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Sentinel Landscape stocktaking pilot study

Report Nicaragua-Honduras

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Sentinel Landscape stocktaking pilot study

Report Nicaragua-Honduras

The CGIAR Research Program on Forests, Trees and Agroforestry (FTA)

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1 Summary

The CGIAR Research Program on Forests, Trees and Agroforestry (FTA) established in 2012 a network of Sentinel Landscapes (SL) to conduct long-term research using standardized methodologies on the temporal and spatial dynamics of land use, trees and forests in selected territories. The SL initiative included eight sites around the globe representative of widely different biophysical and socioeconomic contexts.

The Nicaragua-Honduras Sentinel Landscape (NHSL) is a mosaic of forests, agricultural land, cattle ranches and agroforestry systems, covering 68,000 km^2, including two biosphere reserves and 13 protected areas. This landscape also contains the largest remaining forest area in Central America. Four sentinel sites were chosen for the initial phase of the Sentinel Landscapes initiative, representing a gradient of intensive agriculture, pasture, agroforests and forests. This NHSL transect is a good example of the forest transition curve.

Four central research questions are addressed in each SL using standardized datasets: (i) what drivers and processes determine/influence the presence of trees and forests in the landscape and on farms? (ii) what is the magnitude of the stock and rate of change of the presence of trees and forests in the landscape and on farms? (iii) what are the consequences of changes in trees/forests in landscapes/farms on the provision of ecosystem services? and (iv) what new concepts and models are needed to optimize the presence of trees/forests in landscapes/farms and to secure a sustainable provision of ecosystem services?

This report gives an overview of the process of establishing the NHSL as a multistakeholder platform. This platform uses research to inform on the role of trees and forests in the landscape for the provision of ecosystem services. Here we describe: (i) the NHSL; (ii) land uses and main characteristics of the four study blocks laid out along the forest transition; (iii) biophysical and socioeconomic results of the baseline studies conducted in 2012–2014; and (iv) a synthesis of the master's theses conducted by the Tropical Agricultural Research and Higher Education Center (CATIE) students in the Sentinel Landscape until the year 2017.

2 Introduction

As part of the CGIAR Research Program on Forest, Trees and Agroforestry (FTA), a sentinel landscape (SL) was established in part of Honduras and Nicaragua to conduct long-term research on the dynamics of trees and forest, the causes and effects of land-use change in the region. This SL was part of a network of eight SL set around the world depicting vastly different biophysical and socioeconomic contexts (Dewi et al. 2017). The coordination of activities in the NHSL is the responsibility of CATIE, a managing partner of FTA.

The Nicaragua-Honduras Sentinel Landscape (NHSL) is a 300 km long transect representing a gradient of intensive agriculture, pasture, agroforests and forests. The NHSL transect is a good example of the forest transition curve. The NHSL is a mosaic of forests, agricultural land, cattle ranches and agroforestry systems, covering 68,000 km^2, including two biosphere reserves (UNESCO 2011) and 13 protected areas. This landscape also contains the largest remaining forest area in Central America.

Research in the NHSL generated baseline spatial, tree and forest inventory, and socioeconomic data to support hypothesis-testing on the causes and effects of land-use change, as well as approaches to mitigate threats and maximize benefits for both the resilience of the environment and for settlers who inhabit the areas. The NHSL was also an instrument for the integration of multidisciplinary research conducted by a wide array of national and international organizations, including various flagship sub-programs within FTA and several research departments of CATIE (Vågen & Winowiecki 2014). The NHSL site was selected based on the following criteria: (i) existing baseline and historical data (e.g. long-term human welfare, demographic and human health data, as well as time series of biophysical data); (ii) scientists from various flagship sub-programs within FTA who were interested in co-locating research in this landscape; (iii) variation of tree/forest cover and land use along a contiguous forest transition curve; and (iv) existence of a network of reliable partners on the ground. At the end of 2012, participants in a binational workshop agreed on the boundary of the NHSL. The initiative was presented to 28 participants from 17 organizations in Nicaragua and Honduras in a workshop carried out in Managua, Nicaragua. An organization structure was set up to conduct the activities proposed by the NHSL initiative, including: (i) a technical team; (ii) a committee of partner institutions; and (iii) a scientific committee. An initial time frame of 10 years was agreed upon.

The reduction of the CGIAR fund allocation to FTA resulted in drastic reductions in funding allocation to the Sentinel Landscape network. FTA funding for field research in the NHSL virtually stopped in 2014. However, CATIE's research in the NHSL was sustained during the 2012–2017 period, and other FTA partners such as the French Agricultural Research Centre for International Development (CIRAD) agreed to co-locate research in the NHSL during this period as well. Baseline data was digitalized and cleaned, and databases were ready for analysis in 2016. Small funding from FTA was used to finance student research and to support multistakeholder platforms in Nicaragua, one at the national level and one at the local level. These two platforms organized a series of meetings (twice per year) to convene all stakeholders involved in research, education and development in the NHSL region to share research results, information, lessons learned, and to explore ways to incorporate research results into rural development and education at all levels, from farmer field schools to post-graduate education in national and international universities.

