs to this pasture?

What happens if the deep roots of shrubs have access to water and nutrients that are unavailable to the grasses?

And what if at the same time the shrubs provide high-quality fodder for the cattle?

And what happens when we add enough trees to provide 30% canopy cover, and allow leaf litter to cover part of the soil?

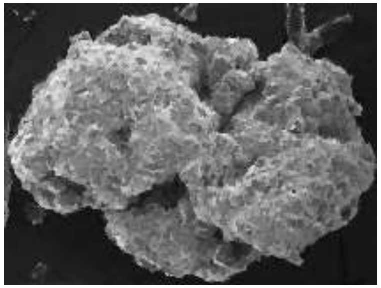
And what if the pasture becomes such a good habitat for dung beetles that they break down the cattle manure in less than four days?

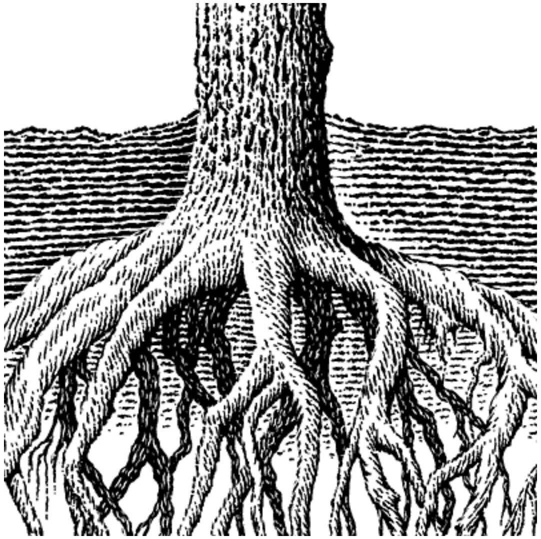
Soil excavated by a beetle that buried a dung ball

And what if the beetles consistently interrupt the biological cycles of pests such as the horn fly and internal parasites of the cattle?

And what if the shrubs and trees sequester enough carbon above and belowground to offset the methane emissions from the cattle?

What happens if we re-design cattle production by enhancing the ecological infrastructure that supports it?





A complex web of interactions and biological processes supports healthy grazing systems.

Do cows only eat grass?

Bos taurus
Spain

Bos taurus x B. indicus
Colombia

Returning cattle to a forested environment:

Silvopasture: Agroforestry systems that combine fodder plants, such as grasses and leguminous herbs, with shrubs and trees for animal nutrition and complementary uses.

Pinzacuá farm, owned by Olimpo Montes. Photo: Alvaro Zapata

Types of silvopastoral systems


Scattered trees


Live fence


Intensive silvopasture


Mixed fodder bank (cut-and-carry)

Intensive silvopastoral systems ISPS

are grazed directly by livestock

Intensive silvopastoral systems ISPS

Murgueitio et al., 2011

500 timber trees planted in east-west lines to minimize shading.

Fodder shrubs planted at high densities (>10,000 plants ha^{-1}), intercropped with

Highly-productive grasses

Intensive silvopastoral systems ISPS

High animal load, brief rotations and long periods of recovery

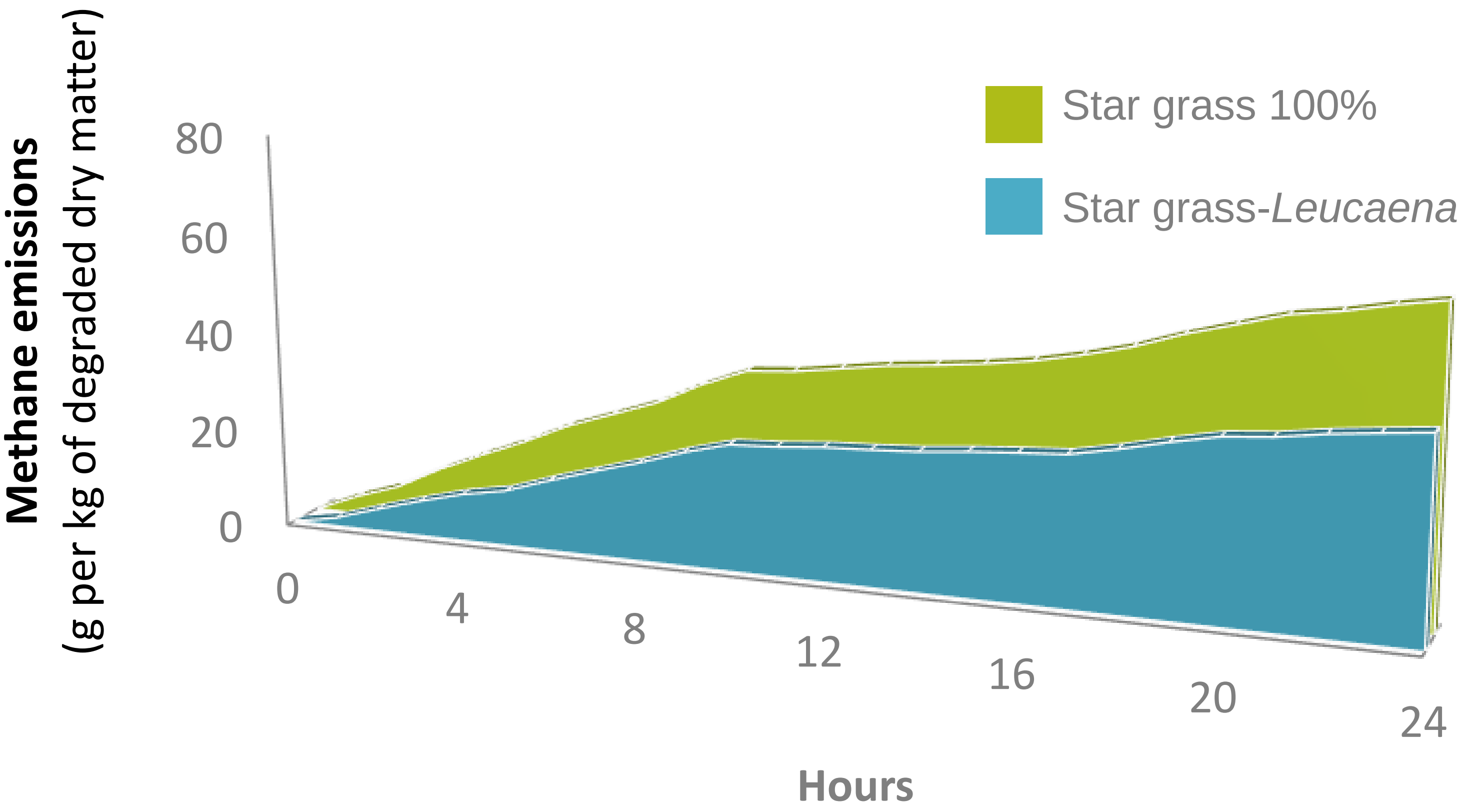
Grazing days: 16

Recovery days: 349

Animals feed on a combination of grass, shrub and tree forages.

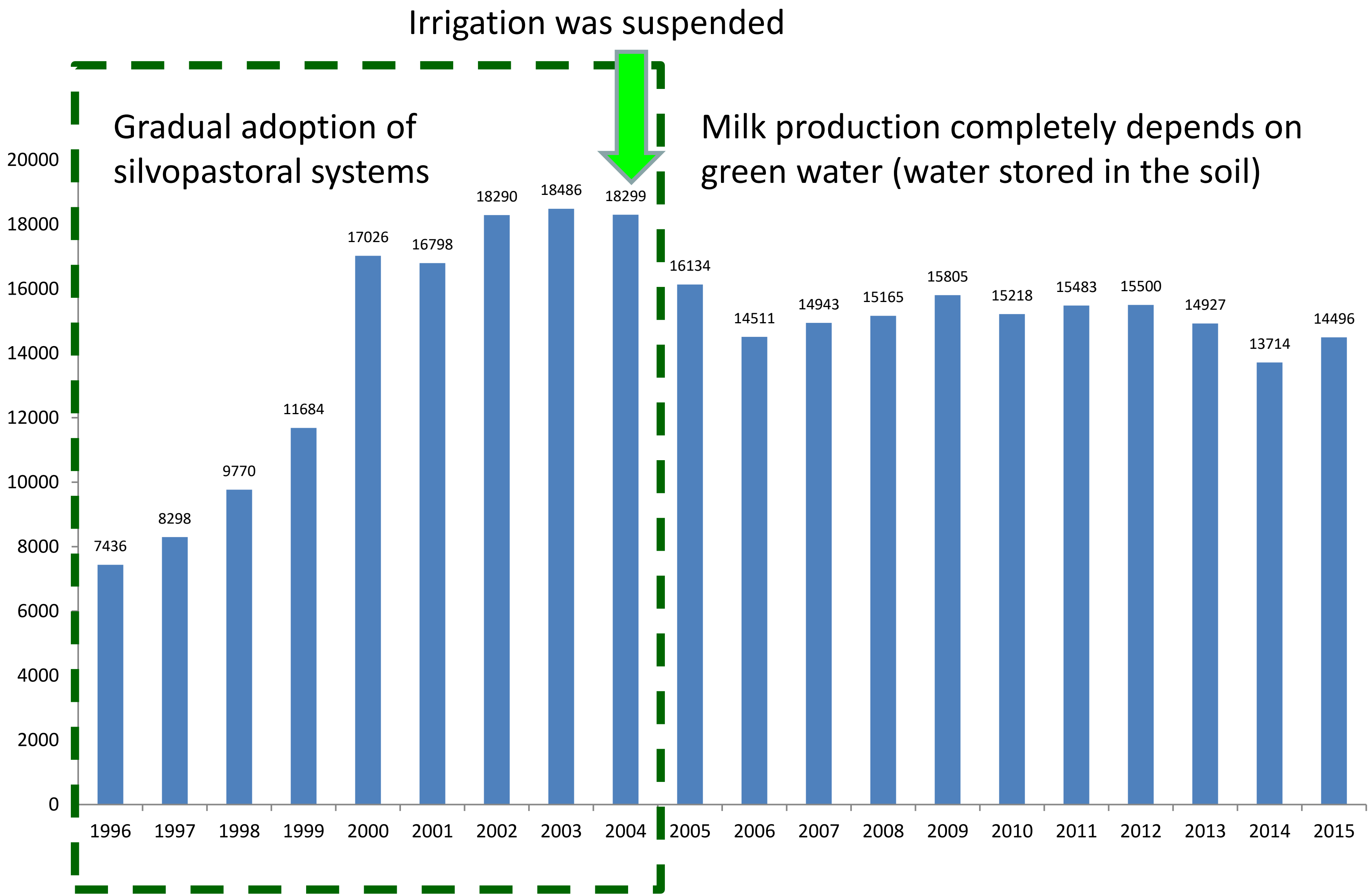
Enteric fermentation in conventional monoculture vs. Intensive silvopastures

