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Florencia Montagnini *Editor*

Biodiversity Islands: Strategies for Conservation in Human-Dominated Environments

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This book is dedicated to my father.

Foreword

It is unfortunate that a book on this topic needed to be written, but it is on a highly relevant subject given the worldwide destruction of natural habitats and the loss of so many biological species. As we, at present, face the sixth great species extinction, the remaining biodiversity survive in small patches or islands, which have become extremely important for the survival of the species they contain or the migrant birds they host. As someone who has worked a lifetime in botanical gardens, I am very aware of the small patches of original vegetation that they often contain and their value for the pollinators that visit the flowers or the occasional visit of migratory birds as they pause on their journey. At the Royal Botanical Gardens at Kew in London, there is rare-listed hoverfly and an endangered species of lichen among other species preserved in this biodiversity island. In my field work in the highly fragmented Atlantic rainforest of Brazil and Argentina, we are still finding new and undescribed species of plants in the small remnants of the original forest. It is fortunate that still many species of animals and plants survive in these often small islands, making them extremely important, and a book drawing attention to them is most welcome.

Until relatively recently, much more attention was given to marine islands following the work of MacArthur and Wilson in 1967 and because of their much-threatened biodiversity, but now there is a growing realisation of the importance of human-made islands on the mainland. The creation of biodiversity islands has been the topic of important research in the Biological Dynamics of Forest Fragments Project near Manaus, Brazil. I have spent many hours identifying plant species for this project. The original name of the project "Minimum Critical Size of Ecosystems Project" indicates its original research purpose to provide data about the minimum area needed to preserve a functioning area of rainforest to assist in the establishment of reserves and conservation areas. This book clearly demonstrates that today there are biodiversity islands of many different sizes, shapes and purposes.

This book treats a great variety of different types of biodiversity islands, all of which are areas of high biodiversity surrounded by highly degraded or intensely used landscapes that act as refuges for the surviving species of the original ecosystem. The many examples given here clearly show the critical importance of biodiversity islands for conservation, restoration and sustainable management of several productive agroforestry systems. It is good to be taken around the world with examples of biodiversity islands in both the tropical and the temperate regions. I like the fact that these examples include not only areas of pristine natural habitats such as the Monteverde Cloud Forest in Costa Rica or the forest islands in the Paraguayan Chaco but also several examples from highly managed islands in agroforestry and regenerative agriculture systems. Some of the examples of the policies and political motivations given in various chapters should be helpful to anyone involved in the creation or management of a biodiversity island. Several chapters here show examples of harmonising food production with conservation. This unity of purpose is important and is far more likely to be of long-term success than placing conservation and agriculture in separate camps. Several chapters show the importance of alternative ways to produce food from more integrated management systems that also preserve biodiversity. The social, ecological, ethical and economic benefits of such systems are clearly outlined in several of the chapters.

I congratulate the editor of this book for gathering together such a varied and useful compilation of the ongoing work on biodiversity islands. This will be of considerable use to people involved in the design of future biodiversity islands because it has much to say about the motivations and politics and also about their size and spatial distribution whether from fragments of the original vegetation or from restoration of degraded and intensely used areas. It will be a most useful tool for both conservation and restoration. My hope is that this will be used by conservation organisations, local communities and indigenous peoples to create effective islands of biodiversity in many different ecosystems of the world and for many more creative types of management.

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Preface

A biodiversity island is an area of high biodiversity located within ecologically degraded, human-dominated landscapes. Biodiversity in the "islands" exceeds the surrounding landscape biodiversity baseline. These biodiversity islands thereby act as ecological refuges, promoting restoration and conservation in altered ecosystems prevalent today throughout the globe.

Biodiversity islands can provide food, water, fuels, and fibers, as well as genetic, medicinal, biochemical, and ornamental resources, pollination services, biological pest control, and maintenance of life cycles of migratory species. These landscapes hold promise for protecting a multitude of plant and animal species for present and future generations. The presence of biodiversity islands spread over a large area can decrease the chances of habitat loss from fire, disease, and other disturbances.

Biodiversity islands can exist within a wide range of human-dominated landscapes, including forest, agricultural, and urban settings, and can vary in scale from square meters to thousands of square kilometers. Design strategies for biodiversity islands depend on the spatial distribution of reserves throughout the landscape, the degree of site degradation, the species present, and their locations within the urban to rural spectrum.

This book is intended to provide an overview for the identification and establishment of biodiversity islands, presenting examples and case studies where the biodiversity islands approach is being used in a variety of locations and contexts worldwide. This book will contribute to design parameters on appropriate sizing and spatial distribution of biodiversity islands to be effective in conservation and regeneration across the landscape, using integrated landscape management approaches.

The chapters discuss current challenges faced today by biodiversity conservation researchers, practitioners, and policy makers and propose innovative approaches to tackle them. Contributors are an assemblage of researchers, academicians, and practitioners from biodiversity conservation, environmental management, forestry, agroecology, agroforestry, and related fields who approach the issues from unique perspectives.

This book comprises five parts: **Part I, Introduction**, establishes the framework for understanding the complexities of biodiversity islands and the variety of strategies that can be used to establish them. The Introduction defines the term "biodiversity islands" and their size, location, and distribution in the landscape; stresses their many ecological, social, and economic benefits; and discusses potential limitations of the use of this framework along with ways to overcome them. **Part II, Biodiversity Islands Establishment and Management: Challenges and Alternatives,** shows how design strategies may depend on landscape use within the matrix of habitat fragmentation, with integrated landscape management (ILM), including sustainable agriculture, agroforestry, and community-led action, providing a framework for implementation. **Part III, Biodiversity Islands Across the Globe: Case Studies,** shows how varied agroecological strategies were applied in the formation or conservation of biodiversity islands in human-dominated landscapes in Paraguay, Peru, Costa Rica, Colombia, Great Britain, Argentina, Panama, and the USA. The variety of case studies from different types of landscapes from several regions of the world reveals the role biodiversity islands play in conserving local flora and fauna that have been largely diminished by anthropogenic activities, while providing cultural connections to nature and supplying ecosystem services that make biodiversity islands advantageous to farmers and nearby communities. **Part IV, Safeguarding the Environmental, Economic, and Social Benefits of Biodiversity Islands,** further details the economic, social, political, and cultural aspects of the establishment and persistence of biodiversity islands in anthropogenic landscapes, emphasizing how community-led action contributes to their development and subsequent management, with examples from Puerto Rico, Ecuador, Brazil, India, the USA, Panama, and Ethiopia. **Part V**, **Conclusions**, summarizes the lessons learned while compiling this volume and lays out the pending challenges and potential solutions ahead.

One late summer afternoon, about 2 years ago, while relaxing in the porch of a house in suburban/rural Northford, Connecticut, a fox ran across the garden, apparently not feeling too threatened by our presence. When wondering where this small animal was coming from, and where did it go when it finally ran away, Kjell E Berg suggested that the water reservoir located about 100 meters from the house was a nice undisturbed forest that perhaps was functioning as a biodiversity island. Soon the idea of digging more into the concept grew in all directions; the next day, Brett Levin at Yale enthusiastically took it as his own project, and soon we wrote the introductory chapter of this book among the three of us.

Other ideas followed as we developed a website: https://biodiversityislands.org/ and led a meeting session called "Biodiversity Islands: Pockets of Protected Land in Human Dominated Environments" at a IUFRO (International Union of Forest Research Organizations) conference in Posadas, Misiones, Argentina, in October 2018. The structure and contents of this book further developed as we met and held conversations with students, colleagues, and friends whose enthusiasm, energy, and joyful attitude made this book possible from start to end. The more than a 100 authors who contributed chapters for this book drove the rest of the way with their dynamism, dedication, and persistence. Numerous colleagues and friends also helped with their intellectual input and moral support.