3 Description of the NHSL, key issues and research questions

3.1 Description

The NHSL is a mosaic of forests, agricultural land, cattle ranches and agroforestry systems, covering 68,000 km^2, including two biosphere reserves and 13 protected areas. This landscape also contains the largest remaining forest area in Central America. The NHSL is part of the Mesoamerican Biological Corridor, one of the most ambitious conservation areas worldwide. Also, part of this area has been nominated to be a Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO). It hosts a great diversity of ecosystems (more than 12) representative of cloud forest, premontane humid tropical forest, low humid tropical forest and pine savannahs that are a genetic reservoir of botanical and fauna species already scarce or missing in other parts of the Mesoamerican tropics, as well as mosaics of agriculture, pastures and agroforestry systems that sustain the livelihoods of 822,175 farm families in both countries (INE 2013, INIDE 2005). It also constitutes the living space of more than 21,000 indigenous representatives of the Mayangna and Miskitu peoples, whose anthropological and cultural wealth must be preserved (The Nature Conservancy Nicaragua, sf). The NHSL is characterized by: (i) a large spatial extension and variation in the levels and functional types of diversity for the provision of environmental goods and services; (ii) a general lack of communication infrastructure (mostly unpaved roads or waterway networks that are only navigable by artisanal boats, requiring time-consuming and expensive travel); and (iii) generalized insecurity, in particular in some bordering areas in the northern part of the landscape, especially in the North and in the Central Region of Nicaragua, and on the south-eastern part of the Honduras side of the NHSL. Markets in the southern section of the NHSL (Nicaragua) are much more developed (and developing) than in the less-accessible northern section of the NHSL (Honduras). Agricultural organizations, including cooperatives, are more developed in the Nicaraguan section (varying degrees of effective functioning) but less developed in most indigenous communities in the Honduras section.

Based on forest transition analysis, Honduras is a late-transition country (with a slowing deforestation rate for the small fraction of its remaining forest) and Nicaragua is an early-transition country (forest cover is being lost at an increasingly rapid rate). The NHSL represents 37% of the total area of Nicaragua and 20% of the total area of Honduras. More than 65% of the Sentinel Landscape area is covered with forest and 30% with other human-modified systems.

On farms that include trees, these are used in patios, pasturelands, and live fences. Land and forest use are conditioned by diverse customary rights, conflicting land use rights, local and indigenous government as well as national laws and regulations, and even international agreements (e.g. two UNESCO biosphere reserves fall within NHSL boundaries). Land use, in turn, impacts socioeconomic outcomes, with differential impacts for men and women. In the forestry (wood production) sector, women's participation is minimal; however, it is not uncommon to find livestock farms managed by women. In general, the area possesses great potential for improved outcomes for livelihood and environmental benefits within and beyond the Sentinel Landscape boundaries.

A study of contrasting conditions between existing land uses (both good and bad), leading to the design of recommended practices, will offer sustainable options with potential applicability to a significant part of the Latin American lowland humid tropics, where agriculture and particularly livestock compete with forest land uses. With democratically elected governments, we observe a positive trend with respect to political stability. The inclusion of both countries in the Sentinel Landscape is an insurance against the effects of political instability on the SL set-up and research; i.e. in the unlikely event of setbacks, it is not probable that political instability would occur in both countries at the same time.

3.1.1 Description of study blocks

Four study blocks were chosen in the NHSL representing a gradient of intensive agriculture, pasture, agroforests and forests (stages of the forest cover transition curve, see below), presence of local partners in the area, accessibility and security.

The four study blocks can be mapped onto a forest transition curve. For example, El Tuma-La Dalia, Matagalpa (800–1000 m) is a matrix of perennial agroforestry coffee systems intermixed with pasture to Waslala at 400 m (which is dominated by smallholder farmers practicing slash and burn with maize and bean cropping systems with dual-purpose cattle and some cacao as a cash crop), to the plains of Siuna (with extensive cattle ranching, the production of *Brachiaria* forage and very little forest), to the low population density zone of intact native forests in the Bosawás and the Rio Plátano Biosphere Reserves in northern Nicaragua and Honduras. Generally, the forest transition curve in Nicaragua and Honduras goes from south to north and from west to east. There is a great diversity of land use, ranging from pristine forests, managed forests, degraded forests, and scattered trees in pastures, to exclusive areas of grasslands with very few trees, to areas of crops under agroforestry systems with coffee and cocoa (Sepúlveda & Ordoñez 2015).

El Tuma La Dalia: In this area, steep and mountainous terrain predominates with patches of pine and cloud forests. It can be estimated that 40% of the land is flat and 60% is fragmented landscape with low forest cover. It has a climate of subtropical, semi-humid forest, with precipitation between 2,000 mm and 2,500 mm (Figure 1). The temperature ranges between 22°C and 24°C. Land uses include cattle ranching, agroforestry coffee, and staple cereals. These activities are the main source of income for families; however the yields are low, due to the impact of fungi (coffee rust), pests (affecting staple cereals), and the alternation of drought and excessive rainfall. Agricultural practices and climate change have taken their toll on the environment: water sources have decreased their flow and are contaminated, and the soils are less fertile.