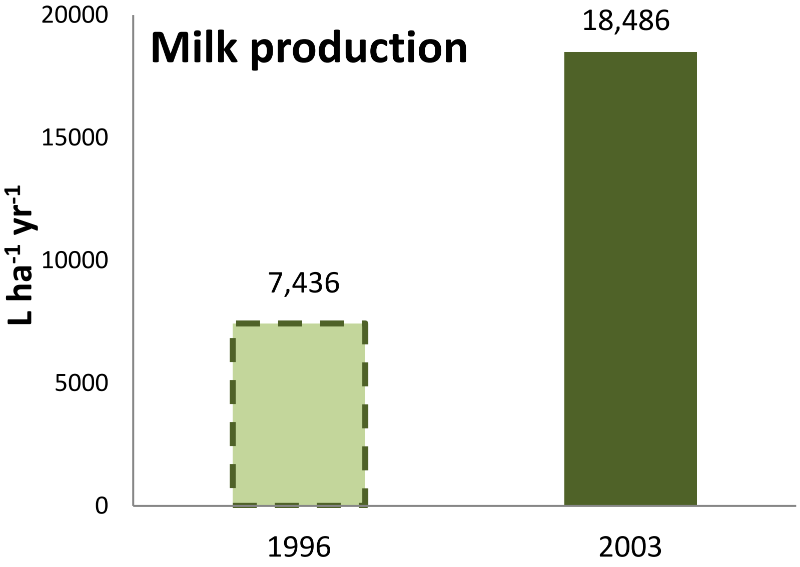
Molina *et al.*, 2015b

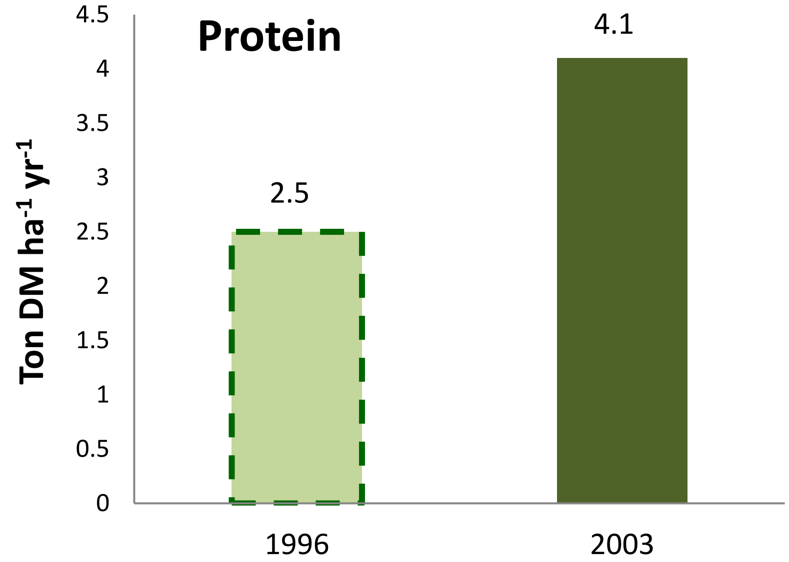


30% lower methane emissions per unit of degraded dry matter

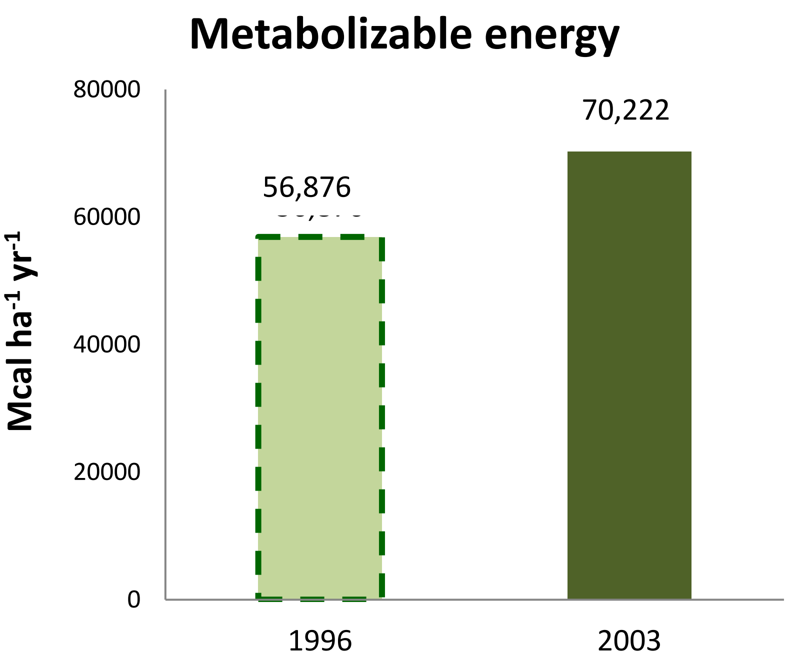
Per hectare milk production during two decades at El Hatico Reserve (Valle del Cauca, Colombia)

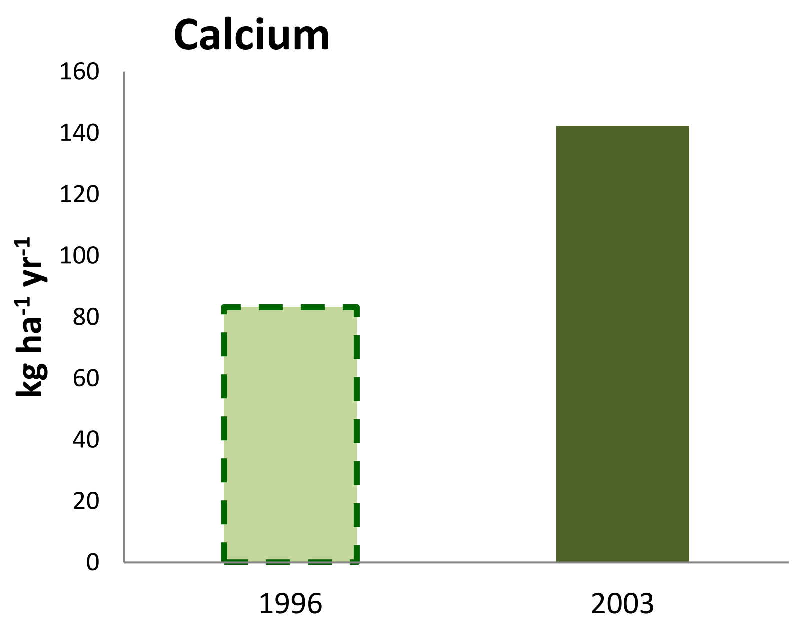






More milk, higher quality





Lucerna Farm	1990 Star grass monoculture	2011 ISPS (30,000 *Leucaena* ha^{-1})
Chemical fertilizer	450-500 kg urea ha^{-1} yr^{-1}	No fertilizer!
Animal load	3.5 cows ha^{-1}	4.5 cows ha^{-1}
Milk production	9000 L ha^{-1} yr^{-1}	15,000 L ha^{-1} yr^{-1}

Lucerna Farm, Bugalagrande (Valle del Cauca, Colombia)

Conventional star grass monoculture vs. intensive silvopastoral systems at El Hatico

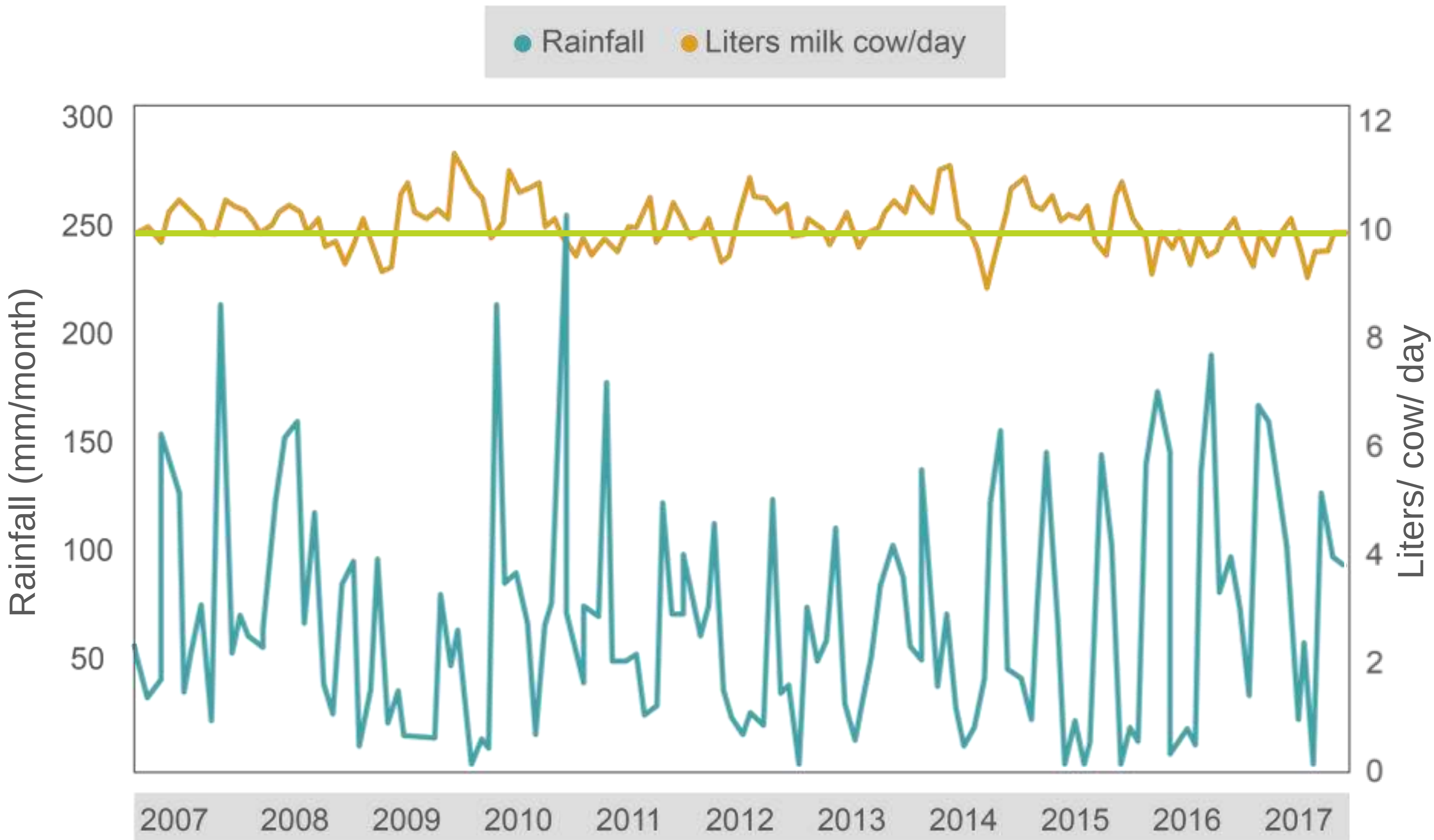
Reserva Natural El Hatico | GLOBAL AGENDA FOR SUSTAINABLE LIVESTOCK

	Monoculture	Intensive silvopasture
Area	111 hectares	69 hectares
Total milk production	667,500 l yr^{-1}	809,706 l yr^{-1}
Market price of 1 l of milk	US $0.35	US $0.47
Fixed costs		
Mineralized salt	US $6,127	US $3,574
Fertilizer	US $25,530	US $0
Irrigation	US $32,647	US $0
Profit ha^{-1} $month^{-1}$	**- US $27**	**US $206**

Organic products: a consequence rather than a goal

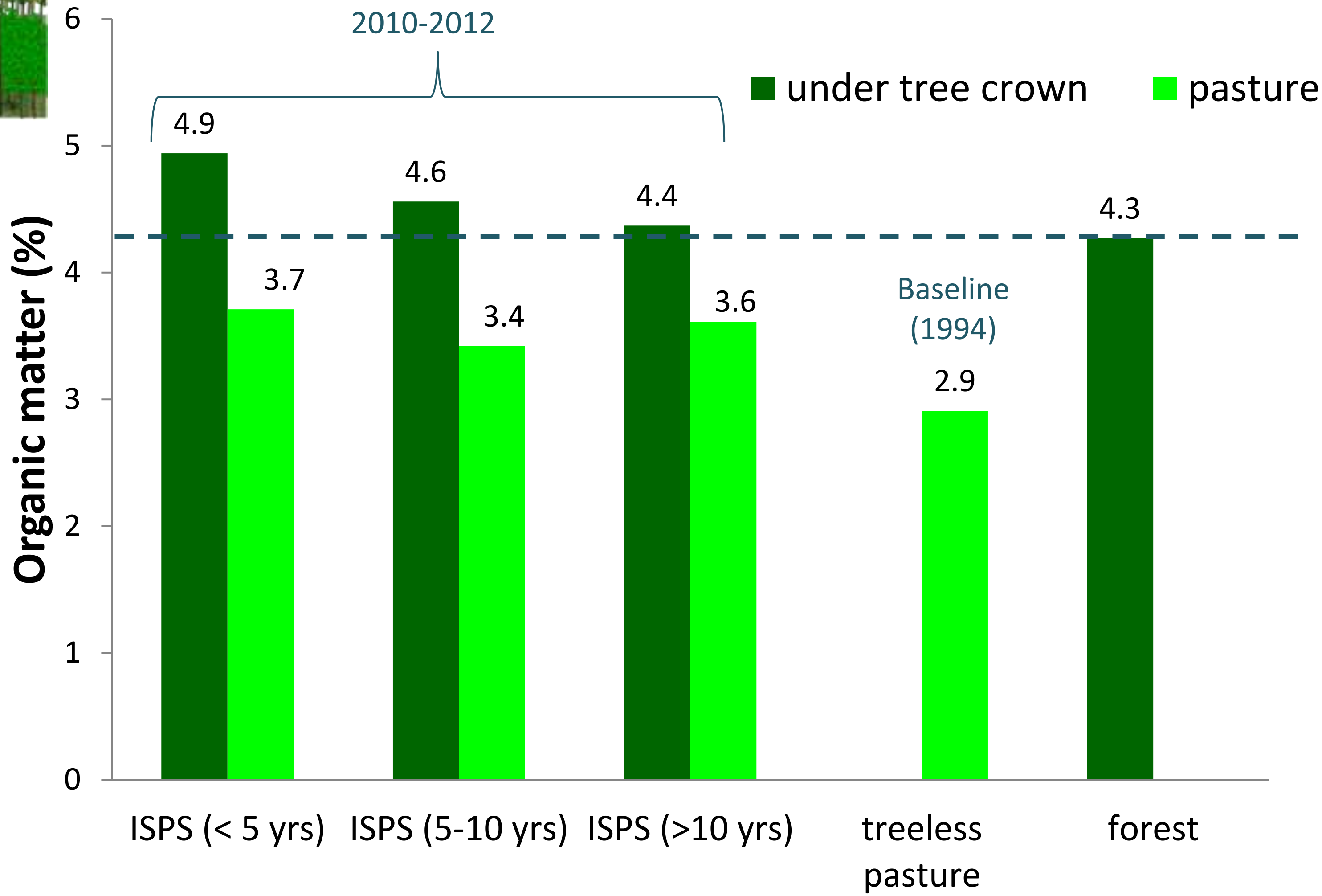
Intensive silvopasture surrounded by forest at El Hatico