There was a total of 105 contributors from 11 countries (32 Argentina; 2 Brazil; 1 Canada; 14 Colombia; 2 Costa Rica; 10 Mexico; 4 Panama; 11 Paraguay; 3 Peru; 23 USA; 2 UK). Different chapters report research, case studies, and experiences from 14 countries: Argentina, Brazil, Colombia, Costa Rica, Ecuador, Ethiopia, India, Mexico, Panama, Paraguay, Peru, Puerto Rico, the UK, and the USA. Thus, the book includes examples of biodiversity islands from tropical as well as temperate regions, ranging from natural habitats to agroforestry and regenerative agriculture systems, and from relatively small to large geographic areas of the world.

A holistic, multidisciplinary perspective was taken in approaching each theme, encompassing factors and variables from multiple disciplines. The contributing authors present views from the academic, practitioner, and policy-making perspectives, offering alternatives and suggestions for promoting strategies that support biodiversity conservation through intentionally designed frameworks for sustainable forest landscapes. With the current worldwide trend of habitat destruction and the need to preserve biodiversity and its values, this book is an essential tool as it provides suggestions and concrete examples that can be used by a variety of stakeholders in various settings throughout the world. This book is useful to researchers, farmers, foresters, landowners, land managers, city planners, and policy makers alike.

New Haven, CT, USA Florencia Montagnini

Acknowledgments

Many chapter contributors acted as independent reviewers of other colleagues' chapters. In addition, other external reviewers generously gave their time to read and offer useful suggestions to improve the chapters. There was a total of 55 reviewers from the academic as well as from the practitioner's realms. The following is a list of chapter reviewers: Oscar J Abelleira, Dara Albrecht, Victor Arroyo-Rodriguez, Gary Bentrup, Kjell E Berg, Robert Bushbacher, Jonathan Cornelius, Sara del Fierro, Beatriz Eibl, Alberto Esquivel, Ben Everett-Lane, Glenn Galloway, Sergius Gandolfi, Eva Garen, Libertario González, Heather Griscom, David Hawksworth, Karen Kainer, Keith Kirby, B. Mohan Kumar, Rafaela Laino Guanes, Ariel Lugo, Brett Levin, Philip Marshall, Paula Meli, Zoyla Mireya Clavo Peralta, Irene Montes-Londoño, Gabriela Morales-Nieves, Mathew Moran, Carlos Navarro, Quint Newcomer, Fernando Niella, Joseph Orefice, Alison Ormbsy, Nahuel Pachas, Pablo Peri, Daniel Piotto, Julio Prieto, Neptali Ramírez-Marcial, Juan Rivero de Aguilar, Carmen María Rojas González, Ricardo Rozzi, Rocío Santos-Gally, John Schelhas, Sara Scherr, Emily Sigman, Jacob Slusser, Ryan Smith, Rosina Soler, Eric Toensmeier, Mateo Vega, Zoe Volenec, Sheila Ward, Catherine Watson, and Gustavo Zuleta. Many thanks to them for their generosity and dedication.

Sara del Fierro and Ryan Smith, both from Yale University's School of the Environment (YSE), performed multiple roles as most efficient, dynamic, and enthusiastic book editors, assistants, reviewers, and co-authors. Dara Albrecht and Ben Everett-Lane, both at Yale College, majoring in environmental science, generously volunteered their time as dedicated, energetic, and passionate editors, assistants, reviewers, and co-authors. They all made the task feel more important and appreciated, and their contributions and collegiality are immensely appreciated.

Financial, logistical, and administrative support from Yale School of the Environment (YSE) made this book possible.

Finally, this book was written to soothe the grief of losing Sunset, constant and faithful companion whose energy, strength, and perseverance were always contagious and made the ride through life smooth and enjoyable for so many years.

Northford and New Haven, CT, USA Florencia Montagnini
June 12, 2021

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About the Editor

Florencia Montagnini has over 30 years of experience researching and teaching in topics on sustainability of managed ecosystems in the tropics, such as forest, tree plantations, and agroforestry systems, with a special emphasis on Latin America. Her work as a scientific advisor and consultant has also taken her to Africa and South East Asia. Her research encompasses sustainable land-use systems that integrate ecological principles with economic, social, and political factors; the principles and applications of forest landscape restoration; the reforestation of degraded lands with native species; identification and quantification of ecological services (biodiversity, carbon sequestration, and watershed protection); organic farming using indigenous resources; biodiversity conservation in human-dominated landscapes; and biodiversity islands. She received her BS in agronomy from the National University of Rosario, Argentina; her master's degree in ecology from the Venezuelan Institute of Scientific Research (IVIC), Caracas, Venezuela; and her PhD in ecology from the University of Georgia. Since 1989, she has worked as a professor and researcher at the Yale School of the Environment, as well as the Tropical Agriculture Research and Higher Education Center (CATIE). She has written 11 books and over 250 scientific articles about the ecology of tropical forests, agroforestry systems, native species reforestation, and forest landscape restoration.

Chapter 11
A Highly Productive Biodiversity Island Within a Monoculture Landscape: El Hatico Nature Reserve (Valle del Cauca, Colombia)

Zoraida Calle D, Carlos Hernán Molina C, Carlos Hernando Molina D, Enrique José Molina D, Juan José Molina E, Bernardo Murgueitio C, Amalia Murgueitio C, and Enrique Murgueitio R

Abstract This chapter describes the landscape-scale, national and regional influence of a rural property that forms a biodiversity island within a monoculture landscape. Managed continuously by nine generations of the Molina family, El Hatico Nature Reserve embodies a set of values grounded in a deep connection to the land. Between 1960 and 1990, the fertile flatlands of the Cauca River valley lost almost all dry forest remnants, wetlands, traditional annual crops, and agroforestry systems, adopting a uniform method of sugarcane production that modified stream banks, eliminated the small-scale topographic heterogeneity, and integrated periodic burning and herbicide applications as part of the management protocols. Meanwhile, El Hatico gained tree cover, enhanced its soil quality, conserved its forest fragments, transformed its conventional pastures into biodiverse silvopastoral systems and transitioned to agroecological sugarcane production. El Hatico's long tradition of agricultural and livestock research and detailed production records helped develop

Coauthor Carlos Hernán Molina passed away during the final stage of editing this book. None of the innovations described in this chapter would exist were it not for his leadership, moral courage and commitment to generational exchange and agroecology. With admirable clarity and wisdom, he guided his family through decades of dramatic land use change and stood up for a diversified agricultural production against the ravaging advance of monoculture. Thanks to Carlos Hernán, El Hatico persists as a biodiversity island.

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the highly efficient intensive silvopastoral systems in which cattle graze on nitrogen-fixing fodder shrubs interspersed with grasses and under the shade of native trees. These silvopastures have inspired thousands of technical assistants, extension workers and farmers in Colombia and other Latin American countries to undertake the transformation of conventional cattle ranching systems. Simultaneously, El Hatico developed organic sugarcane by applying the principles of agroecology to produce sugar while storing carbon, enhancing the soil biota and making an efficient use of water. El Hatico's forest fragment is surrounded by a wildlife-friendly silvopastoral matrix that is permeable to the movements of birds and arthropods. This property's unique combination of land uses provides a model for the integration of agroecology, agroforestry and ecological restoration.

Keywords Agroecology · Ecological restoration · Functional biodiversity · Intensive silvopastures · Silvopastoral systems · Sugarcane

11.1 Introduction

Can a single rural property make a difference for biodiversity and sustainability? If so, on which scales can that occur? This chapter explores the spheres of influence of a family estate that stands out as a biodiversity island within an intensive monoculture landscape. Seen from the air, El Hatico Nature Reserve, located in the fertile flatlands of the geographic Cauca river valley in Colombia, is the only woodland in a landscape dominated by sugarcane plantations. On closer inspection, what appears to be a secondary forest is in fact an old growth dry forest remnant, partially surrounded by silvopastures with a high density and diversity of trees. On one edge, this forest fragment borders a sugarcane plantation that has been managed agroecologically for two decades, produces certified organic sugar, and has lines of native palms and trees between rows of sugarcane plants.