This site is part of CATIE's key territory and characterized by high population density (>250 persons/km^2). Farm sizes range from ~0.5 ha to 300 ha, and are most commonly managed by smallholders with individual private ownership and good roads and accessibility to markets. In El Tuma-La Dalia, more than 50% of the site is cultivated. The soils are clay and loamy clay, with moderate erosion and mostly with agricultural coverage. The population of the municipality is 64,780 inhabitants, of which 85% are rural and 15% urban. The main challenges for the local people are poverty, unemployment, low agricultural production, lack of access to education and delinquency. The greatest migratory movement in recent years has been from rural to urban areas. It is estimated that an average of 236 people move out annually in search of better living conditions. The main access to this municipality is a paved roadway that is in its final phase of execution and corresponds to a section of inter-municipal highway crossing the territory from southwest to northeast. The most travelled route is a 45 km road, which joins the municipality with the department of Matagalpa. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is led by the International Center for Tropical Agriculture (CIAT), co-located research in this study block of the NHSL. A comprehensive baseline study was conducted by CCAFS in a 40,000 ha study block (200 m x 200 m) that overlaps

part of the NHSL study block in this territory (Leguía et al. 2018).

Columbus Mine: This site is a part of the Tasba-Pry indigenous territory and is characterized by a tropical humid climate, with an average annual rainfall of more than 3,000 mm. In late 2007, Hurricane Felix, a Category 5 hurricane, struck the northeastern Caribbean coast of Nicaragua, destroying a total of almost 510,764 ha of forest. Forest is now in the recovery phase, but is also undergoing land use change due to slash and burn and livestock encroachment. Population density is low, at 1–5 persons/ km^2. There is a high percentage of non-indigenous settlers (50% of the population), leading to frequent conflicts over ownership. Indigenous communities practice communal land ownership, which is recognized by the government. Settlers, on the other hand, pursue individual private ownership.

This site is of great interest for a wide range of factors associated with the governance of natural resources: (i) a model of local governance including various levels of decision-making (national, regional, indigenous territory, communal); (ii) the coexistence of Miskitu communities – one of the four indigenous groups in Nicaragua that still maintain their ancestral organization and culture – with a strong settler presence due to a range of economic and political factors, both local and national, that have driven migration to the area; (iii) the coexistence of two types of ownership (communal and private) have a direct effect on the forms of forest exploitation, in particular timber extraction; (iv) the existence of conflicts with respect to decision-making over natural resources use and exploitation, rooted in an approach to dialogue that is not grounded in the way in which Miskitu communities have been traditionally governing the forest; (v) the permanent threat of forest invasion by outsiders, essentially mestizo (people from outside the indigenous communities) individuals and families, that try to take advantage of the remoteness of the site; and (vi) the lack of control over illegal settlements and agricultural fields and pastures (Fréguin-Gresh et al. 2014).

Agriculture is the main economic activity in the area, with all family members participating in production (either using slash-and-burn techniques in forested areas or planting and cultivating on the banks of the rivers). According to community leaders, all families have access to land, with an average plot size of 9.8 ha; of which 2.3 ha are cultivated with rice, beans, corn, tubers, plantain, bananas and sugarcane. While the main objective of agriculture is the satisfaction of basic needs and subsistence, a proportion of production is commercialized in order to acquire other basic products and goods (oil, salt, soap and clothes, among others) or to pay for services (education and health). One sector of importance is cattle-raising; according to fieldwork, 63% of families have at least one cow (Figure 2).

Rio Blanco: The Rio Blanco site is located in the municipality of Catacamas in a valley just 450 m above sea level. To the north is the Blanca Mountain, part of the Sierra de Agalta National Park, with a great variety of botanical species, such as conifers, broad-leaved plants, some 80 species and varieties of orchids, and abundant fauna that includes felines and quetzals. The average annual precipitation reaches around 1,300 mm, of which 88% is registered in the rainy

Figure 1. Tuma-La Dalia site: coffee agroforestry system (left); local team augering soil in a coffee plantation (center); firewood collected from coffee agroforestry systems (right)

Credits: Norvin Sepúlveda

period. The meteorological phenomena that influence the climate of Honduras are those typical of the zone of tropical convergence: low atmospheric pressure centers, cold fronts and marine breezes. According to the Holdridge bioclimatic classification, the climate corresponds to tropical dry forest.

The main land use types include small pockets of forest remnants (mostly along rivers), staple cereals production, and a massive conversion from forest to cattle ranching that started in the 1980s. Located between three protected areas –Patuca National Park, Sierra de Agalta and Tawahka Asangni Biosphere Reserve – the site is characterized by low population density, in the range of 5–25 persons/km^2. Farm size varies considerably, from 0 ha to 352 ha. Forty-four percent of the families possess more than 20 ha of land, while 21% have only 0–1 ha (Figure 3).