Milk yield during a decade of exceptional climate variability *El Hatico* (2007-2017)



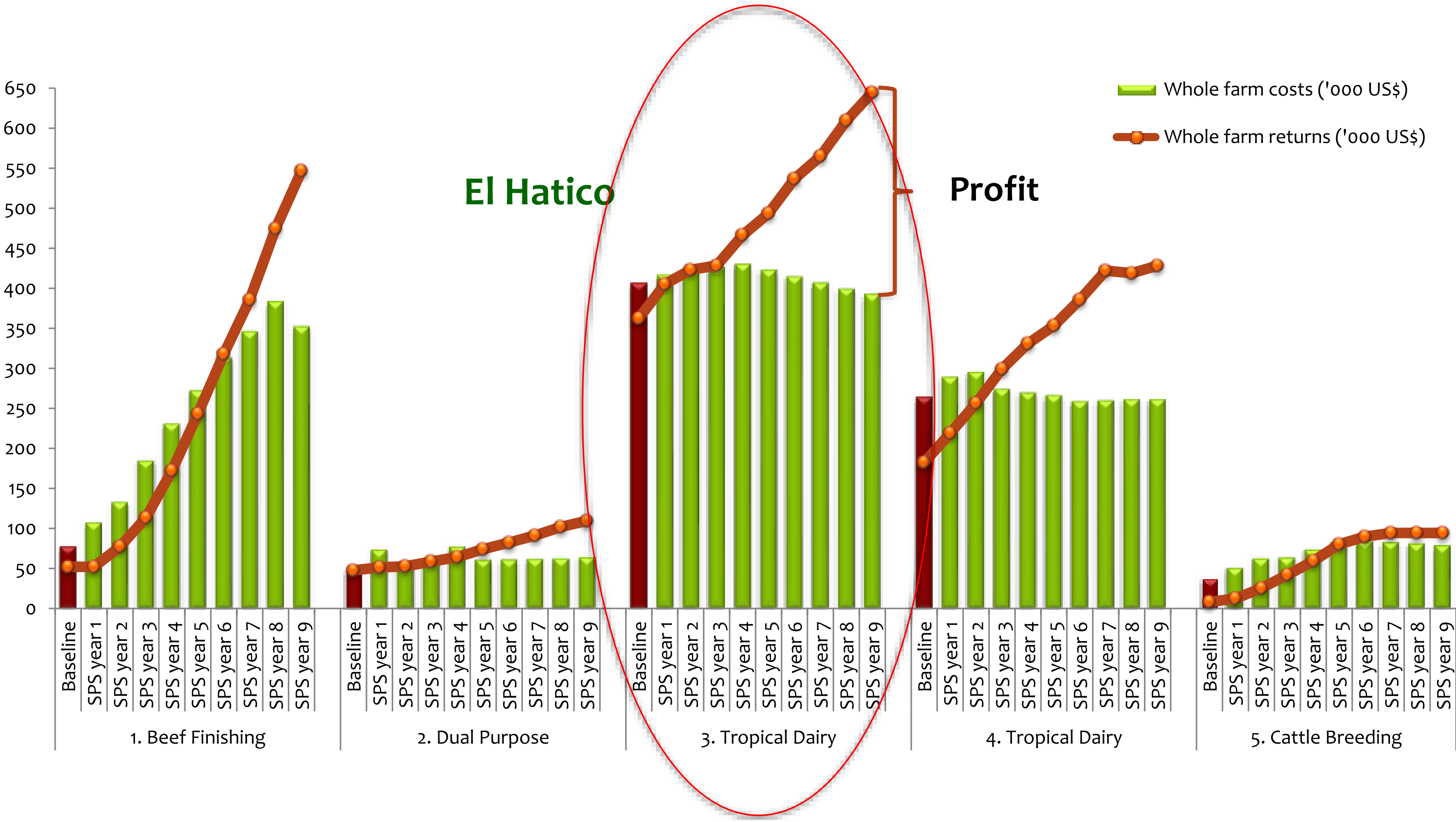
Soil organic matter in intensive silvopastoral systems (ISPS) , conventional pasture and forest

Vallejo, 2012



Soil under ISPS can store significant amounts of carbon.

Agribenchmark Global Network evaluation of livestock systems



CIPAV, *Agri benchmark*, Thúnen , WAP, FEDEGAN, 2014

Intensive silvopastoral systems apply the principles of agroecology to maximize biomass production


Photo: M. Kohut (WAP)

What is *intensive* about ISPS?

Efficiency of biological processes:

Photosynthesis & biomass production

Nitrogen fixation

Solubilization of soil phosphorus and other nutrients

Organic matter and soil biological activity

The "inputs" of the system are the natural processes themselves

A complex and wildlife-friendly matrix

Palms *Syagrus zancona*, *Attalea butyracea*, and *Roystonea regia* and **timber trees** *Swietenia macrophylla, Cedrela odorata, Zanthoxylum rhoifolium*.

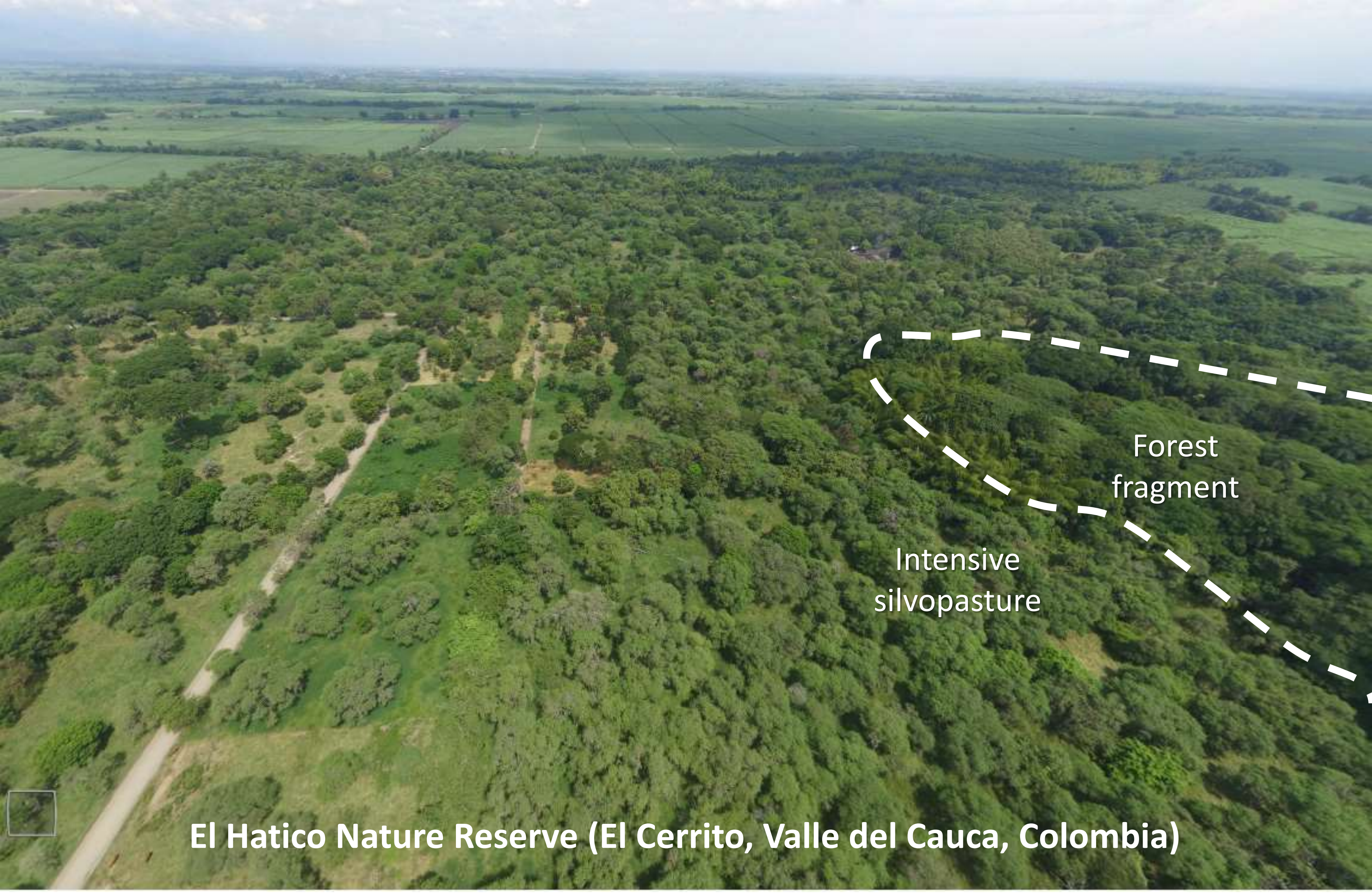
Large trees *Ceiba pentandra*, *Samanea saman*, *Enterolobium cyclocarpum* at low density

Medium sized trees *Prosopis juliflora, Senna spectabilis, Guazuma ulmifolia, Guarea guidonia,* **30-50 ha^{-1}**

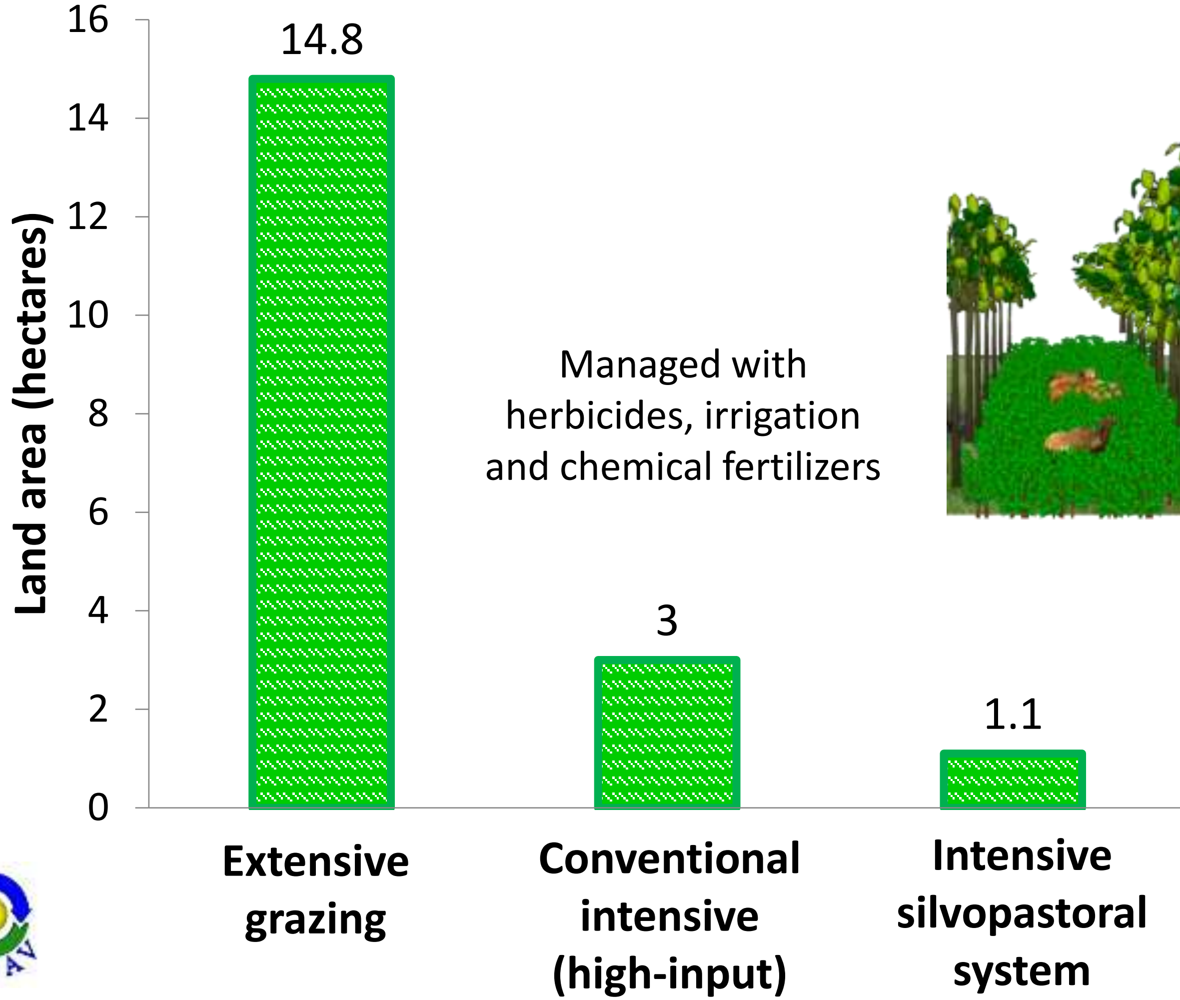
Leucaena 10.000-15.000 shrubs ha^{-1}

Grass cover *Cynodon plestostachys*, *Panicum maximum*, *Cynodon dactylon* and *Paspalum notatum*