The first section of this chapter provides a brief historical context of land use change in the geographic Cauca river valley and the lower Amaime river basin, where El Hatico is located. The following sections describe two land-use changes that were occurring at El Hatico while the surrounding landscape was following the opposite trends: the transition from conventional cattle ranching to silvopastoral systems and the adoption of agroecological practices in sugarcane production. Then, we summarize the results of research projects done at El Hatico on the spatial distribution of ants, parasitic wasps, spiders and birds, and the functional biodiversity in silvopastures and sugarcane. In the final section, we explore El Hatico's influence at larger spatial scales through research, training and inspiring farmers, extension workers, and decision makers. We also discuss El Hatico's impacts on land use policy related to livestock, sustainable agriculture, and private conservation initiatives.

This chapter focuses on why El Hatico is an outstanding leader in tropical sustainable agriculture, with broad impacts from local to global scales. The farm provides critical habitat for biodiversity within its agricultural matrix, modeling the alignment of increased productivity with enhanced ecological functioning.

11.2 Historical Context: Land Use Change in the Geographic Cauca River Valley

The geographic Cauca river valley comprises 421,000 hectares of flatlands in the high Cauca river basin, surrounded by the central and western Andean ranges (Cordillera Central and Cordillera Occidental) in the Colombian departments of Valle del Cauca, Cauca and Risaralda. Between 1957 and 1986, 66% of the forest cover in the upper Cauca river basin was transformed into agricultural land (CVC 1990). Today this landscape retains only 1.76% of its original forest, represented by scattered fragments with a mean area of 6 ha (Arcila et al. 2012). Wetlands once occupied almost one quarter of the geographic Cauca river valley; the few remaining wetlands are besieged by urban and agricultural expansion (Rivera et al. 2007).

As a result of fragmentation, the extreme isolation of forest remnants and the opportunity cost of the land, the agricultural landscape of the geographic Cauca River valley has very limited opportunities for conservation based on protected areas and restored biological corridors alone. Close to 75% of the remaining forest fragments are separated from their nearest neighbor by distances of 500 m or more (Arcila et al. 2012). Approximately 50% of these fragments lack a real forest interior area when assuming a 50 m edge effect. The fact that the isolated forest patches are surrounded by hostile matrices that barely promote the movement of organisms heralds an uncertain future for the regional biodiversity. Small populations of animals and plants in isolated remnants tend to have a high probability of local extinction, related to low genetic variability combined with demographic and stochastic effects (Eibl et al. 2022; Niella et al. 2022). All conservation or restoration initiatives in the geographic Cauca river valley should involve redesigning and managing the agricultural matrix to enhance the movement of plants and animals in a landscape dominated by sugarcane (Calle et al. 2012, 2013).

El Hatico Nature Reserve is located at the lower Amaime river basin, close to the site where the Amaime river joins the larger Cauca river (162 km south-west of Pinzacuá farm; see Fig. 12.1 in Montes-Londoño et al. 2022). The lower Amaime basin retained an extensive forest cover until the 1950s. Between 1950 and 1970, agriculture expanded in this area with public and private investment at the expense of forests, wetlands and even cattle ranching (Murgueitio 2019). Large areas were planted with cotton, millet, corn, soy, beans, rice and sugarcane. Landscape transformation in the 1960s was driven mainly by the economic blockade of Cuba and the increasing demand for sugar in the United States. The growing dominance of intensive sugarcane production has continued until the present.

Fig. 11.1 Sugarcane, silvopastures and forest at El Hatico Nature Reserve. (Photo: Juan Diego Vanegas)

Murgueitio (2019) analyzed the changes in land cover that took place between 1986 and 2018 in the lower Amaime river basin. Land covered by perennial crops (mainly sugarcane) increased from 62.2 to 74%, while annual crops declined from 15.3 to 2.2%. Areas occupied by infrastructure increased by 1.9%, areas covered by natural vegetation increased by 0.8%, and pastures declined by 1.6%.

El Hatico Nature Reserve occupies 0.64% of the lower Amaime river basin but conserves 4% of its forested areas (Murgueitio 2019). This 288-ha property combines silvopastoral systems (140 ha), sugarcane (100 ha), forest (14 ha), *Guadua angustifolia* forest (26 ha), restored biological corridors (2 ha) and mixed fruit trees (5 ha); Figs. 11.1 and 11.2). El Hatico is located at 1000 m of altitude and has average temperature of 24 °C, average annual rainfall of 750 mm and 75% relative humidity (Molina-Castro et al. 2012). Due to its location at the center of the geographic Cauca river valley, evapotranspiration at El Hatico (1600 mm year^{-1}) far exceeds rainfall, creating a significant moisture deficit. The Cauca river valley is considered a dry tropical forest according to the Holdridge life zone system, although most trees retain their foliage even during the driest periods. This mild deciduousness is explained by the bimodal distribution of rainfall and the superficial water table.

In 1942, land use in El Hatico showed a pattern similar to other rural properties in the area, with one forest fragment, giant bamboo (*Guadua angustifolia*) stands, pastures with a low density of trees, and sugarcane plantations. However, an aerial photograph from 1986 shows a radically different landscape context; El Hatico's forest had become the only remaining fragment in the area, and the surrounding matrix had been transformed into a simplified grid of sugarcane plantations with few strips of giant bamboo forest. Satellite images from 2007 and 2018 show another

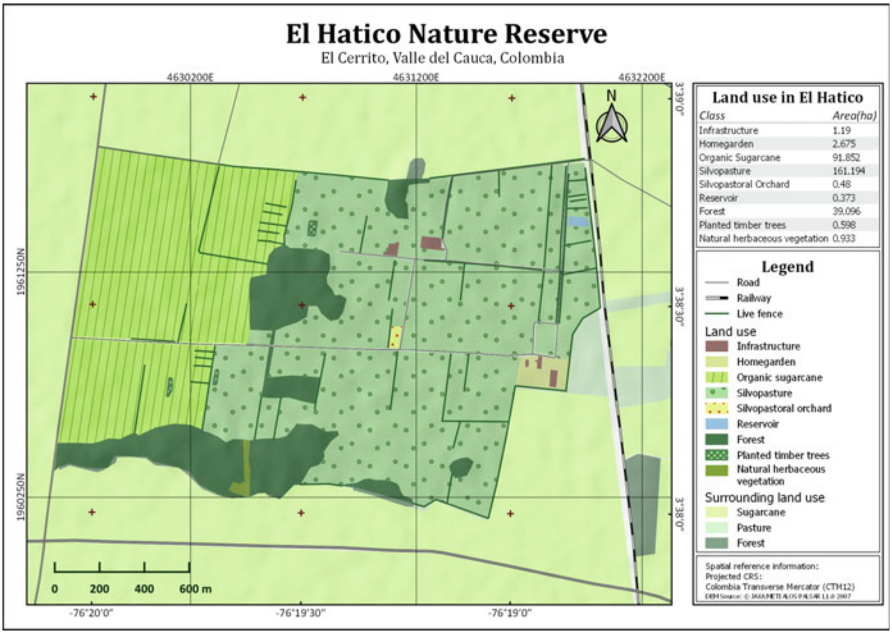

Fig. 11.2 Land use distribution at El Hatico Nature Reserve

reality, in which tree density and canopy cover had increased in El Hatico's silvopastures, creating an open woodland physiognomy in which the edges of the forest fragment had become blurred (Molina-Castro et al. 2012). In two decades, vegetation structure was enhanced and the once simplified agricultural matrix became suitable habitat for diverse groups of organisms.

11.3 From Conventional Cattle Ranching to Silvopastoral Systems

El Hatico has a long tradition of cattle farming. For several generations, livestock production focused on beef, horses, mules and bovine breeding stock. Dairy farming played a marginal role until the development of local road infrastructure in the 1950s.

The foundations of El Hatico's silvopastoral systems go back to the first decades of the twentieth century. The first Colombian publication on the role of trees in cattle pastures, written by a member of the Molina family, mentions the failure of the initial trials with temperate legumes planted as feed for cattle in the tropics and highlights the nutritional value of fruits from native leguminous trees such as *Samanea saman* and *Enterolobium cyclocarpum* (Molina-Garcés 1938).