Catacamas is a predominantly rural municipality, characterized by low levels of education and a subsistence agriculture economy. Poverty is high, at 68.5% of the urban population and 81.7% of the rural population. Altogether, 8 out of 10 people live in poverty and 6 out of 10 live in extreme poverty. According to the National Census, INE 2001, of the total number people living in poverty (60,581 inhabitants), 50.3% (30,485) are men and 49.7% (30,096) are women.

The principal means of communication is a paved road to the capital (Catacamas – Tegucigalpa 210 km) with connection to San Pedro Sula (Catacamas – San Pedro Sula 545 km). There is also a non-paved road to Dulce Nombre de Culmí (Catacamas – Culmí 40 km).

Rio Plátano: Located in the municipality of Iriona, the site is largely covered by primary forests and is characterized by a tropical humid climate, with an average annual temperature that fluctuates between 23°C and 26°C, with little variation throughout the year, and an average annual rainfall varying between 1,800 mm and 3000 mm, concentrated in the period from June to January. The dry season, which is quite pronounced, occurs between March and April. The topography of the site has two features: (i) a hilly area where broadleaf forest

Figure 2. Landscape in Columbus Mine: silvopatoral systems (left); pasturelands and remnant trees in the landscape (right)

Credit: Norvin Sepúlveda

Figure 3. Landscape in Río Blanco: cattle raising under the shade of trees (left); pastureland and deforested mountains (center); pastureland with remnant tree patches (right)

Credits: Amilcar Aguilar and Norvin Sepúlveda

is found, and (ii) a mainly flat area, which is interrupted by an arc of hills and small mountains. The soils are mostly shallow, undeveloped and characterized by little natural fertility and a high content of rocks. As such, they are susceptible to water erosion and range from well drained to poorly drained.

Despite Iriona only having a total population of approximately 10,000 people and a very low demographic density (2–3 inhabitants/ km^2), deforestation has been very important. Throughout the low parts of the valley of the Sico and Paulaya Rivers, the landscape is mostly characterized by a large extension of pastures, which are scattered in some areas with newly established oil palm plantations. However, in the middle and upper valley of the Paulaya River, a large area of virgin forest still exists in the Biosphere Reserve of Río Plátano, where the site is located. It is home to several indigenous groups, whose land rights have not been recognized by the government. Security issues include drug trafficking and land grabbing.

Copen is considered to be a success in terms of community forest management in the Honduran Moskitia, since people from the community are active in the exploitation of timber under a certification of minimal environmental impact, and are also organized into a local agroforestry cooperative that is part of a regional network of cooperatives. The extraction of forest resources is a successful experience from many points of view (e.g. there has been an increase in the legal extraction of certified timber, particularly mahogany as a source to manufacture guitar parts, directly exported to a US company). However, the cooperative remains heavily dependent on technical and administrative assistance from the Green-Wood Foundation, despite many years of timber export.

However, natural resources in Copén continue to be threatened by deforestation, illegal logging, and the advancement of the agricultural frontier, all of which the authorities are unable to control.

In general terms, transportation constraints limit commercial activity. Most products are for domestic use (food, construction of houses and furniture, or firewood for cooking). Only mahogany, which is extracted by the cooperative members, has a high enough value to cover the costs of transportation out of the community forest. Our data shows that the forest does not play a major role in the subsistence or commercial economy.

3.1.2 Key issues

Fieldwork in the four sites has helped to identify the following key issues in the NHSL

- Alternative and sustainable ways to use timber and non-timber products from the forest have not been promoted to any significant extent. The lack of these alternatives means that other productive activities that degrade the forest are preferred. However, there are some cases of community forest management in the municipality of Iriona and some areas in the Caribbean coast of Nicaragua that could serve as positive examples.
- Expansion of the agricultural frontier, mostly based on the expansion of cattle ranching (extensive production systems) and slash

Figure 4. Landscape in Rio Plátano: local dweller from a local cooperative checking timber ready for export/selling (left); scattered trees in pastureland (center); livestock in Rio Plátano (right)

Credit: Jenny Ordoñez

and burn, subsistence agriculture is widespread. Cattle ranching is reported as being one of the most profitable and suitable activities in the region. It is also reported that in some areas of Honduras, selling and buying land for money laundering is becoming more common.