Silvopastoral systems form a wildlife friendly agricultural matrix



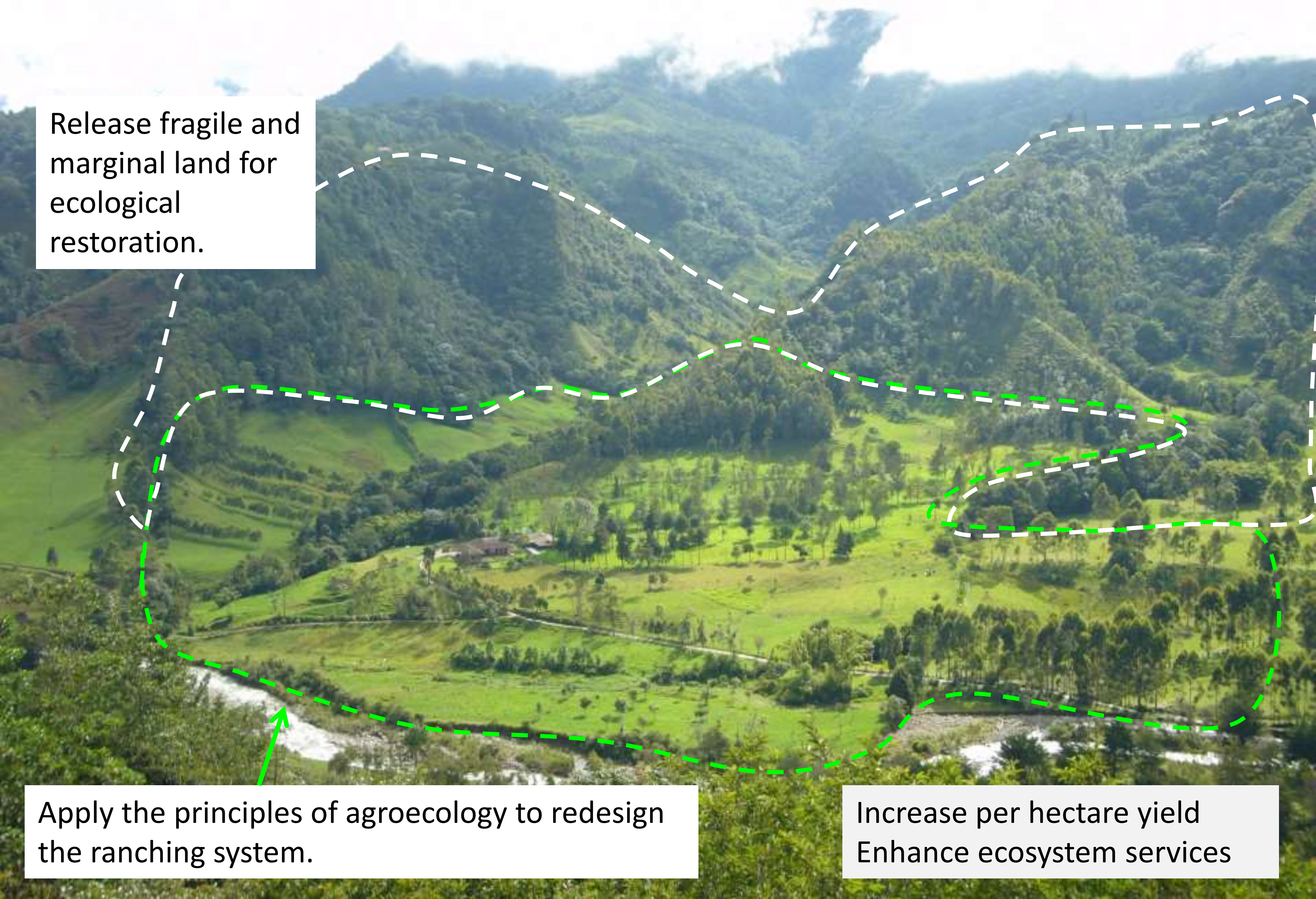
How much land is needed to produce 1 ton of beef yr^{-1} in the dry Caribbean region of Colombia?



Shifting paradigm in tropical cattle ranching

Maximum biomass production is not achieved in treeless grass monocultures, but in agroforests combining pastures, trees and shrubs.

Silvopastoral Systems and Ecological Restoration

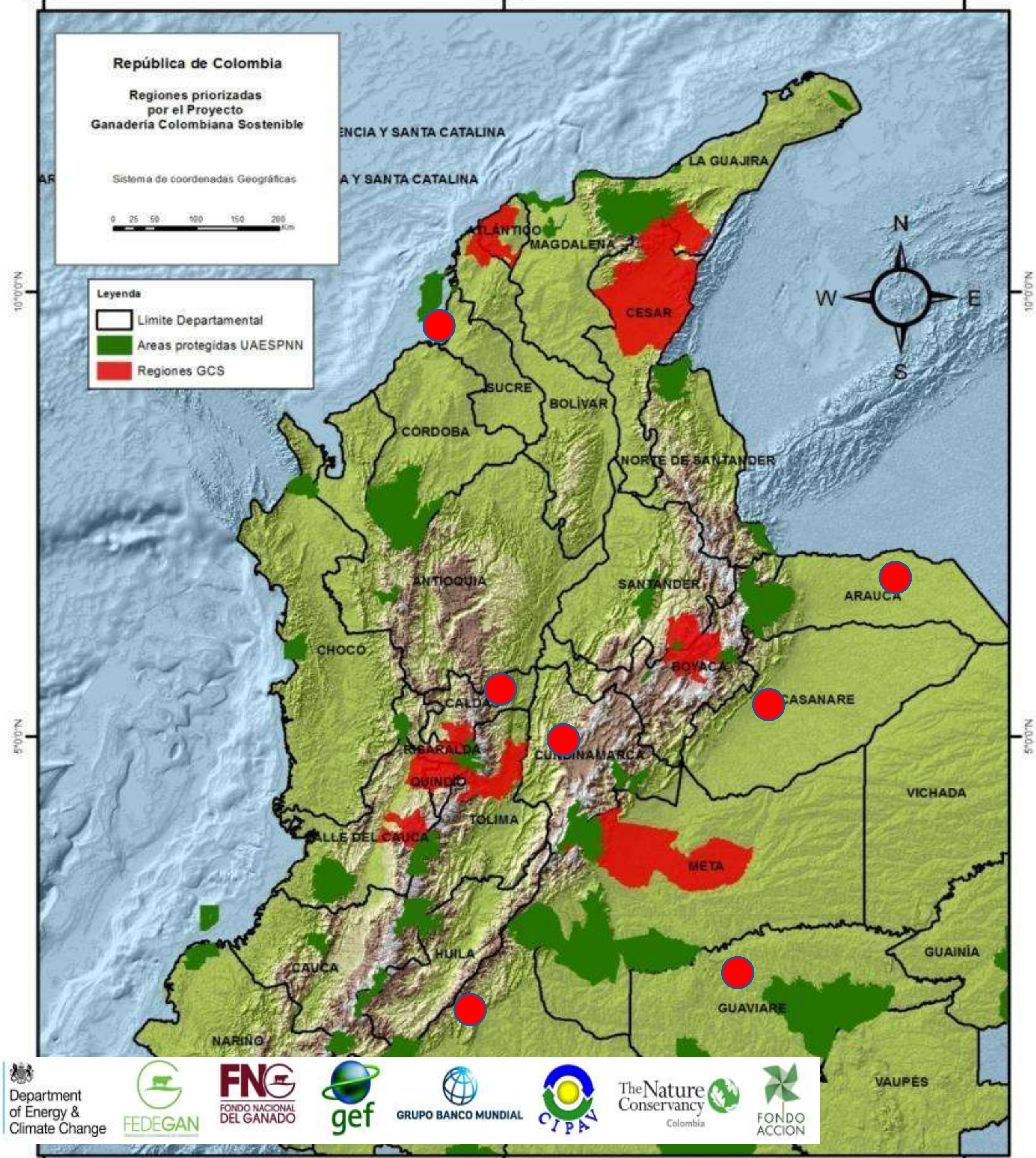


1: 1, the inevitable scale

Technological tools facilitate landscape-scale analyses and decisions. But, promoting positive change on the ground involves building trust with landholders.

Rural extension

- Rural extension work is essential to achieve the desired change in livestock production.
- Apart from knowledge, farmers need friendly and stimulating interaction with their technical assistants.
- Extensionists must complete a comprehensive training process before interacting with producers.
- Projects must invest in training extension agents because silvopastoral systems apply knowledge and practical skills beyond the college training of these professionals.



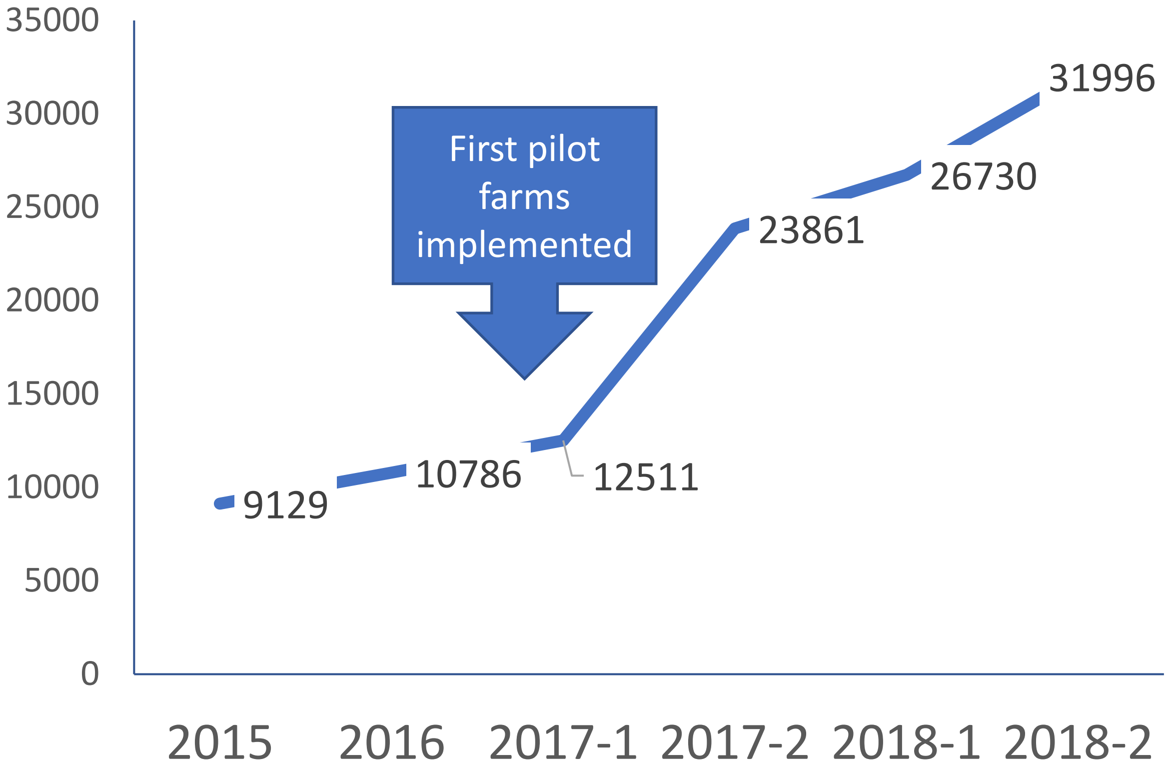
Colombian Sustainable Cattle Ranching **Project**

Ecoregions:

- Cesar River valley
- Lower Magdalena
- Andean Oak Corridor (Boyacá and Santander)
- Coffee Ecoregion
- Eastern Andes foothills (Meta).

Pilot farms outside Project areas in: Arauca, Casanare, Guaviare, Caquetá, Cudinamarca, Caldas and Sucre.

CSCRP: Pilot farms accelerated the adoption of sustainable ranching practices



Cascajal farm, Piojó, Atlántico, Colombia owned by Angel López

February 25, 2019

Angel Lopez greets a group of Cuban ranchers who visit his farm:

"There was nothing here, just rocks. Then, we started planting trees and letting the *trupillo* (mesquite, *Prosopis juliflora*) grow, even though no one wanted it. Now it's paradise and people have started to change. We have wood, fertility, food and above all, shade".