Trees of a high-yield ecotype of *Prosopis juliflora* were planted in paddocks of El Hatico in the 1940s to provide nutritious fruits for the cattle. These trees offer a high energy supplement in the form of sweet pods during the driest months of the year, when grass biomass drops to its lowest level. In the 1980s, *Gliricidia sepium* trees were planted at high density to provide cut-and-carry fodder; this *Gliricidia* fodder bank was used for more than two decades. However, the manual harvest of forage is labor-intensive and most tree and shrub species with highly nutritional forage do not tolerate cattle browsing. This motivated El Hatico's team to integrate leguminous shrubs that could be browsed directly in the paddocks. An empirical observation of cattle browsing *Leucaena leucocephala* trees led to the initial idea of planting this species in an intensive silvopastoral system (Murgueitio et al. 2015).

11.3.1 Intensive Silvopastoral Systems

El Hatico pioneered the adoption of silvopastoral systems in the 1970s and the development of intensive silvopastoral systems (ISS) in the 1990s. ISS are characterized by the high-density cultivation of fodder shrubs (5000–80,000 plants ha^{-1}) interspersed with improved tropical grasses, legumes, trees and palms (Murgueitio et al. 2015; Chará et al. 2017; Santos-Gally and Boege 2022).

Today, El Hatico's ISS form a complex and wildlife friendly agricultural matrix that combines grass species such as *Cynodon plectostachyus*, *Megathyrsus maximus*, *Cynodon dactylon* and *Paspalum notatum*; a high density of the nitrogen-fixing tree *Leucaena leucocephala* (up to 30,000 plants ha^{-1} managed as fodder shrubs); 30–50 medium sized planted and regenerating trees ha^{-1}; a lower density of large shade and timber trees and palms (Murgueitio et al. 2011; Calle et al. 2013; Chará et al. 2015). Paddocks are separated by 40 km of live fences of trees such as *Gliricidia sepium* (some of which are more than 100 years old), broad leaf mahogany (*Swietenia macrophylla), Guazuma ulmifolia, Maclura tinctoria,* the large bromeliad *Bromelia plumieri* and mixed live fences formed by naturally regenerating trees, shrubs and herbs (Molina-Castro et al. 2012). Table 11.1 presents the most common tree and palm species found in silvopastures; Figure 11.3 shows a live fence of broad-leaf mahogany.

The grazing method applied in El Hatico's ISS combines high animal loads (50 Lucerna dairy cows with an average weight of 450 kg in 4000 m^2 paddocks) with brief rotations (2 days), followed by long periods of recovery (45 days). Therefore, throughout the year, each individual paddock is grazed intensively for a total of 16 days and recovers during the remaining 349 days.

El Hatico has access to two sources of irrigation: a concession agreement providing a fixed volume of water from the Amaime river and groundwater that is pumped from a deep well (100 m) at a high energetic cost. Both sources were used for several decades to irrigate pastures. The gradual adoption of complex silvopastoral systems allowed El Hatico to increase its per-hectare productivity from 7436 l of milk in 1996 to 18,299 l in 2004 (El Hatico, unpublished data). After reaching that historical peak yield, the owners decided to suspend irrigation,

Table 11.1 Common trees and palms in silvopastures and live fences at El Hatico

Scientific name	Local name	Family	Origin	Uses
Attalea butyracea (Mutis ex L. f.) Wess. Boer	Palma corozo de puerco	Arecaceae	P, NR	FW
Roystonea regia (Kunth) O.F. Cook	Palma real	Arecaceae	P, NR	A
Syagrus sancona H. Karst.	Palma zancona	Arecaceae	P	A, FW
Bromelia plumieri (E. Morren) L.B. Sm.	Piñuela	Bromeliaceae	P	LF, FW
Enterolobium cyclocarpum (Jacq.) Griseb.	Orejero	Fabaceae	NR	T, FC
Gliricidia sepium (Jacq.) Kunth ex Walp.	Matarratón	Fabaceae	P	LF, T
Prosopis juliflora (Sw.) DC.	Mezquite, Algarrobo	Fabaceae	P, NR	T, FC
Samanea saman (Jacq.) Merr.	Samán	Fabaceae	NR	T, FC
Senna spectabilis (DC.) H.S. Irwin & Barneby	Vainillo	Fabaceae	NR	FC
Ceiba pentandra (L.) Gaertn.	Ceiba	Malvaceae	NR	A
Guazuma ulmifolia Lam.	Guácimo	Malvaceae	NR	FC, LF
Guarea guidonia (L.) Sleumer	Cedro macho	Meliaceae	NR	T, FW
Swietenia macrophylla King	Caoba	Meliaceae	P	T, LF
Cedrela odorata L.	Cedro rosado	Meliaceae	P, NR	T
Maclura tinctoria (L.) D. Don ex Steud.	Dinde	Moraceae	P, NR	LF, T, FW
Zanthoxylum rhoifolium lam.	Tachuelo	Rutaceae	NR	T, FW

Origin: Planted (P), Natural Regeneration (NR); Uses: Aesthetics (A), Fruits for cattle (FC), Fruits for wildlife (FW), Live fence (LF), Timber (T)

making their milk production depend on the water stored in the soil, known as "green water". Since then, ISS became 100% rainfed and milk yield stabilized around 15,000 l ha^{-1} $year^{-1}$ (Molina-Castro et al. 2012).

Organic dairy products from El Hatico (and the closely related Lucerna farm[1]) have been a logical consequence of the superior quality and safety of this agroecological milk, rather than being an explicit goal of the adoption of silvopastoral systems. By replacing its conventional monocultures of African star grass (*Cynodon plectostachyus*) with ISS, El Hatico cut down fixed costs, added value to the milk through organic certification and increased the profitability of dairy farming. The cost of mineral salt was reduced by 42% because ISS provide abundant minerals and the animals limit their salt intake. The costs of irrigation and fertilizer were completely eliminated. Without ISS, the current per hectare profit would be US$ -27 ha^{-1} $month^{-1}$ for a milk price of US $0.35. With ISS, the monthly per hectare profit is $206 for a market price of US $0.47 l^{-1} for certified organic milk (El Hatico, unpublished records).

[1] Lucerna is another rural property dedicated to organic milk and sugarcane production, located in Bugalagrande, Valle del Cauca.

Fig. 11.3 Live fence of broad-leaf mahogany (*Swietenia macrophylla*). (Photo: Carlos Pineda)

11.3.2 Soil Recovery in ISS

Several studies on soil conditions and other environmental factors that influence crop and animal productivity have been conducted at El Hatico. For example, Vallejo et al. (2010) studied the microbiological, physical and chemical properties of the soil in a chronosequence of silvopastoral systems (3–6, 8–10 and 12–15 years old), and compared them to a conventional pasture outside of El Hatico that had been grazed intensively for 35 years and illustrates the baseline condition for the farm's silvopastures. In the conventional pasture, lower microbial responses (hydrolytic enzyme activities) from bacteria involved in decomposition and nutrient mineralization were explained by the high bulk density and penetration resistance that create a less favorable environment for root exploration of nutrients and water (Vallejo et al. 2010). In contrast, lower penetration resistance values in silvopastoral soils indicate improved soil aggregation and greater pore space, both of which enhance microbial habitats and activity.

The oldest silvopastures at El Hatico (12–15 years) showed the highest microbial biomass and enzyme activity levels when normalized for carbon or clay contents (Vallejo et al. 2010). The microbial responses summarized in Table 11.2 indicate that silvopastures are improving soils; however, the results of this research suggest that it takes at least 8 years (though likely >12 years) to fully appreciate this effect under the conditions of El Hatico (Vallejo et al. 2010).