- Human migration is bringing landless people from other areas of the country towards the less populated areas (e.g. forest edges) in search of land. Various partners report that reduction of poverty in some areas of the country is not due to actual poverty reduction but to the expulsion of the poorest groups to other areas.
- Competition for land is high in areas with mosaics of crops, agroforestry systems, and forest remnants. Speculation and land renting are common means to get income from land, but these arrangements drive deforestation, hinder long-term investments (i.e. trees) and exacerbate land degradation. In recent years, purchases of large extensions of land for establishing teak or oil palm plantations are becoming more common.
- Pastures and fallow land in different stages of regeneration occupy most of the area in these mosaics, but they are under inadequate management and provide little income for farmers. The most common use of this land is extensive cattle ranching and crop rotations.
- Agroforestry and forestry options are highly promoted by government and non-government organizations (there is a very strong conservation narrative from these organizations and also from some groups like indigenous peoples and some farmers). Most of these interventions work for a short time; when the projects end, in many cases the practices implemented are also abandoned.
- Equity in the division of resources is an issue. Large areas of land are in the hands of a few people, and most farmers have small properties. Given that communal property is not a common form of ownership in the region, particularly for non-indigenous groups, there are few options for landless people and smallholders. Therefore, increasing tree cover in landscapes could be achieved if there is involvement of large farmers, but this will not necessarily translate into direct benefits for the most marginalized groups.
- In both Nicaragua and Honduras, countless conflicts related to natural resources rights are also related to conflicts over land. Among the situations and scenarios found in the mosaic, conflicts arise due to: (i) the granting of land under national tenure to individuals or groups without legal documentation; (ii) the granting of land claimed by indigenous people to third parties; (iii) the allocation of municipal land without this land being divided up; (iv) the invasion by third parties of land claimed by indigenous groups, even in demarcated and titled territories; (v) the overlapping of common property rights between different indigenous communities; (vi) the expropriation of land under private tenure without legal procedures and their allocation to beneficiaries of the agrarian reforms without the legal process of awarding titles; (vii) the informal sale of land under common property regimes and/or its allocation during agrarian reforms.
- Citizen participation in natural resource management is valued, but challenges remain to ensure that this participation is effective and equitable. In Honduras, as in Nicaragua, most of those surveyed through the NHSL process said they didn't think there any mechanisms for participation in decisions about use of natural resources (33%) or that these mechanisms don't work (22%). Opinions varied based on population subgroups. For example, 40% of all respondents expressed that women and agricultural producers participate often or always in the decision-making process; however among indigenous peoples the estimated percentages for participation by women was 81%, and among private sector respondents it was 42%.
- The current state of local natural resources governance in indigenous territories presents challenges due to highly complex processes. On the one hand, communities have their own internal processes for governing access, use and exploitation of natural resources, and these correspond to a model of traditional local indigenous governance and have been frequently sanctioned by formal rules; on the other

hand, there is a need to comply with formal rules for commercial exploitation of forest and other natural resources. This involves respecting the formal national rules, which do not necessarily take into account the communal rights of indigenous peoples.
- There is a lack of mechanisms of management or coordination between Nicaragua and Honduras.
- The effects of climate change are expected to be severe, particularly with respect to water provision, and these effects could be exacerbated by non-sustainable land uses.
- The effects of extreme events such as hurricanes pose a serious challenge.

3.2 Interventions needed

- geospatial monitoring of land use change and deforestation (its dynamics) and implementation of indicators for monitoring;
- forest production and forest management with emphasis on community management, for the best use of forests, including timber and non-timber products;
- addressing the problems created by the advance of the agricultural frontier and extensive cattle ranching, as well as promoting sustainable options for the reintroduction of trees in degraded landscapes;
- governance, institutions and legal framework, with particular emphasis on ownership and the position of indigenous peoples within public laws and (in) compliance with current laws on ownership;
- strengthening capacities and mechanisms to disseminate knowledge at various scales from researchers, technicians, extension agents and finally, farmers and people living in the forest;
- development of methods, harmonization of activities among various actors within the Sentinel Landscape (different CGIAR Research Programs [CRPs], and local partners), to implement baseline studies (data collection) and interventions

3.3 Research gaps

The knowledge gaps can be grouped under three main themes.:

Theme 1: Forest production and forest management

- What are the trends in land cover within the landscape?
- What are the political, socioeconomic and cultural factors that influence these trends?
- What are the implications of these changes for ecosystem services, such as mitigation of climate change and hydrological network, landscape connectivity?
- What is the future potential state of the landscape under different scenarios of change, and are there states in which the supply of ecosystem services is jeopardized? Note projections of increased coverage of coffee and cocoa in the Región Autónoma Atlántico Norte (RAAN), Nicaragua.
- How does the political framework influence community forest management, what are the barriers imposed by the political framework, and how can they be eliminated?
- What have been the changes in community welfare linked to exploitation and forest management?
- What are the effects of exploitation and forest management on biodiversity and ecosystem services of community forests?
  - What modifications to the practices can be implemented to mitigate negative effects?
  - How do forest interventions interact with climate variability in determining changes in the forest?
- What are the effects of extreme climate events on forest management, and what are the necessary adaptation measures in political and technical terms?
- What are the implications of market trends, potential climate change and other factors for the use of land in community territories, and for forest management in particular?
- What are the practical and relevant indicators for stakeholder groups to monitor the future evolution of the use and conservation of forests and the well-being of communities?

  - Are the current frameworks adequate or can they be modified?
  - Is management sustainable according to the criteria of different groups of stakeholders?
- What are the implications of the above factors regarding the resilience of the socio-ecological system?
- How do the answers to the previous questions differ between the two countries and why?

Theme 2: Advance of the agricultural frontier and options for introducing trees in degraded landscapes

- Can we observe a forest transition and land use changes -— do they exist?
- What are the conditions that exist in each of these stages?
- Are there ways to transition from forest degradation to a recovery stage without going through maximum degradation?