"We've had strong weapons for this struggle: heart, soul and love of the land. Without these, we would not have achieved it."
(Angel Lopez, owner of Cascajal farm)

"The trees are the magic of this farm"
(Angel Lopez, owner of Cascajal farm)

“You need patience, perseverance and love.”
(Angel Lopez, owner of Cascajal farm)

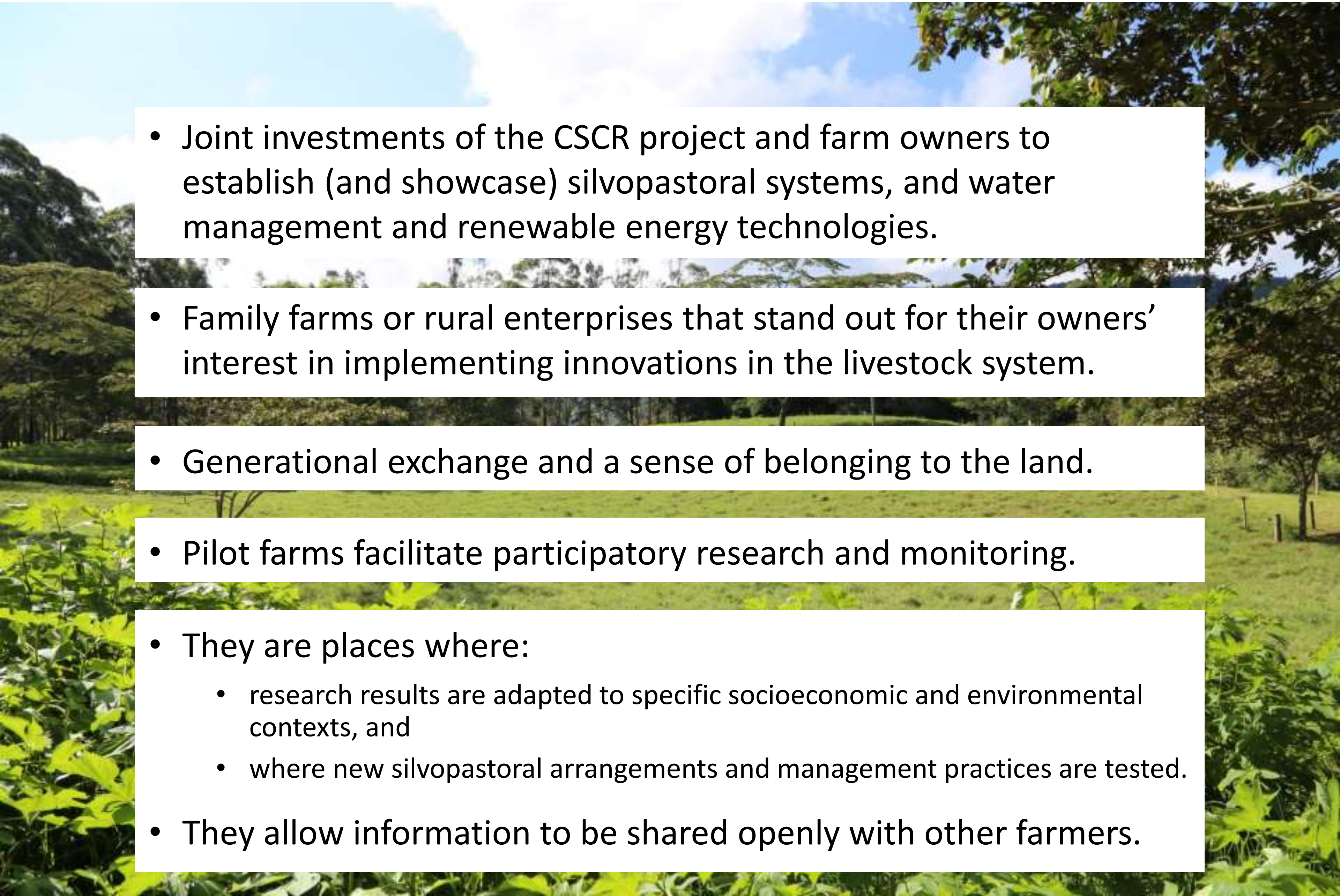
Department of Energy & Climate Change | FEDEGAN | FNG FONDO NACIONAL DEL GANADO | gef | GRUPO BANCO MUNDIAL | CIPAV | The Nature Conservancy Colombia | FONDO ACCION

Pilot farm owners work actively in farmer-to-farmer training

They play a key role in scaling-up the adoption of SPS and ecological restoration practices, and in promoting a culture of sustainable livestock production.

Department of Energy & Climate Change · FEDEGAN · FNG Fondo Nacional del Ganado · gef · Grupo Banco Mundial · CIPAV · The Nature Conservancy Colombia · Fondo Acción

Pilot farms: generation of knowledge and farmer-to-farmer training



- Joint investments of the CSCR project and farm owners to establish (and showcase) silvopastoral systems, and water management and renewable energy technologies.
- Family farms or rural enterprises that stand out for their owners' interest in implementing innovations in the livestock system.
- Generational exchange and a sense of belonging to the land.
- Pilot farms facilitate participatory research and monitoring.
- They are places where:
  - research results are adapted to specific socioeconomic and environmental contexts, and
  - where new silvopastoral arrangements and management practices are tested.
- They allow information to be shared openly with other farmers.

Innovative farmers

- Curious
- Familiar with risk as a form of learning.
- Have the ability to analyze results from different angles (not just the economic one)
- Are willing to invest in long-term benefits.
- Are open to a dialogue of knowledge (traditional vs. technical or scientific).
- Value their own knowledge
- Are willing to teach and to learn.
- Like to visit other places to see, verify and learn.








La Estancia Pilot Farm
Belén, Boyacá (Andean Oak Corridor)

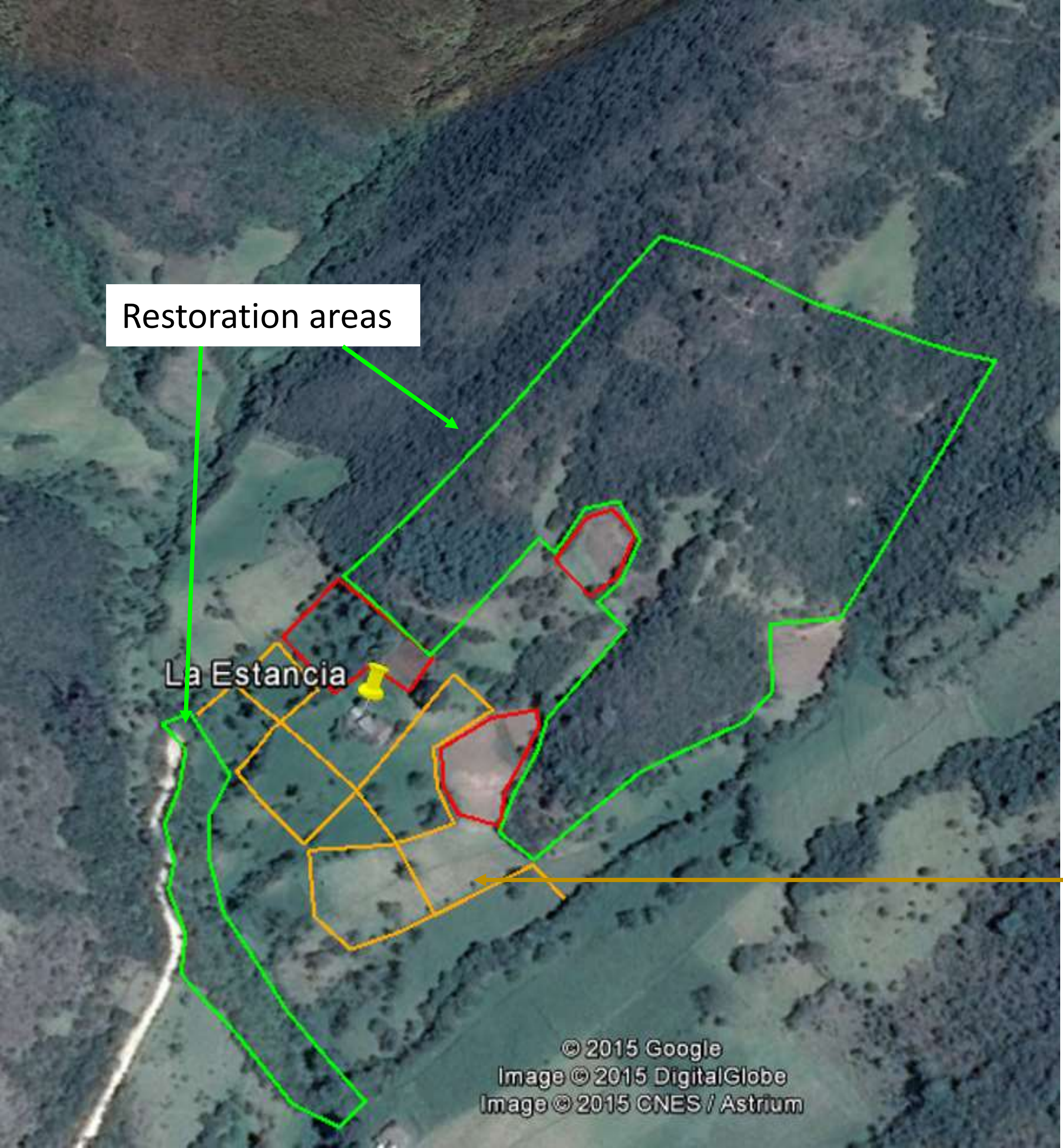
Isaac Gómez, innovative owner of La Estancia

Participatory farm planning

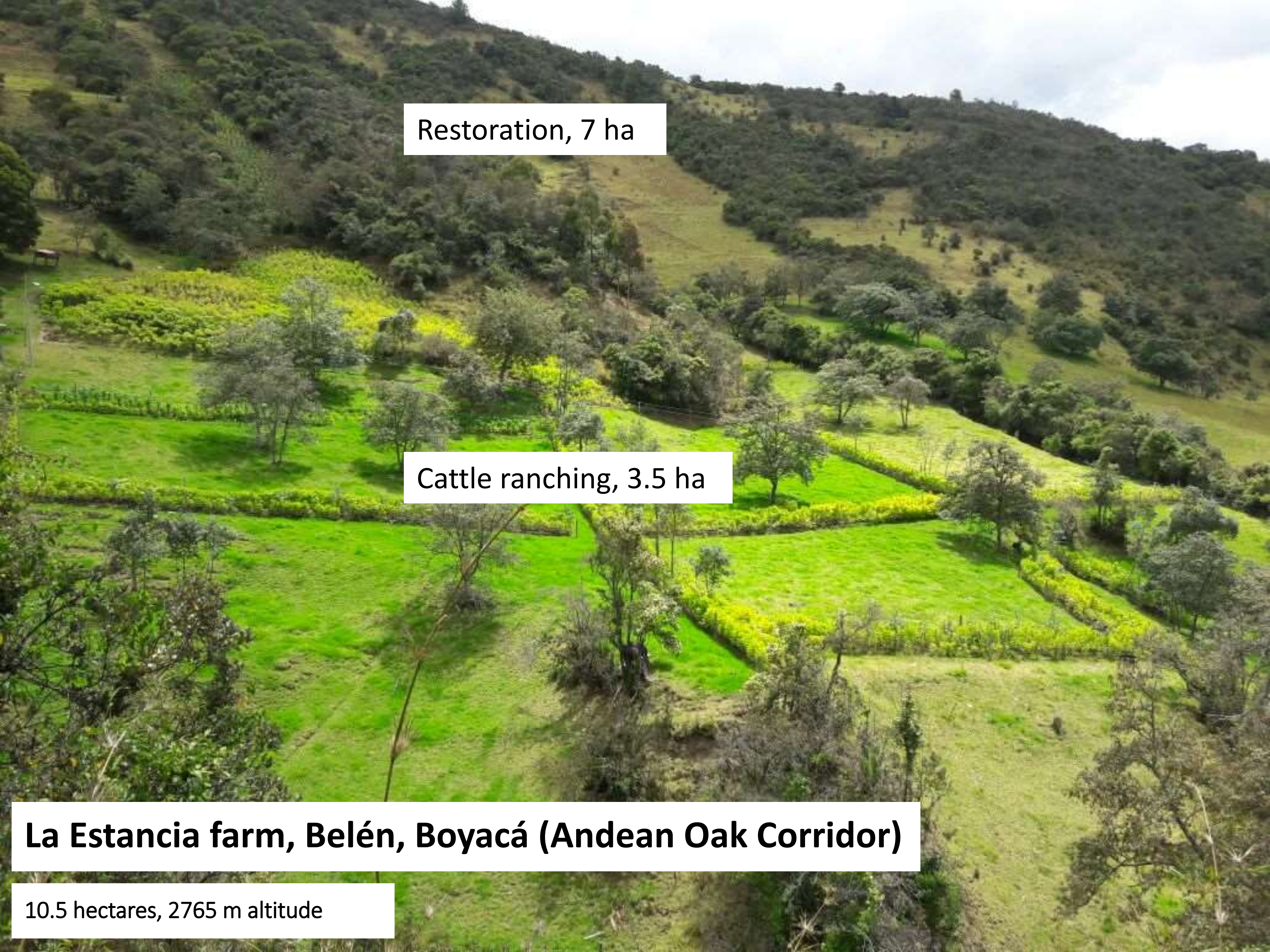
La Estancia farm, Belén (Boyacá, Colombia)