The diverse and multi-layered plant community (as shown in Fig. 11.4) is one of the factors that explains greater microbial responses in ISS. With the adoption of

Table 11.2 Total carbon (per clay unit), bulk density, soil penetration resistance and enzyme activity in silvopastures, conventional pasture and forest at El Hatico Nature Reserve

Land Use	Age (years)	C clay^{-1} (x100%)	BD (g cm^{-3})	SPR (MPa)	Relative enzyme activity per unit of C: (B-glucosidase, alkaline phosphatase and urease)		
SS12	12–15	10.0^{a}	1.39^{b}	3.30^{b}	***	***	***
SS8	8–10	8.5^{a}	1.40^{b}	2.47^{b}	**	**	**
SS3	3–6	8.6^{a}	1.44^{b}	2.85^{b}	**	*	**
CP	>30	7.9^{a}	1.52^{a}	3.98^{a}	**	*	**
F	>100	8.3^{a}	1.21^{c}	1.49^{c}	***	*	***

Source: Vallejo et al. (2010, 2012)

C clay^{-1} Total carbon per clay unit basis, *BD* Bulk density, *SPR* Soil penetration resistance. Asterisks indicate the relative magnitude of enzyme activity levels; land uses sharing the same number of asterisks are not significantly different at $P < 0.05$

silvopastures, fodder biomass production at El Hatico increased from 23 to 39 Mg ha^{-1} year^{-1} (Mahecha 2003). Higher biomass production and fodder yield in these systems imply a higher return of carbon to the soil. Animal manure and urine enhance soil microbial activity by providing readily usable substrates (Clegg et al. 2006). The root systems of multi-layered silvopastures likely have a higher biomass that fully explores the soil profile. Increased above and belowground carbon inputs seem to drive the microbial responses in older silvopastures. The results summarized in Table 11.2 suggest that silvopastoral systems promote agroecosystem sustainability by improving the ability of soils to perform decomposition and nutrient mineralization, as reflected by hydrolytic enzyme activities (Vallejo et al. 2010).

The enhanced soil moisture and water use efficiency of ISS is probably related to the recovery of soil organic matter (Vallejo et al. 2010, 2012). The baseline condition for soil organic matter (SOM) in El Hatico's paddocks was 2.9% in 1994, while the reference condition for the forest is 4.3% (Arias 1994). The chronosequence of ISS illustrates two contrasting situations: 3.4 to 3.7% of SOM outside tree crowns and 4.4 to 4.9% under trees (Vallejo et al. 2012). These results show that the soil under ISS as the one shown in Fig. 11.3 can store significant amounts of carbon and that trees form high-carbon "islands" within the paddocks.

An additional benefit of El Hatico's ISS is the reduction of greenhouse gas emissions. Methane is a potent greenhouse gas with a global warming potential equivalent to 25 times that of carbon dioxide (CO_2). In cattle ranching, this gas results mostly from the activity of anaerobic microorganisms of the Archaea domain, that hydrolyze proteins, starches and cell wall components in the rumen. Animals with high fiber and dry matter intakes (DMI) release more methane. However, diet composition affects enteric methane production; when forages have high digestibility, less methane is produced per unit of DMI. Also, the presence of condensed tannins in leucaena is known to reduce methane production by inhibiting the growth

Fig. 11.4 Intensive silvopasture with *Leucaena leucocephala* and native trees. (Photo: Zoraida Calle)

of cellulolytic and proteolytic bacteria. Methane released by the cattle per unit of degraded dry matter is 30% lower in El Hatico's ISS with leucaena than in conventional star grass monocultures (Molina et al. 2015, 2016 and references therein).

11.4 Agroecological Sugarcane

For several decades, sugarcane in the geographic Cauca river valley has been planted in intensive monocultures that use chemical fertilizers, herbicides and insecticides. Pre-harvest herbicide is applied to induce stress and increase the concentration of saccharose in the sugarcane. Pre- and post-harvest burning are done to facilitate the manual harvest and to eliminate crop residues, respectively. Conventional practices result in significant water pollution, soil compaction, greenhouse gas emissions and an increasing vulnerability of sugarcane to pests. Currently, the sector is transitioning from manual to mechanical harvest with heavy machinery in the region; this makes burning unnecessary but will bring new challenges related to soil physical degradation.

El Hatico joined the sugarcane industry in 1960 and implemented pre- and post-harvest burning in 1972. In 1994, they realized that 50% of the soil organic matter had been lost after two decades of conventional sugarcane cultivation (Arias 1994).

Since 1993 they had been monitoring parameters such as per hectare monthly sugarcane biomass production with the Colombian Sugarcane Research Center (Cenicaña, www.cenicana.org).

The transition to organic sugarcane production included the adoption of agroecological practices such as minimum tillage, mulching crop residues instead of burning them, and integrating nitrogen-fixing legumes (*Vigna unguiculata* and *Crotalaria juncea*) between cane rows to provide green manure. Herbicides were replaced with African hair sheep (breed of *Ovis aries* that does not grow wool) that consume all grasses and weeds, complemented with selective manual weed control. These practices have promoted functional biodiversity and water economy (Sadeghian and Madriñan 2000; Hincapié et al. 2019).

Stem borers (*Diatraea* spp., Lepidoptera: Crambidae) are considered the main pests of sugarcane in the Americas and cause severe economic losses (Vargas et al. 2015; Solis and Metz 2016). Conventional biological control involves releasing parasitoids such as *Lydella minense, Billaea claripalpis, Trichograma demanun* and *Cotesia flavipes*, which have low survival rates in conventional sugarcane plantations, where they lack vital resources such as pollen and nectar. Natural control of *Diatraea* spp. by ants such as *Solenopsis achinid, Wasmannia auropunctata, Ectatomma ruidum, Pheidole* spp., *Solenopsis* spp., *Camponotus* sp., *Nylanderia* spp., and *Pachycondyla ferruginea* has been observed at El Hatico and other organic farms (Gómez and Vargas 2014; Rivera et al. 2019). The Tachinid fly *Genea jaynesi* is a native parasitoid that controls this pest in the Cauca river valley. Its mass-rearing has not been successful in the laboratory, but it thrives in native vegetation strips, where it feeds on flowers of common weeds (Vargas et al. 2006, 2015; Cenicaña 2017; Rivera et al. 2019).

In 1996, El Hatico obtained its organic certification for sugarcane and livestock production. Shortly after, they started to integrate lines of native trees such as the endangered *Caesalpinia ebano* and palms (*Sabal mauritiiformis* and *Syagrus sancona*) within the sugarcane plots as shown in Fig. 11.5. Palm and tree lines were established between the sugar cane lines, spaced 36 m apart, which is equivalent to 24 lines of sugarcane, since the distance between sugarcane lines is 1.5 m. Planting distance between palms was 2 m to facilitate the manual harvest of the palm leaves for thatching, and there were 5 m between trees. Additional *Syagrus sancona* palms are being planted between each pair of trees.

11.4.1 Yields of Agroecological Sugarcane at El Hatico

In the geographic Cauca river valley, the yield of sugarcane per kilogram of nitrogen applied to the crop has declined steadily in conventional sugarcane, from 1.03 ton in 1985 to 0.58 ton in 2015 (Cenicaña, unpublished results). This waning response to chemical nitrogen fertilization has triggered a soil degradation alert in the region. In contrast to conventional sugarcane, the yield of El Hatico's agroecological sugarcane varied between 1.3 and 1.87 ton per kilogram of nitrogen (from organic

Fig. 11.5 Line of *Sabal mauritiiformis* palms in agroecological sugarcane plantation at El Hatico. (Photo: Carlos Pineda)

fertilizer and green manure) between 2002 and 2018 (El Hatico, unpublished yield records). Conventional producers currently use 180–220 kg of synthetic N ha^{-1} $year^{-1}$, compared to 80 kg ha^{-1} $year^{-1}$ from poultry manure used at El Hatico. Crop residues, green manure crops and free-living N-fixers such as soil bacteria provide approximately 80 kg of additional nitrogen at El Hatico (Cenicaña, unpublished data); however, this nitrogen is more difficult to quantify.

Between 2001 and 2018, El Hatico's agroecological sugarcane consistently outperformed its conventional counterpart (average yield: 9.99 vs. 8.58 tons of sugarcane ha^1 $month^{-1}$, respectively). Even more important than the higher yield is the fact that agroecological sugarcane behaves as a long-lived perennial crop. Several plots at El Hatico have been harvested 18 times between 2001 and 2020 without a decline in yield (El Hatico, unpublished yield records); in contrast, the conventional counterparts are being replaced after only five harvests due to decreasing productivity (Cenicaña 2001–2018, annual reports). This frequent replanting of sugarcane has high financial and environmental costs.