Specific questions with emphasis on the transition to the reforestation and agroforestry phase:

- What are the types or models of reintroduction of trees in the landscape?
- What are the conditions –or trajectories that lead to these types of reintroduction of trees?
- What are the consequences of the different models of reintroduction of trees (with emphasis on ecosystem services, livelihoods and equity)?
- How to ensure that interventions that promote reforestation and agroforestry are sustained?
- How to support intensification in production systems (for example, livestock and agroforestry)?

Theme 3: Governance, legal frameworks, and institutions

- What are the demands, needs and interests of indigenous peoples in all their diversity, and what is the best way to incorporate them into an inclusive state policy in Sentinel Landscapes?
  - Identify the demands and interests of the indigenous people.
  - Identify the specific weaknesses of state policy and the relationship with indigenous peoples.
  - Develop advocacy strategies and communication and negotiation mechanisms.
  - Incorporate the interests and needs of indigenous peoples into the strategic development plans at the different levels of government.
- What are the dynamics and factors that encourage the invasion and usurpation of the land?
  - Obtain relevant information in the short term for decision- making, and guarantee the rights of ownership.
  - Promote the security of tenure of smallholder producers and indigenous peoples.
- What is the state of natural resources and their economic potential for sustainable use?
  - Investigate production cycles in the ecosystem.
  - Identify the markets.
  - Know the socioeconomic and ecological impacts of the use, both legal and illegal, of natural resources.
- What are the demands and interests of indigenous peoples and other ethnic groups living in natural reserves and areas of expansion of the agricultural frontier?
- What are the practical and relevant indicators for the different stakeholders to monitor the evolution in land use, forest conservation and human welfare within the communities?
- What are the implications of governance, climate change and community forest management for the resilience of this socio-ecological system?
- What are the windows of opportunities and the key areas in current national and local policies to secure the incidence of indigenous groups and other ethnic groups on the formulation of policies?

4 Description of data and data collected

The Sentinel Landscapes initiative has made rapid progress towards understanding important metrics of ecosystem health, as well as drivers of land degradation across a range of ecosystems in the global tropics. An important part of this initiative is the integration of socioeconomic surveys and ecosystem health metrics. All data are available at: http://dx.doi.org/10.7910/DVN/OTSSRA

4.1 Biophysical data

The Land Degradation Surveillance Framework (LDSF) is a spatially stratified, randomized sampling design, developed to provide a biophysical baseline at the landscape level and a monitoring and evaluation framework for assessing processes of land degradation and effectiveness of rehabilitation measures over time (Vågen et al. 2013b) (Figure 5). Measured variables included: land cover, tree and shrub densities, tree biodiversity, erosion prevalence, and infiltration capacity, along with an assessment of impact to habitat and occurrence of soil conservation structures. Soil samples were also collected and processed. Topsoil (0–20 cm) samples were collected at each subplot (n=4) per plot and composited. Subsoil (20–50 cm) samples were also collected at each subplot (n=4) per plot and composited. Processed samples were subjected to infrared spectroscopy and wet chemistry analysis. These combined datasets were used to assess soil and ecosystem health for the landscape.

The LDSF has been applied in more than 35 countries in the tropics for baseline assessments of land degradation at multiple spatial scales, as well as for local assessments of soil health and land degradation with spatial resolutions of 5–30 m (Vågen et al. 2013b; Vågen and Winowiecki 2013; Winowiecki et al. 2016a) and at continental scale with a spatial resolution of 500 m (Vågen et al. 2016). Further, the LDSF has been used to assess the effect of cultivation on key indicators of soil health, such as soil organic carbon (Winowiecki et al. 2016b), to map herbaceous cover as a measure of rangeland health, as well as to assess land restoration potential in rangelands (Winowiecki et al. 2018) and smallholder farming systems (Lohbeck et al. 2018), among other applications. For more

Figure 5. Local team training in biophysical methodology in a coffee agroforestry system

Credit: Norvin Sepúlveda

information visit: http://landscapeportal.org or http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/.

The methodology has four main components:
1. a spatially stratified, hierarchical, field sampling design using 10x10 km study blocks, which contain: 16 clusters of 1 km^2 , 160 plots of 1000 m^2 plots and 640 subplots of 100 m^2 per 100 km^2 study block (Table 1);
2. use of soil infrared spectroscopy for prediction of soil properties;
3. use of remote sensing and ensemble learning methods for mapping of land degradation and soil health;
4. remote sensing for mapping of land cover and land use change.

The LDSF was carried out at the four study blocks in 2012. These sites were selected using a stratified random sampling design across the intensity of land use and forest cover (e.g. from protected natural forest in Río Plátano to perennial agroforestry systems in El Tuma-La Dalia to intensive grazing systems in Río Blanco).