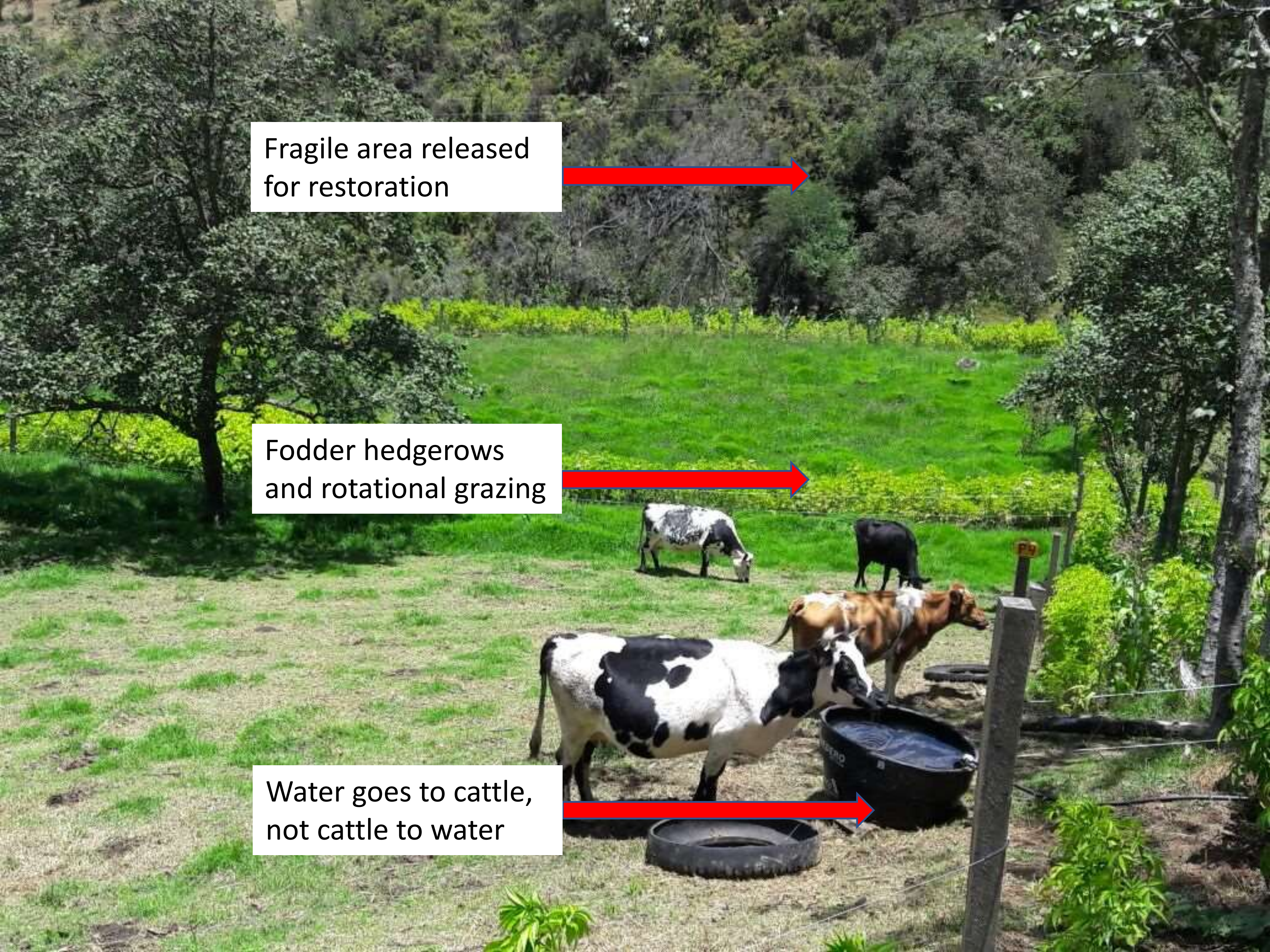
Department of Energy & Climate Change FEDEGAN FNG FONDO NACIONAL DEL GANADO gef GRUPO BANCO MUNDIAL CIPAV The Nature Conservancy Colombia FONDO ACCION

Land use planning



Areas that will undergo productive intensification with silvopastoral systems


Restoration, 7 ha
Cattle ranching, 3.5 ha
La Estancia farm, Belén, Boyacá (Andean Oak Corridor)
10.5 hectares, 2765 m altitude


Fragile area released for restoration
Fodder hedgerows and rotational grazing
Water goes to cattle, not cattle to water


Restoration & connectivity
Food sovereignty
Sustainable livestock production

May 10, 2017

July 11, 2017

Silvopastoral heir of La Estancia

Marisol Gómez

Ensuring cross-generational cultural change: Silvopastoral Heirs

Field course *Silvopastoral Heirs: Sustainable Cattle Ranching and Ecological Restoration in Pilot Farms.* June 14-16, 2017

Ensuring cross-generational cultural change: Silvopastoral Heirs

Children, teens and adults who gradually and voluntarily receive from their elders a legacy of principles and values grounded in the love of the land, and strive to give continuity to their family project.

Brayan Ortiz

Mission of the Silvopastoral Heirs

To generate and disseminate a culture of production in harmony with nature, to preserve and enrich the natural heritage, and improve the quality of life.

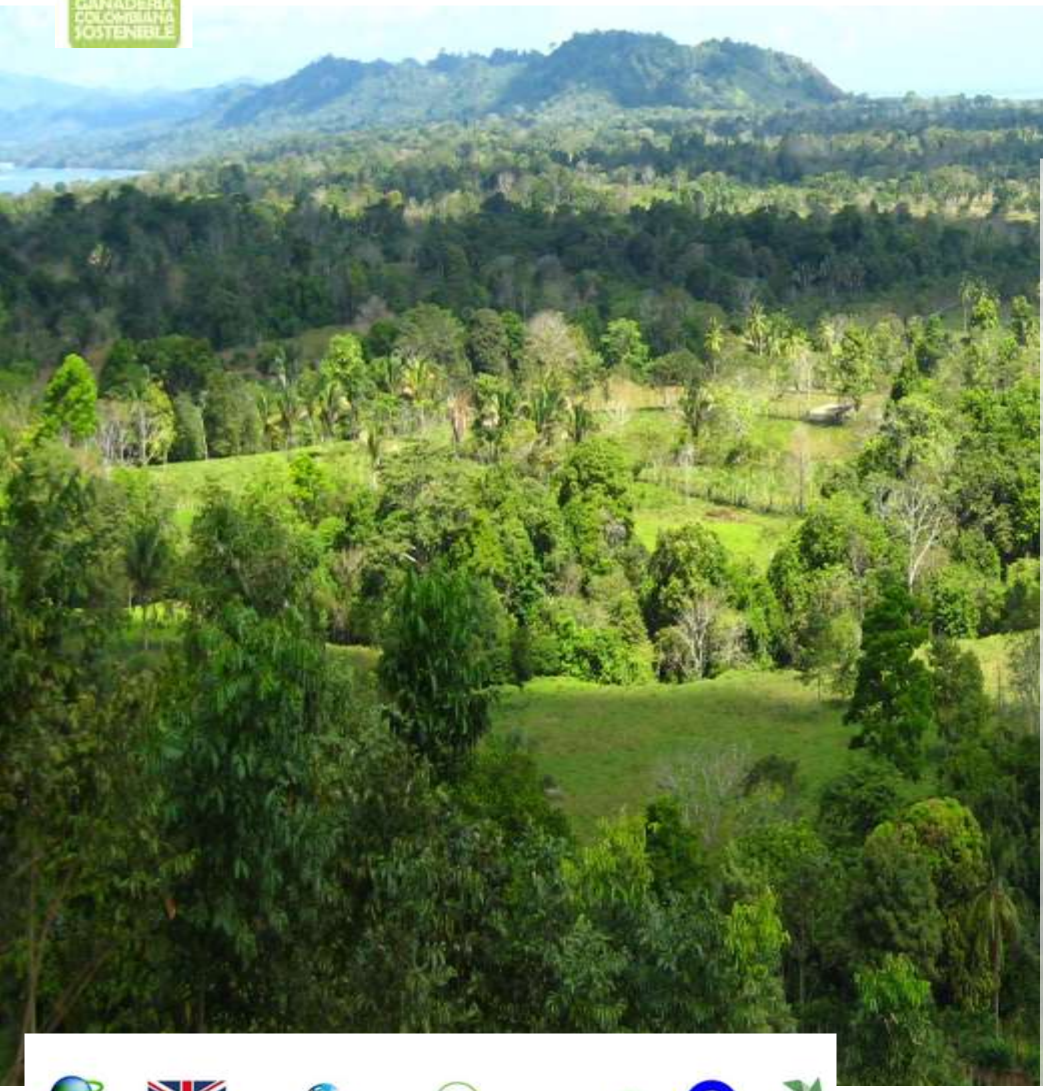
Colombian Sustainable Cattle Ranching Project

Camagüey farm, Meta

The project reached 4,100 families who manage 160,000 ha in 87 municipalities and 5 ecoregions.

These families preserved >18,000 ha of forests, planted 3 million trees, enriched 3,466 ha of second growth areas, allowed 18,603 ha to regenerate naturally, and established 38,390 ha of silvopastoral systems.

Colombian Sustainable Cattle Ranching Project



- Silvopastures:13,217 ha of live fences, 1,930 ha of paddocks with planted trees, 18,603 ha of paddocks with regenerating trees and 4,240 ha of intensive silvopastoral systems.
- Average animal load increased by 32%, and milk production increased by 29%.
- 1,565,026 tons of CO_2e were sequestered.

Silvopastoral systems increased the carrying capacity of cattle farms

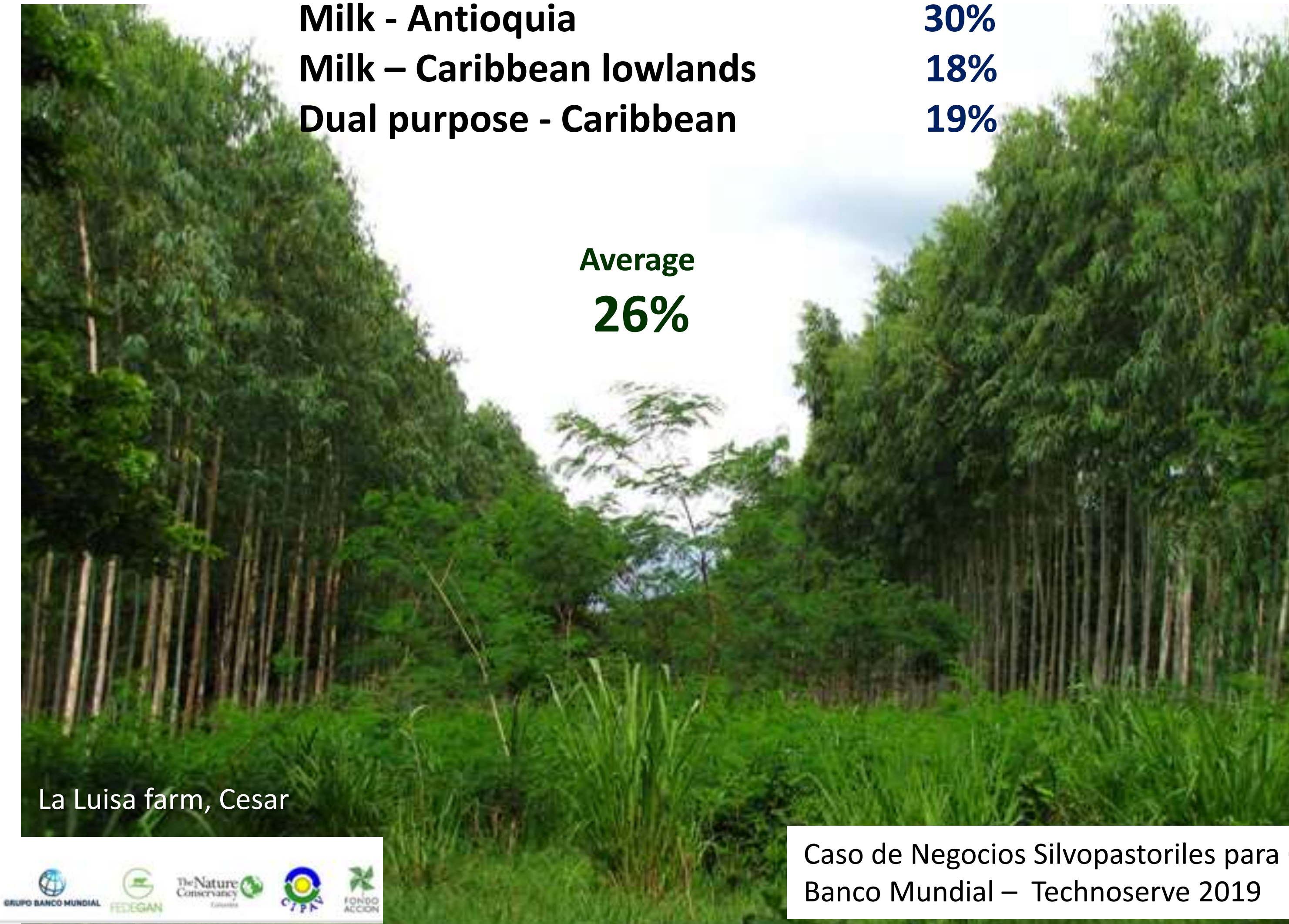
Bajo Magdalena	59%
Valle del Río Cesar	14%
Piedemonte Orinoquia	36%
Boyacá y Santander	14%
Ecorregión Cafetera	19%
Average	**26%**