11.4.2 Environmental Impacts of Conventional and Agroecological Sugarcane

In conventional sugarcane, herbicides are used periodically to eliminate grasses and other weeds in plots and alleys between plots (which occupy 10% of the land in plantations). El Hatico solved the problem of weed control by integrating African hair sheep. This makes sense, both financially and environmentally. Sheep use marginal areas that produce a high biomass of grasses, legumes and other species. Grazing replaces costly and unsustainable management practices such as the application of herbicides and mechanic weed control in sugarcane alleys and plantations. In addition to making marginal areas productive, sheep reduce the cost of weed control by 35% (Molina et al. 2013, 2014). Each hectare planted with sugarcane supports two to three adult hair sheep, transforming weeds into high-quality meat and manure that can be used as organic fertilizer (Molina et al. 2013, 2014). Some manure remains in the crop and another part is collected in enclosures (750–1000 g are collected daily from each 30–40 kg animal) (Fig. 11.6).

Agroecological management of sugarcane enhances soil biological activity (Sadeghian and Madriñan 2000). Data summarized in Table 11.3 show that populations of beneficial soil fungi and bacteria differ significantly between conventional and agroecological sugarcane plantations at different depths in the soil profile (Manrique et al. 2006).

Pardo (2009) found dramatic differences in macroinvertebrate biomass related to the type of management (agroecological at El Hatico vs. conventional in a nearby property) and between the moist and dry seasons. Macroinvertebrate biomass was 15.3 times higher in agroecological than in conventional sugarcane during the moist season (26.44 vs. 1.73 g per 0.75 m^3 of soil), and 59% higher during the dry season (6.56 vs. 4.11 g per 0.75 m^3 of soil). These differences were largely driven by variations in the biomass of earthworms and millipedes during the moist season, and earthworms during the dry season (Pardo 2009; Pardo et al. 2017).

Since 1994 soil organic matter (SOM) has increased from 2% to 4% at El Hatico's agroecological sugarcane, which means that it has almost recovered the forest reference value (4.2%). With the increase in SOM, the use of irrigation water has declined from 10,000 to 6000 m^3 ha^{-1} $cycle^{-1}$ at El Hatico (a cycle at El Hatico is 12 months). This water economy has huge economic and environmental implications. The doubling of SOM in less than three decades highlights the climate change mitigation potential of agroecological sugarcane. If the whole region transitions to sustainable practices, sugarcane producers will be able to sequester large amounts of carbon, save precious water resources and cut down production costs while increasing yields significantly. Scaling-up agroecological practices in sugarcane would enhance ecosystem services and revitalize the regional economy.

Fig. 11.6 African hair sheep under a line of endangered *Caesalpinia ebano* trees. (Photo: Zoraida Calle)

11.5 Biodiversity Studies at El Hatico: Arthropods and Birds

11.5.1 Ants

Ants are considered good indicators of biodiversity, disturbance, ecological succession and ecosystem rehabilitation (Dominguez-Haydar and Armbrecht 2011). Armbrecht and Chacón (1997, 1999) studied ant species richness and diversity in

Table 11.3 Populations of beneficial fungi and soil bacteria at different depths in the soil profile in Hatico's agroecological sugarcane plantations and reference conventional plantations

Beneficial fungi[a]	Conventional	Agroecological
0–5 cm	37	88
5–10 cm	30	60
10–20 cm	23	37
20–40 cm	10	30
>40 cm	7	25
Beneficial bacteria[b]	**Conventional**	**Agroecological**
0–5 cm	400	580
5–10 cm	280	500
10–20 cm	250	480
20–40 cm	155	400
>40 cm	50	100

Source: Manrique et al. (2006)
[a]Colony forming units $g^{-1} \times 10^4$
[b]Colony forming units $g^{-1} \times 10^6$

the seven largest forest fragments of the Cauca river valley and their surrounding agricultural matrixes, including El Hatico as one of their study sites. They found a total of 137 morphospecies, grouped into 37 genera and 6 subfamilies; 90% of the ant species were captured in forest fragments and 54% in their surrounding matrixes. They also found a significant correlation between ant species richness in the forest fragments and their matrixes (Armbrecht and Chacón 1999).

In these studies, the highest species richness and diversity values were found at El Hatico: a total of 81 ant species (66 in the forest and 35 in the surrounding silvopastoral matrix). El Hatico also had the highest number of exclusive ant species (ants that were not found in any other study site) in the agricultural matrix (6). Interestingly, the diversity index for El Hatico's silvopastoral systems ($H' = 3.07$) was higher than the diversity indexes of four of the seven forest fragments (H' between 1.96 and 2.87) (Armbrecht and Chacón 1999). The studied agricultural matrixes were on average 7.7 °C warmer than the forest fragments; however, El Hatico was only 3.7 °C warmer. El Hatico's silvopastures formed the coolest matrix, with an average temperature of 30.1 °C (Armbrecht 1995).

In another study conducted in dry forest fragments in this same region Armbrecht et al. (2001) found that the assemblages of ant species in dry forest fragments were not simple subsets of the regional pool of species, but rather, that each fragment preserved an assembly with unique elements. The loss of any one of these small forest patches would cause the disappearance of a fraction of the regional ant diversity. This study highlights the importance of every remaining forest fragment for the long-term viability of the populations of several ant species (Armbrecht et al. 2001).

11.5.2 Spiders

Spiders (Aranae order) are considered as appropriate models for studies of community structure, composition and dynamics because they are diverse and abundant in terrestrial ecosystems, and their communities are affected by habitat, land use, vegetation structure and plant species composition (Pearce and Venier 2006). In tropical ecosystems, structurally complex vegetation tends to support diverse spider assemblages (Baldissera et al. 2012).

Delgado et al. (2014) studied the species composition and diversity of spiders at El Hatico in 1-ha plots located in a silvopastoral system, a forest fragment and agroecological sugarcane. They collected 3635 adult spiders, belonging to 156 morphospecies and 30 families; these species represent approximately 75% of El Hatico's total estimated spider fauna (Delgado et al. 2014). The silvopastoral system plot had the highest number of spider species (74), followed by the forest (71 species), and the agroecological sugarcane plot (46 species). Average similarity between land uses in the composition of spider assemblages was 45.4%; this suggests a high beta diversity or species turnover between land uses at El Hatico. The forest fragment and the silvopastoral system shared 54.4% of spider species (Delgado et al. 2014).

In the study conducted at El Hatico, the silvopastoral system was the most diverse habitat type, while the forest fragment was the least diverse one, given that half of the collected spiders belonged to a single species (*Leucauge* sp.). El Hatico's spider fauna found in this research included eight different guilds; this ecological diversity shows that different land uses provide a variety of microhabitats and resources for spiders with different hunting strategies. A high diversity of spiders suggests the presence of diverse prey species at El Hatico.

11.5.3 Parasitoid Wasps

Parasitoid wasps form a large group of hymenopterans that lay their eggs on (or inside) the bodies of other arthropods, causing the slow death of their hosts. Different parasitoid groups specialize in hosts from different insect orders. López et al. (2013) studied the diversity of parasitoid wasps in four silvopasture plots and the forest fragment at El Hatico. They collected 1376 parasitoids belonging to 7 super-families, 18 families and 42 morphospecies.

Vegetation structure and plant species composition in different land uses at El Hatico were clearly related to the abundance of parasitoids. These small wasps were more abundant in the silvopastures (319–364 individuals captured in traps throughout the study) than in the forest fragment (11 captured individuals). Species richness was also higher in silvopastures (22–26 species) compared to the forest fragment (11 species). However, the diversity index (H') was higher at the forest ($H' = 2$) compared to the silvopastures (H' values from 1 to 1.22), as a result of the higher equitability index (0.572 in the forest and 0.281–0.397 in the silvopastures).