4.2 Socioeconomic baseline

Socio-economic surveys

The socioeconomic baseline study utilized several tools that were applied at the community and household level to gather information on indicators of poverty, quality of life, food security and use of the forest resources (Table 2). The socio-economic data was collected in the same communities where biophysical assessments were conducted. Households were sampled randomly from community list that were provided by the local leaders. With the data, *a Guide on the Construction of Socioeconomic Indicators on Farm Dependency, Income Diversification, Poverty and Food security for the Nicaragua and Honduras Sentinel Landscape was developed* (Sepúlveda et al. 2015). Protocols and data are available at: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/G42GSD and https://doi.org/10.7910/DVN/G42GSD.

- Sentinel Landscapes Baseline - Methodological Overview[1]
- Sentinel Landscape Household Module[2]
- International Forest IFRI forms A[3], F[4], R[5] and S[6]
- Land Degradation Surveillance Field Guide[7]
- Land Degradation Surveillance Framework[8]

Community surveys

The community surveys were conducted using the International Forestry Resources and Institutions (IFRI) survey instruments, namely (the Settlement, Forest Associations Form, Forest Form, Forest Product Form, Poverty).

An International Forestry Resources and Institutions (IFRI) survey was conducted (Settlement, Associations, Forests, Products, Poverty): To develop the socioeconomic baseline, workshops were carried out with groups of at least 30 participants and focus groups with smaller numbers of participants (particularly for uses and products). Individual interviews were conducted with key informants, including community leaders, teachers, and other people with unique knowledge and perspectives, as recommended by the leaders of the villages.

Gender components: The data collection team worked to engage both men and women, with a goal of surveying 50% men and 50% women. In order to achieve a

1 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/SL_Baseline.pdf

2 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/SL_Household_Module.pdf

3 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/Association_Form_A.pdf

4 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/Forest_Form.pdf

5 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/SL_Product_Form_R.pdf

6 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/SL_Settlement_Form.pdf

7 http://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/LDSF_Field_Guide.pdf

8 http://landscapeportal.org/blog/2015/03/25/the-land-degradation-surveillance-framework-ldsf/

Figure 6. Household in Columbus Mine Site

Credits: Norvin Sepúlveda.

Table 1. Number of measurements taken per LDSF study block

		Biophysical baseline				
Country	**Sites**	**Infiltration**	**Soils (top and sub)**	**Soils Cum mas**	**Vegetation (plots)**	**Trees (subplots)**
Nicaragua	**Tuma-La Dalia**	48	320	480	160	640
	Columbus	48	320	480	160	640
Honduras	**Río Plátano**	48	320	480	160	640
	Río Blanco	48	320	480	160	640
Total	**4**	**192**	**1280**	**1920**	**640**	**2560**

Table 2. Socioeconomics by country and SL site

		Socio-economic baseline					
			Community surveys				
Country	**SL Site**	**Household surveys**	**Settlement**	**Association**	**Forest**	**Product**	**Poverty stages**
Nicaragua	**Tuma-La Dalia**	297	8	10	28	104	8
	Columbus	302	8	7	9	302	8
Honduras	**Río Plátano**	146	9	11	14	146	9
	Rio Blanco	104	8	0	18	104	8
Total	**4**	**849**	**33**	**28**	**69**	**849**	**33**

gender balance, the interviews considered not only farming activities but also household activities.

Institutional mapping: This mapping was done to survey the institutions involved in the governance and use of natural resources in order to: (i) understand the institutional settings and the state of governance of natural resources in the SL; (ii) document how institutions of interest operate, in order to illustrate trends in the complexity, issues, and challenges of their functioning; (iii) identify and characterize the key stakeholders involved in the governance of natural resources; and (iv) establish a list of measurable indicators that could be used to monitor institutional changes in the landscapes. For the implementation of the institutional mapping, CIRAD, the Universidad Centroamericana (UCA)'s Nitlapán Institute and CATIE-Honduras developed a pluridisciplinary approach within a team formed of agroeconomists, foresters and sociologists. A protocol for institutional mapping at a landscape scale was developed and implemented, with leadership from Sandrine Fréguin-Gresh (CIRAD) working with Nitlapán and CATIE (Fréguin-Gresh et al. 2014).

5 Description of other projects deliberately linked to/ co-located with NHS

CATIE steered the process of finding common ground among different actors working in the NHSL landscape in order to create synergies, cooperation mechanisms and data sharing to further advance the interventions needed in the Sentinel Landscape initiative. Collaboration across CGIAR Centers and CRPs existed in the first phase of CRPs in Nicaragua although there was no central coordination mechanism of all Centers/CRP activities. The humid tropics CRP work resulted in a national Research for Development Platform representing the country's coffee, cocoa, and mixed staple crop-livestock production sectors. At the local level, three Territorial Learning Alliances were established with 41 local organizations representing the three target productive sectors, including academic, research, public sector, civil society, women's and farmers' associations, and cooperatives. Building on those collaborations, a national consultation was held in November 2015 with partners, CRPs and CGIAR Centers to help identify the focus and modalities of collaborative work. Participants included representatives from Bioversity International, CIAT, the International Maize and Wheat Improvement Center (CIMMYT), the International Potato Center (CIP), World Agroforestry (ICRAF), and the International Food Policy Research Institute (IFPRI), as well as CATIE, CIRAD, CRP representation (CCAFS, Livestock, A4NH , PIM [9], FTA[10], RTB [11] and WLE [12]) and 20+ national partners.