Caso de Negocios Silvopastoriles para Colombia.
Banco Mundial – Technoserve 2019

Intensive Silvopastoral Systems were the most profitable ones in all regions

Milk - Altiplano Cundiboyacense	**46%**
Milk - Antioquia	**30%**
Milk – Caribbean lowlands	**18%**
Dual purpose - Caribbean	**19%**

Average
26%



La Luisa farm, Cesar

Caso de Negocios Silvopastoriles para Colombia. Banco Mundial – Technoserve 2019

Birth rate (most important parameter in the cattle business) increases in silvopastoral systems with good management practices

Scenario	Baseline (year 0) birthrate	Year 9 birthrate
National average (no silvopasture)	58%	**58%**
25 – 30% SP or intensive SP	58%	**62.8% (+ 4.8%)**
35% SP and 20% intensive SP	58%	**70.7% (+ 12.7%)**

Caso de Negocios Silvopastoriles para Colombia.
Banco Mundial – Technoserve 2019

Per hectare investment for silvopastures: scattered trees and live fences

Caso de Negocios Silvopastoriles para Colombia.
Banco Mundial – Technoserve 2019

Per hectare investment for intensive silvopastures, fodder hedges and fodder banks

US$ 1206 – 1530

(regional differences)

Includes electric fencing and water troughs

Caso de Negocios Silvopastoriles para Colombia. Banco Mundial – Technoserve 2019

Biodiversity in silvopastoral systems

Intensive silvopastures provide habitat for 60.7% of forest dung beetle species and 275 bird species.

	Bosque Maduro	Bosque secundario o humedal	Árboles dispersos en potrero y sucesión vegetal	Cultivo agroforestal	Cercas vivas y barreras rompevientos	Sistema silvopastoril intensivo	Pasto sin árboles	Pasto y suelo degradado
	++++	+++	+++	+	+++	++	+	---
	++++	++++	+++	+++	++	+++	+	--
	++++	+++	++	+++	+	+++	++	-
	++++	++++	++	++	+++	++	-	-

ESCARABAJOS ESTERCOLEROS AMIGOS DE LA GANADERÍA EN BOYACÁ-SANTANDER

Los escarabajos estercoleros construyen bolas de estiércol en las que depositan sus huevos y las entierran en el suelo. Desintegran el excremento de los bovinos, descompactan y fertilizan el suelo. Al enterrar las boñigas (bostas), eliminan los sitios donde se reproducen las moscas y los parásitos y, por lo tanto, mejoran la salud de los animales.

Para proteger y recuperar los escarabajos en su finca:

* Aumente la cantidad de árboles y arbustos en los usos de la tierra destinados a la ganadería.
* Evite el uso de ivermectinas, insecticidas y herbicidas químicos.

Hábitos de nidificación

Rodadores: Ruedan bolas de estiércol y las depositan en túneles verticales que construyen en el suelo.

Tuneleros residentes:

Tuneleros grandes:

Residentes:

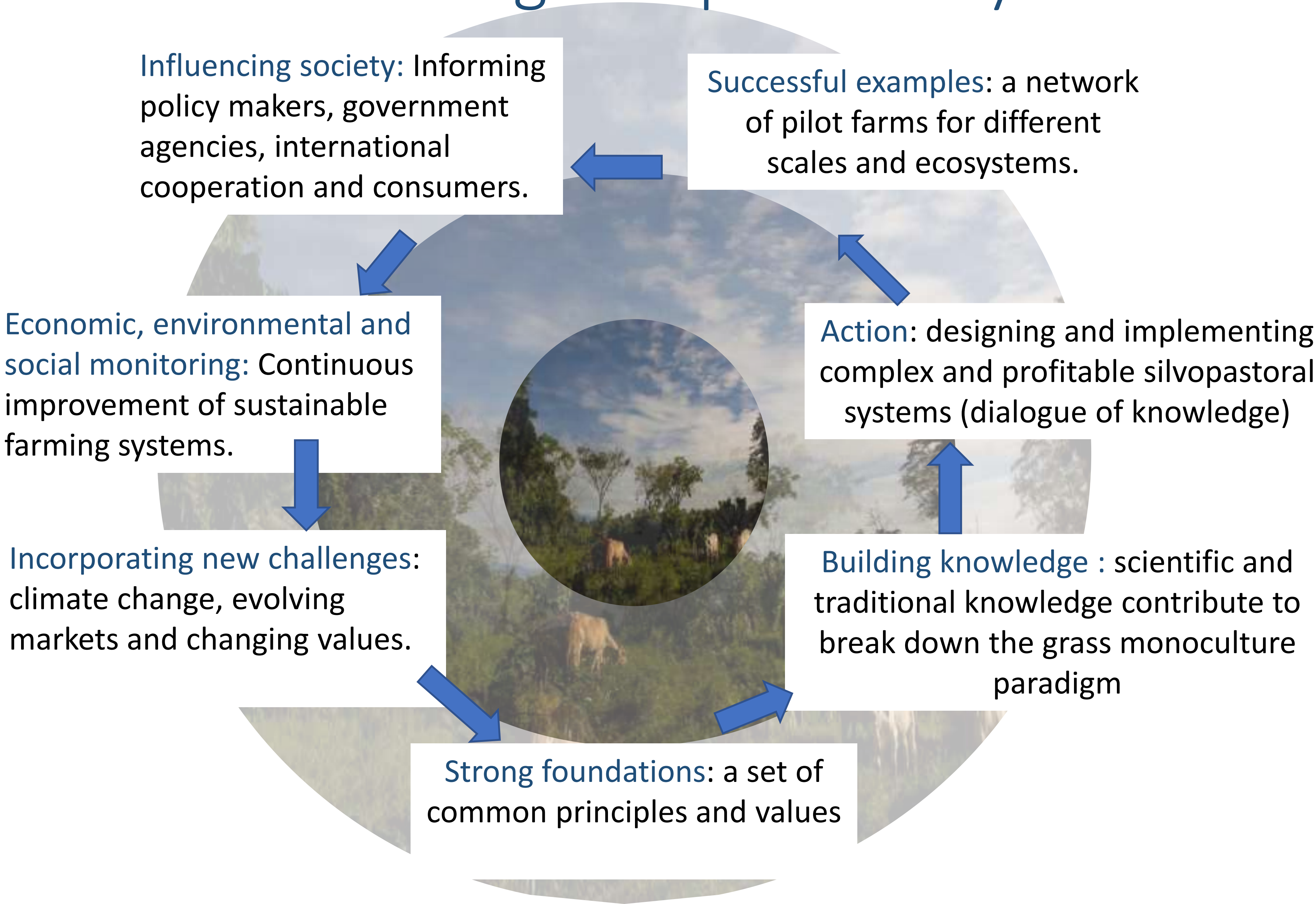
Usos de la tierra

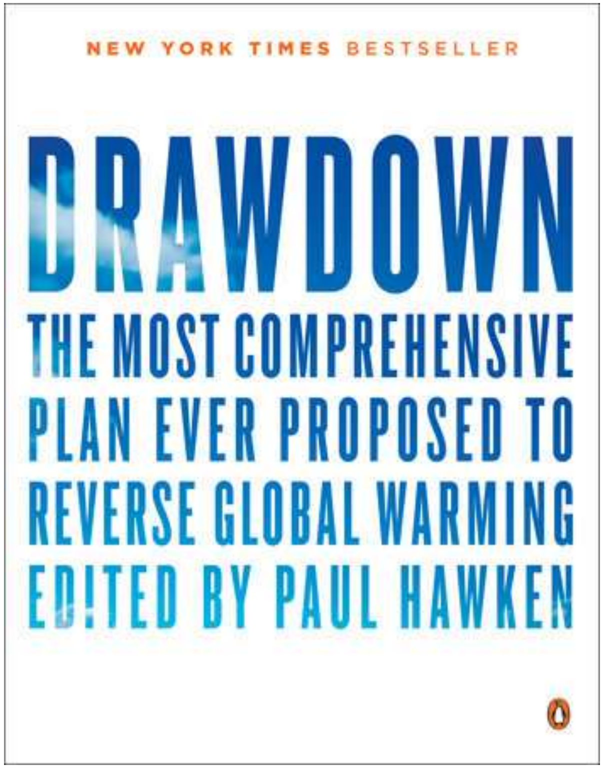
En el siguiente esquema, el color del recuadro y el número de cada escarabajo se relaciona con el uso de la tierra en donde se distribuye.

gef
Funded by UK Government
GRUPO BANCO MUNDIAL
FEDEGAN
CIPAV
The Nature Conservancy Colombia
FONDO ACCIÓN

Autores: Carolina Giraldo[1]. Investigadores: Carolina Giraldo[1], Julián Mondivil[1], Cindy Quevedo[1], Julián Chará[1]. [1]Fundación CIPAV. Fotografía de fondo: Carlos Pineda. Fotografías de escarabajos: Francisco López Machado Fotografía. Diseño e ilustración: The Freelancers Design Group. Infografía Proyecto Ganadería Colombiana Sostenible.

Mainstreaming silvopastoral systems





Rank	Solution	Sector	TOTAL ATMOSPHERIC CO2-EQ REDUCTION (GT)	NET COST (BILLIONS US $)	SAVINGS (BILLIONS US $)
1	**Refrigerant Management**	Materials	89.74	N/A	$-902.77
2	**Wind Turbines (Onshore)**	Electricity Generation	84.60	$1,225.37	$7,425.00
3	**Reduced Food Waste**	Food	70.53	N/A	N/A
4	**Plant-Rich Diet**	Food	66.11	N/A	N/A
5	**Tropical Forests**	Land Use	61.23	N/A	N/A
6	**Educating Girls**	Women and Girls	59.60	N/A	N/A
7	**Family Planning**	Women and Girls	59.60	N/A	N/A
8	**Solar Farms**	Electricity Generation	36.90	$-80.60	$5,023.84
9	**Silvopasture**	Food	31.19	$41.59	$699.37
10	**Rooftop Solar**	Electricity Generation	24.60	$453.14	$3,457.63

Related Solutions

COMING ATTRACTIONS

INTENSIVE SILVOPASTURE

Intensive silvopasture intercrops a leguminous woody shrub with grasses and trees. Through rapid rotational grazing, livestock yields increase alongside carbon sequestration in soil.

LAND USE

AFFORESTATION

Afforestation—creating forests where there were none before—creates a carbon sink, drawing in and holding on to carbon and distributing it into the soil.

FOOD

FARMLAND RESTORATION

The world's abandoned farmland is an opportunity for drawdown. Restoring it sequesters carbon and can improve food security, farmers' livelihoods, and ecosystem health.

Related Solutions

FOOD

MANAGED GRAZING

Managed grazing imitates the activity of migratory herds to improve soil health, carbon sequestration, water retention, and forage productivity.

COMING ATTRACTIONS

A COW WALKS ONTO A BEACH

Asparagopsis taxiformis, a species of seaweed, shows promise for reducing methane emissions from livestock—currently 6 to 7 percent of annual greenhouse gas emissions.

COMING ATTRACTIONS

PERENNIAL CROPS

Perennial crops sequester carbon because they leave the soil intact. Researchers are pursuing grain, cereal, and oilseed plants that are perennial food providers.

This multiuse silvopastoral landscape in Colombia is an example of forest landscape restoration that improves both ecological integrity and human well-being.

CONSERVATION

Restoring tropical forests from the bottom up

How can ambitious forest restoration targets be implemented on the ground?

By **Karen D. Holl**

Recent initiatives at regional, national, and global scales have called for unprecedented levels of forest restoration to counteract decades of rapid deforestation (*1*, *2*). Thus far, 30 countries have committed to restore 91 million hectares (ha) of deforested landscapes, an area the size of Venezuela, by 2020; at the 2014 United Nations Climate Summit, a global target of 350 million ha was set for 2030 (*1*). These bold targets are motivated by diverse goals, including conserving biodiversity, sequestering carbon, improving the water supply, and sustaining human livelihoods (*2*, *3*). How can these challenging targets be met, given competing land uses and limited funds for restoration?