The abundance of parasitoid wasps was correlated with plant species richness. The diversity of parasitoids in silvopastures is related to shade and the diversity of complementary food resources (nectar and pollen), including common weeds such as *Lantana camara* (Verbenaceae), *Parthenium hysterophorus* (Asteraceae) and *Sida acuta* (Malvaceae); parasitoids require nectar and pollen apart from insect prey.

The parasitioid wasp fauna identified at El Hatico includes species that have been released in the farm since the 1960s as biological control agents for pest species such *Diatraea saccharalis* (Pyralidae) in sugarcane and *Spodoptera* sp. (Noctuidae) in corn and sorghum (López et al. 2013). Apparently, these commercial biological control agents have established populations at El Hatico's silvopastures, which probably enhances biological pest control.

11.5.4 Birds

El Hatico's bird fauna is outstanding. In a one-year study based on periodic bird censuses, Cárdenas (1998) observed a total of 135 species, belonging to 39 families and 17 orders. Two thirds of the birds (89 species) used agroecosystem habitats during the censuses. Tyrannidae was the richest bird family with 19 species (14%), followed by Fringillidae (11 species, 8%) and Thraupidae (8 species, 6%); 30 families were represented by 4 species or less. Waterfowl richness and the presence of species belonging to specialized taxonomic groups were also noteworthy. A total of 51 bird species showed evidence of reproductive activity. The bird list compiled by Cárdenas (1998) includes nine species that had not been reported previously in the Valle del Cauca and that expand the latitudinal distribution described by Hilty and Brown (1986) for the birds of Colombia.

This study found a considerable bird species richness in silvopastoral systems: 57 species in a system with fruit trees, 46 in an ISS with *Leucaena leucocephala* shrubs and 43 in a star grass silvopasture. The forest and the agroecological sugarcane had 33 bird species each. The lowest bird species richness was observed in the bamboo forest with 29 species and in a conventional sugarcane (outside of El Hatico) with 19 species (Cárdenas 1998).

Diversity indices (H′) were consistent with those of species richness: 3.21 for the silvopasture with fruit trees, 3.07 for ISS with *L. leucocephala*, 2.98 for the silvopasture with star grass, 2.86 for the forest, 2.73 for the bamboo forest, 2.43 for the agroecological sugarcane and 1.53 for the conventional sugarcane (Cárdenas 1998). Bird diversity and richness in the agroecological sugarcane are likely related to the proximity of the forest fragment and the bamboo forest, as well as the presence of live fences and tree-lined alleys that enhance structural and floristic diversity.

In a more recent but shorter study of El Hatico's bird fauna, Hurtado-G et al. (2016) observed a total of 109 bird species belonging to 37 families and 16 orders. They observed the highest species richness in the agroecological sugarcane system (57), followed by the fruit orchards (50), forest and silvopastoral systems (43 each). Conventional sugarcane plantations outside of El Hatico had 40 bird species (Hurtado-G et al. 2016).

Of the bird species observed by Hurtado-G et al. (2016), 9.2% were migratory. The forest and agroecological sugarcane had the highest number of migratory birds (4 species each), followed by the silvopastoral system (3 species), conventional sugarcane (2) and fruit trees (1).

Migratory birds are not restricted to pristine areas in the tropics; instead, they use agroecosystems during their winter residence. Trees in crops or paddocks favor the arrival and permanence of Nearctic-Neotropical migratory species by providing perches, shelter, foraging substrates and corridors (Rice and Greenberg 2004).

Hurtado-G et al. (2016) also studied the diet of migratory bird species at El Hatico. Food fragments obtained from fecal samples of migratory birds included mostly arthropods (99%) from the orders Coleoptera (64%), Hymenoptera (18%), Araneae (9%), Hemiptera (5%), Diptera (1.6%), Lepidoptera (1.6%), Acari (0.4%) and Psocoptera (0.4%). Most migratory bird species fed on similar items, although in different proportions related to their foraging habits. Beetles were important components of the diet of most migratory birds, varying from 28% for *Catharus ustulatus* to 72% for *Setophaga petechia*. Consumption of Hemiptera and spiders was common among all species except for *Hirundo rustica*; this bird consumed a high proportion of Hymenoptera (40%). Hurtado's results confirm that migratory birds that visit El Hatico each year are mostly insectivorous.

11.6 Functional Biodiversity: Natural Enemies of Pests

The term functional biodiversity includes the value and range of species and organismal traits that influence ecosystem functioning (Tilman 2001). Here we use the term in the narrower agroecological sense, referring to species with positive effects on agroecosystems such as natural enemies of pests.

Many organisms that behave as pests in conventional cattle ranching and agriculture are controlled naturally by different species at El Hatico without external inputs or energy. Some examples include:

- Birds such as the cattle egret (*Bubulcus ibis*), the yellow-headed caracara (*Milvago chimachima*) and the smooth-billed ani (*Crotophaga ani*) contribute to the integrated management of ticks *(Rhipicephalus microplus)* and other ectoparasites of cattle.
- The ant *Ectatomma ruidum,* the entomopathogenic fungus *Nomuraea rileyi* and minute wasps *(Trichogramma* sp.*)* that are endoparasitoids of insect eggs control periodic outbreaks of the lepidopteran *Azeta versicolor*, which completely defoliates *Gliricidia sepium* trees (Gómez et al. 2002).
- The cattle egret, together with spiders and entomopathogenic fungi, control two important pests of sugarcane, the fall armyworm (*Spodoptera frugiperda*) and the small mocis moth (*Mocis lapites*), rendering insecticides unnecessary in agroecological sugarcane (CH Molina, personal observations).

- *Bacillus thuringiensis*, *Trichogramma* sp. and paper wasps (*Polistes erythrocephalus*, Vespidae) controlled an outbreak of a defoliator worm (Noctuidae) that reduced the available biomass of *Leucaena leucocephala* by 30% in El Hatico's ISS during the El Niño drought in 2008–2010 (Montoya et al. 2010).
- Lacewings (Chrysopidae) and at least 10 parasitoid wasps from 8 different families control the microlepidopteran *Eccopsis galapagana*, which defoliates *Prosopis juliflora* trees in El Hatico's ISS (Reyes et al. 2012).
- The smooth-billed ani (*Crotophaga ani*), a common large bird in the cuckoo family, controls outbreaks of *Calligo illioneus* butterflies, which lay their eggs on the leaves of sugarcane (Gómez and Lastra 1998).
- Dung beetles such as *Dichotomius belus, Ontophagus marginicollis* and *Coprophanaeus jasius* disrupt the biological cycle of flies by burying manure, thus controlling populations of the stable fly *Stomoxys calcitrans* and the horn fly *Haematobia irritans,* both of which suck blood from cattle (Giraldo et al. 2018b).
- Ants such as *Ectatomma ruidum, Crematogaster* sp., *Nylanderia fulva, Azteca* sp. and *Dolichoderus* sp., wasps (*Polistes erytrociphalus*), together with spiders and birds such as *Theristicus caudatus, Vanellus chilensis, Crotophaga ani, Milvago chimachima* and *Bubulcus ibis* are predators of leafcutter ants (considered the most problematic herbivores in the Neotropics) at El Hatico. Arthropods and birds that control winged leafcutter ants prevent the proliferation of new colonies (Castaño et al. 2019).

Diverse birds, arthropods (including parasitoids) and fungi play important productive roles at El Hatico as they help avoid the economic and environmental costs of pest control in animal and plant-based systems. As seen, predation by birds, together with entomopathogenic fungi and management practices facilitate the production of organic milk by helping avoid the use of toxic substances for tick control (Giraldo and Uribe 2007). It is remarkable that judicious management and associated biodiversity control pests and weeds in agroecological sugarcane, thus making the use of toxic agrochemicals unnecessary. Hopefully, farmers in the region and beyond will try to emulate these examples, as discussed in the following sections.