There is often a striking disconnect between the groups that set restoration targets and those that implement projects and guide restoration science (*3*, *4*). Commitments to restore millions of hectares of forest are made by international groups and national governments, but successfully achieving these targets requires working with individual landowners and local communities. In a recent review, Murcia *et al.* found that only 2 of 90 recent forest restoration projects initiated by government agencies in Colombia involved local communities in the design (*3*). Governments that adopt this top-down approach are unlikely to gain the community support needed to successfully maintain restoration projects over the long term.

To be successful, restoration efforts also require approaches that are practical at large scales. Yet, the vast majority of scientific studies are conducted in plots of a few to hundreds of m^2 at one or a few sites (*5*). This spatial mismatch is problematic because the methods tested (such as intensive weed removal or moving topsoil from a reference forest as a source of seeds) often are not feasible at large scales. Moreover, results of restoration studies depend on past land-use history, soil type, and other local conditions (*6*). Results from single-site studies can therefore not be generalized to guide restoration projects at scales of a few to hundreds of hectares.

Successfully restoring the amount of forest needed to meet national and international targets requires a frameshift in both restoration planning and science. It requires bottom-up engagement of landowners, nongovernmental organizations, local government leaders, scientists, private restoration businesses, and indigenous and community groups to set restoration goals tailored to regional ecological and socioeconomic conditions and to develop, evaluate, and manage restoration practices that are cost-effective and practical at a large scale (*4*, *7*).

Ecological restoration has historically focused on assisting the recovery of degraded ecosystems toward a narrow set of ecological end points—most often a semblance of predisturbance ecosystem functions and species composition. In contrast, recent "forest landscape restoration" initiatives have aimed to simultaneously improve both ecological integrity and human well-being by balancing multiple restoration goals across the landscape (*2*, *7*). Collaborative planning efforts can identify those locations where restoring large forest areas is most ecologically, socially, and economically feasible and those where

Environmental Studies Department, University of California, Santa Cruz, CA 95064, USA. Email: kholl@ucsc.edu

El Cortijo farm, Salento, Colombia

Science, February 2017

The Washington Post
Democracy Dies in Darkness

The WorldPost • Opinion

How we can make beef less terrible for the environment

Intensive silvopasture in Colombia, where the agricultural practice is quickly spreading.

By **Eric Toensmeier**
May 30, 2018

REVIEW SUMMARY

CONSERVATION

Landscapes that work for biodiversity and people

C. Kremen* and A. M. Merenlender

BACKGROUND: Biodiversity is under siege, with greatly enhanced rates of local and global extinction and the decline of once-abundant species. Current rates of human-induced climate change and land use forecast the Anthropocene as one of the most devastating epochs for life on earth. How do we handle the Anthropocene's triple challenge of preventing biodiversity loss, mitigating and adapting to climate change, and sustainably providing resources for a growing human population? The answer is in how we manage Earth's "working lands"; that is, farms, forests, and rangelands. These lands must be managed both to complement the biodiversity conservation goals of protected areas and to maintain the diverse communities of organisms, from microbes to mammals, that contribute to producing food, materials, clean water, and healthy soils; sequestering greenhouse gases; and buffering extreme weather events, functions that are essential for all life on Earth.

ADVANCES: Protected areas are the cornerstone of biodiversity conservation. Although the total area of protected regions needs to be increased, parks will nonetheless continue to lose species if these areas are isolated from one another by inhospitable land uses and are faced with a rapidly changing climate. Further, many species, such as those that migrate, remain unprotected as they occupy lands outside of parks for all or portions of their life cycles. Lastly, protected-area effectiveness is greatly influenced by surrounding land management. "Working lands conservation" aims to support biodiversity while providing goods and services for humanity over the long term, assuring sustainability and resilience. By managing lands surrounding parks favorably, working lands can buffer protected areas from threats and connect them to one another. This approach complements protected areas by providing accessory habitats and resources for some species while facilitating dispersal and climate change adaptation for others. Further, by maintaining the biodiversity that supplies critical ecosystem services within working lands, these approaches ensure that the production of food, fiber, fuel, and timber can be sustained over the long run and be more resilient to extreme events, such as floods, droughts, hurricanes, and pest and disease outbreaks, which are becoming more frequent with climate change. A variety of biodiversity-based land management techniques can be used in working lands, including agroforestry, silvopasture, diversified farming, and ecosystem-based forest management, to ensure sustainable production of food and fiber.

OUTLOOK: The underlying principle of biodiversity-based management of working lands has been practiced since ancient times. Today, these systems have largely been replaced by unsustainable resource extraction, rather than serving as models that could be adapted to modern conditions. Although various regulatory, voluntary, and financial tools exist to promote sustainable land management, many barriers prevent individuals, communities, and corporations from adopting biodiversity-based practices, including deeply entrenched policy and market conditions that favor industrialized or extractive models of land use. Thus, uptake of these approaches has been patchy and slow and is not yet sufficient to create change at the temporal and spatial scales needed to face the triple Anthropocene threat.

Biodiversity-based land management practices are knowledge- rather than technology-intensive. They are well adapted to empower local communities to manage their natural resources. One of the most exciting emerging trends is community-driven initiatives to manage working landscapes for conservation and sustainability. By linking up through grassroots organizations, social movements, and public-private partnerships, these initiatives can scale up to create collective impact and can demand changes in government policies to facilitate the conservation of working lands. Scientists and conservation practitioners can support these initiatives by engaging with the public, listening to alternative ways of knowing, and cocreating landscapes that work for biodiversity and people. ■

ON OUR WEBSITE

Read the full article at http://dx.doi.org/10.1126/science.aau6020

TOMORROW'S EARTH

Read more articles online at scim.ag/TomorrowsEarth

The list of author affiliations is available in the full article online.
*Corresponding author. Email: ckremen@berkeley.edu

Cite this article as C. Kremen and A. M. Merenlender, Science 362, eaau6020 (2018). DOI: 10.1126/science.aau6020

Strawberry production in Central Coast, California. On the left, a homogeneous landscape of strawberry monoculture, including organic fields, supports fewer wild species than a diversified, organic farm (right) in the same region, which includes a small field of strawberry, surrounded by orchards, hedgerows, diverse vegetable crops, and natural habitats. The monoculture landscape creates barriers to wildlife dispersal, whereas the diversified landscape is more permeable.

PHOTO: C. KREMEN

Science, October 2018

Fig. 1. Rebuilding connectivity in the matrix by using silvopasture. Photo of Finca La Luisa showing several types of silvopastoral systems, including regenerating secondary tropical dry forest trees with grass understory (yellow) and rows of planted *Eucalyptus* trees interspersed with nitrogen-fixing *Leucaena leucocephala* fodder shrubs and forage grasses (blue). These systems were established on former monoculture agricultural lands to restore compacted, degraded soils; the red area shows early stages of tropical dry forest regeneration prior to grass seeding for silvopasture. Silvopastures produce more cattle sustainably on less land, buffer ranchers from economic losses due to climate extremes, and create landscape connectivity to other forest fragments (orange) in the Cesar river valley, Colombia.

Ensuring the sustainability of production requires balancing across provisioning, regulating, and supporting services; in other words, seeking multifunctionality and stability rather than maximal production. For example, conventional (chemically intensive) monoculture agriculture produces high yields but often at the expense of water quality, climate regulation, and soil health (Fig. 2A) (20) and can suffer production collapse in response to periodic extreme weather, pests, and diseases (31–33). Although transforming to a more sustainable system may reduce average yields somewhat [e.g., (34)], by relying on ecosystem services produced on the farm and in the surrounding landscape, a sustainable system is both multifunctional and more resilient to change (20, 31) (Fig. 2C).

Working landscapes often comprise heterogeneous patch types, including novel communities made up of mixtures of native and nonnative species, as well as remnants of natural or seminatural habitats whose composition is more similar to that of a historical ecological community (35). Although management goals likely will differ among patch types, both individual patches and the whole landscape should be managed for sustainability. For example, patches whose communities are far from historical could be managed principally for crops (a provisioning service) by using sustainable agricultural practices to minimize negative effects on biodiversity and ecosystem services on and off site. Remnant patches could be retained as stepping-stone habitats to support species dispersal and provide regulating services such as pollination (29, 31). Maintaining mosaic landscapes composed of different patch types provides opportunities to maximize diversity, resilience, and multifunctionality. Radar diagrams reveal likely trade-offs and sustainability within and across patches (Fig. 2B), as well as multifunctionality at the landscape scale (Fig. 2C).

Conservation in working landscapes draws upon several related concepts. Integrated landscape management initiatives seek to simultaneously improve food production, biodiversity or ecosystem conservation, and rural livelihoods and are being implemented by governments and nongovernmental organizations in Latin America and Africa (36). The ecosystem stewardship concept focuses on the need to sustain Earth's capacity to provide ecosystem services and support socioecological resilience under conditions of uncertainty and change (27). The socioecological production landscape of the Japan Satoyama Satoumi Assessment refers to dynamic landscape mosaics that have been shaped over time by the interactions between people and nature in ways that jointly support biodiversity and human well-being (37). These concepts also emphasize critical social components, such as involving multiple stakeholders at the landscape scale, community participation, intersectoral coordination, flexible and adaptive governance systems, social learning, and adaptive management, which are necessary for successful conservation of working landscapes.

The underlying principle of maintaining ecological diversity inherent to these approaches has been practiced since ancient times. Some of these management systems, such as indigenous use of fire, weeding, pruning, and the seed dispersal that shaped Californian ecosystems (38), no longer exist in their original form, whereas others, such as regional pastoral and high-mountain farming systems in Europe (39), persist in some areas. By creating highly simplified and intensified production systems (21, 40), from corn and soy in U.S. midwestern states to palm oil plantations in southeast Asia and vineyards in Chile, we have abandoned this critical sustainability principle across much of Earth's cultivated landscapes. However, it is a fallacy that such systems will ultimately spare more land for nature conservation or feed the world indefinitely; rather, we need to find ways to allow biodiversity-based production methods to figure much more prominently in local, regional, and global markets (16).

Working lands conservation as a complement to protected areas

Given the dire situation facing many species and the expectation of further species losses and shifts in ecosystem composition due to climate change (2, 4, 11), ceasing further habitat conversion completely and protecting large regions of Earth effectively are critical necessities for conservation (6–8), although just how much should be protected is highly debated (41). [By "protected area," we refer to parks whose primary function is to conserve biodiversity and wilderness (International Union for Conservation of Nature and Natural Resources categories I to IV, constituting 6.75% of terrestrial area) (42), in contrast to areas blending conservation and livelihood objectives (categories V to VI, constituting 8.65%).] However, the protected-area strategy alone will not be successful without complementary working lands conservation in the surrounding landscapes. First, even the largest protected areas will lose species over the long term (9) unless surrounding landscapes can be managed to provide connectivity among parks. Further, less than 10% of protected areas are expected to represent current climatic conditions within 100 years, increasing the criticality of matrix connectivity to permit species to follow their suitable climates (12). Lastly, effectiveness in controlling threats, such as invasive species, encroachment, poaching, and other impacts on protected lands, also critically depends on the surrounding matrix (10). Thus, to stem the tide of biodiversity loss, we must expand beyond protected areas, using working lands conservation both to buffer and to reduce the threats that cross park boundaries and to create accessory habitats for both movement and persistence.

Working lands conservation is a key linchpin for combatting the triple Anthropocene challenge of biodiversity loss, climate change, and unsustainable land use. A large-scale example is the Mesoamerican Biological Corridor project, which has fostered a multistakeholder participatory process to enhance connectivity on cultivated, range, and forest working lands to link

La Luisa farm, Codazzi, Colombia

Science, October 2018

Silvopastures produce more cattle sustainably on less land, buffer ranchers from economic losses due to climate extremes, and enhance landscape connectivity (Kremen & Merenlender, 2018).

Department of Energy & Climate Change FEDEGAN FNG FONDO NACIONAL DEL GANADO gef GRUPO BANCO MUNDIAL CIPAV The Nature Conservancy Colombia FONDO ACCION




Final comment






Complex problems demand complex approaches.

This means:

- Embracing complexity and biodiversity
- Strengthening synergies between agroecology and restoration
- Incorporating human values and the cultural dimension of food production
- Empowering women and youth
- Ensuring cross-generational cultural change

In which of these livestock systems would you prefer to live if you were a cow or a steer in the warm and dry Caribbean region of Colombia?

Thanks!

- El Hatico Nature Reserve and Lucerna farm (Valle del Cauca, Colombia)
- Global Network of Silvopastoral Systems
- Colombian Sustainable Cattle Ranching Project (Proyecto Ganadería Colombiana Sostenible)

Department of Energy & Climate Change
FEDEGAN
FNG FONDO NACIONAL DEL GANADO
gef
GRUPO BANCO MUNDIAL
CIPAV
The Nature Conservancy Colombia
FONDO ACCION