11.7 El Hatico's Influence on Society at Different Scales

El Hatico has strong a commitment to the generation of knowledge on sustainable agriculture and livestock production. Technical knowledge is shared openly with research centers, networks, universities, farmers and decision makers; a total of 13,732 people from 815 institutions and 59 countries visited El Hatico between 2005 and 2016 (El Hatico, unpublished records). This section describes the scales of influence of El Hatico, demonstrating how a single rural property can make a difference for biodiversity and sustainability at a regional scale and beyond.

11.7.1 Promoting Sustainable Cattle Ranching

The local or landscape-scale impacts of sustainable ranching practices developed at El Hatico have been modest because cattle grazing is no longer an important economic activity in the geographic Cauca river valley. However, El Hatico has become a national and international reference for sustainable cattle ranching. Field visits of ranchers, extensionists and decision makers have been instrumental to overcome skepticism about tree-based ranching practices (Calle et al. 2012, 2013). El Hatico played a key role in convincing the Colombian government and the national cattle ranchers association (FEDEGAN) about the strategic value of silvopastoral practices. Extensionists and other members of the technical team of the Colombian Sustainable Cattle Ranching Project[2] were trained at El Hatico and later influenced 4200 farms (95,000 ha) in five regions of Colombia (Giraldo et al. 2018a). In 2011, El Hatico received FEDEGAN's national sustainable livestock award.

Ten Colombian universities have integrated field visits and scientific knowledge developed at El Hatico into their academic programs of agronomy, environmental studies, animal science, veterinary medicine and biology. Different research groups have studied the productivity and ecosystem services of silvopastoral systems at El Hatico (Chará et al. 2015).

Through a strategic alliance with the Celema dairy plant in Manizales, El Hatico and Lucerna farm developed Colombia's first organic ultra-pasteurized or extended shelf-life milk and a variety of certified organic dairy products that have penetrated national markets.

11.7.2 The Expansion of Agroecological Sugarcane

Agroecological sugarcane developed by El Hatico's team has impacted land use change at the local and landscape scales, and has inspired a large number of international producers. The agroecological protocol developed for the farm's 100 ha of sugarcane has influenced the regional sugar sector by guiding producers in the adoption of sustainable practices. More than 20,000 ha of sugarcane that supply eight sugar mills have shifted to organic production in the Valle del Cauca and more than 20% of the sugarcane in the lower Amaime river basin (surrounding

[2]The Colombian Sustainable Cattle Ranching Project (CSCRP) was designed by an alliance between the Global Environment Fund (GEF), the UK government, FEDEGAN, The Nature Conservancy (TNC), CIPAV and Fondo Acción, under the supervision of The World Bank. It took place from 2010 to 2020 in five ecoregions where cattle ranching exists close to protected areas, and aimed to overcome the main barriers to the adoption of sustainable practices.

El Hatico), is now organic (Murgueitio 2019). Agroecological and biodiversity-friendly farming practices have entered the vocabulary of the regional sugar industry and have influenced Cenicaña's research agenda (Torres 2006; Hincapié et al. 2019).

El Hatico and its closely related farm Lucerna inspired the adoption of more efficient practices for brown sugar production in Mexico. Sugar mills from El Salvador, Brazil and Argentina began the transition to organic sugarcane after their teams visited El Hatico. The Better Sugarcane Initiative of Bonsucro (global sugarcane platform, www.bonsucro.com) integrates technical knowledge developed at El Hatico. Organic sugar from El Hatico and Lucerna is exported to Europe, Asia and North America.

11.7.3 Rural Sustainability Values and Generational Exchange

El Hatico is a founding member of Resnatur,[3] the Colombian Network of Private Nature Reserves, which currently joins 168 farm-scale conservation initiatives that preserve 57,296 ha of natural ecosystems in the five regions of the country. El Hatico influenced Resnatur's vision of biodiversity conservation integrated to sustainable agriculture and livestock production. Currently, the Colombian System of Protected Areas (SINAP, https://www.parquesnacionales.gov.co/portal/es/sistema-nacional-de-areas-protegidas-sinap/) recognizes this conservation strategy and its philosophy of sustainable production.

El Hatico's vision of integrated livestock production, agriculture and forestry, rooted in the principles of agroecology and ecological restoration, has reached national and regional audiences through ELTI,[4] CIPAV[5] and SOCLA's[6] field courses on Agroecology and Restoration. Case studies of El Hatico are available for global audiences through ELTI's Online Program. Since 1986, training events offered by CIPAV and El Hatico have inspired thousands of alumni from 40 countries to undertake sustainable livestock production and agriculture projects.

[3] www.resnatur.org.co

[4] Environmental Leadership & Training Initiative at Yale University's School of the Environment, a program dedicated to capacity building for forest and landscape restoration in the tropics.

[5] Center for Research on Sustainable Agricultural Production Systems (www.cipav.org.co), a Colombian organization dedicated to research, training and outreach on sustainable agriculture and livestock production, ecosystem services, water-based systems and ecological restoration.

[6] The Latin American Scientific Society for Agroecology (www.soclaglobal.com)

11.8 Influencing Policy

Knowledge on sustainable cattle ranching generated at El Hatico has influenced projects developed by The World Bank, FAO, IDB, The Nature Conservancy and CIAT. Silvopastoral systems were included in Colombia's public policy and the current government's development plan (DNP 2019). In addition, tree-based sustainable ranching is part of Colombia's strategy to meet the 20% reduction goal for greenhouse gas emissions committed by the country for 2030 (DNP 2019).

In 2014, El Hatico hosted the meeting of the institutional members of the Global Agenda for Sustainable Livestock.[7] This was a unique opportunity for livestock specialists from around the world to closely analyze El Hatico's silvopastoral systems. One effect of that meeting was the creation of the Global Network on Silvopastoral Systems that brings together 107 members from 50 institutions and 29 countries. This multi-stakeholder partnership works to strengthen and scale-up silvopastoral systems worldwide, by generating, exchanging and disseminating knowledge, documenting public policy and facilitating dialogue to address the challenges related to the sustainable development goals (https://globalsilvopastoralnetwork.org/). A case study of silvopastoral systems developed by FAO, CIPAV and Agri Benchmark (Germany) analyzes natural resource use efficiency, land productivity, economic performance and environmental benefits of ten silvopastoral production models in Colombia (including El Hatico's ISS), Mexico and Argentina (Chará et al. 2019). This document provides policy recommendations for promoting and scaling-up silvopastoral systems in Latin America and other regions.

11.9 Conclusions

El Hatico has played a pivotal role in spreading two ideas that are key for implementing sustainable farming systems. First, farm-scale biodiversity conservation should go beyond the protection of natural ecosystem remnants to include productive areas. Second, the redesign of farming systems based on the principles of agroecology can result in higher yields, better quality of agricultural products, lower production costs and multiple ecosystem services, without known trade-offs. Such changes can take place when landowners have a strong intergenerational

[7] The Global Agenda for Sustainable Livestock, established in 2011, is a multi-stakeholder partnership with the aim of fostering and guiding the sustainable development of the global livestock sector in alignment with the SDG framework of the UN Agenda 2030. It provides a platform to address comprehensively the sector's multiple challenges towards sustainable development by facilitating global dialogue and encouraging local practice and policy change, focusing on innovation, capacity building, incentive systems and enabling environments (www.livestockdialogue.com)

commitment to the land, motivation to innovate and improve their farming systems, and a desire to share knowledge with peers, scientists and decision makers.

Biodiversity conservation in fertile productive landscapes, such as the geographic Cauca river valley, should include the agricultural matrix with actions that enhance habitat for native species and facilitate wildlife movements. Even small forest fragments such as the one protected at El Hatico can contribute to regional conservation if surrounded by wildlife-friendly agroecosystems.

Synergies between sustainable livestock production, agroecology and ecological restoration can allow rural properties to increase their profitability and productivity, while protecting forests and integrating native trees into cattle grazing areas and agriculture. Innovative and efficient farming systems such as those found at El Hatico can inspire positive change at local, regional and global scales by motivating producers to enhance thousands of hectares. Mahatma Gandhi wrote that *"a small body of determined spirits fired by an unquenchable faith in their mission can alter the course of history"*. El Hatico inspires people to believe that the sum of individual decisions in the right direction has the power to transform whole regions.

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