Other synergies were mobilized, including with five CATIE projects: the Mesoamerican Agri-Environmental Program (MAP Noruega), Finnfor, and three institutional programs: the International Model Forest Network, Sustainable Forest Management, and Programa Centroamericano de Gestión Integral de la Roya del Café (PROCAGICA) in Nicaragua-Honduras (coffee adaptation to rusts and climatic change). The development of management models for secondary forests supporting Initiative 20x20 is another important project conducted by CATIE in synergy with the NHSL initiative.

In Nicaragua, CIRAD has two projects related to the NHSL initiative: STRADIV (multi-actors' conception of agroecological systems in coffee) and Forecast (towards multifunctional, sustainable and connected rural territories, relying upon the multifunctionality of agriculture). Bioversity International/CCAFS and CATIE have worked together on another related project: Climatic adaptation through on-farm trials, using the triadic comparisons of technologies (tricot) approach (participatory mass evaluation) while continuing with data to improve early warning in crops.

9 A4NH – CGIAR Research Program on Agriculture for Nutrition and Health

10 PIM – CGIAR Research Program on Policies, Institutions, and Markets

11 RTB – CGIAR Research Program on Roots, Tubers and Bananas

12 WLE – CGIAR Research Program on Water, Land and Ecosystems

6 The NHSL: co-locating data collection and research through institutional partnerships

The baseline studies were led by ICRAF and CATIE in collaboration with local organizations like the National Agricultural University in Catacamas, the Green-Wood Foundation, the National Institute for Conservation and Forest Development, Protected Areas and Wildlife (ICF) of Honduras, the University of the Autonomous Regions of the Nicaraguan Caribbean Coast (URACCAN), CIRAD, Nitlapán (Nicaragua), CIAT, and the National Technical Offices of CATIE in both countries.

Since 2012, various regional partners have been engaged in the Sentinel Landscape initiative:

- In Nicaragua: Ministerio de Ambiente y Recursos Naturales; Universidad Nacional Agraria; Fundación Madre Tierra; Instituto Técnico de Waslala, Ministerio de Agricultura, Ganadería y Forestal, Secretaria Técnica de Bosawás; Universidad Centroamericana, Instituto de Investigación y Desarrollo Nitlapán (UCA-Nitlapán); Universidad Nacional de Ingeniería; URACCAN – Instituto de Conservación Forestal.
- In Honduras: Universidad Nacional Agraria Honduras; Secretaria de Ambiente y Recursos Naturales; Secretaria de Agricultura y Ganadería; German Corporation for International Cooperation (GIZ) GmbH .

A total of 12 non-CGIAR organizations were actively involved in site selection and data collection. 18 team members from six organizations were trained in the biophysical field methodology: CATIE, National Agricultural University (UNA) in Catacamas, Fundación Madera Verde (FMV) in La Ceiba, ICF in Tegucigalpa, Honduras, and CIAT and URACCAN in Nicaragua. In addition, 24 people from five organizations participated in training on participatory methods for household interviews conducted by the IFRI network.

In Nicaragua, the institutional mapping protocol was implemented in 11 municipalities (out of 18 of the NHSL) and 6 indigenous territories (out of 18 of the NHSL). Most municipalities (9) and indigenous territories (5) are within the Bosawás Biosphere Reserve. The protocol was applied with two types of instruments, covering four scales within the landscape: the national level; the regional level (Autonomous North Atlantic Region) or departmental; the municipal/territorial level (for these three, a governance questionnaire was used); and the community level (application of the revised IFRI protocol). A case study was chosen in the indigenous territory of Diez Comunidades (Municipality of Puerto Cabezas), focused on the block of six Miskitu communities SIPBAA (abbreviation corresponds to the initials of the communities name that form the group/block)[13], and located in the buffer zone of Bosawás Reserve. The governance questionnaire has been broadly applied to more than 60 representatives of state agencies in charge of natural resource management, but the team did not manage to include representatives of the private sector, external cooperation or civil society due to time and budget constraints.

In Honduras the institutional mapping protocol was implemented in two municipalities (out of eight within the NHSL): Catacamas (Olancho department) and Iriona (Colon department). These municipalities were chosen because they coincide with the location of the sites where the biophysical and socioeconomic

13 Sangilaya, Il Tara, Panua, Butku, Auhya Tara y Auhya Pihni (SIPBAA)

baseline study is being conducted. In both Iriona and Catacamas, a community was chosen for application of the revised IFRI protocol to produce two case studies. The governance questionnaire was used with representatives of the main stakeholders involved in the governance of natural resources at the national/municipal and community levels, but in contrast to Nicaragua, the questionnaire was used with a selection of representatives of state agencies, the private sector and cooperatives.

A close relationship was established with CIRAD-Nitlapán for the analysis of the impact of human migration and other social processes on land use evolution, and on trees in forests and outside forests in the NHSL networking and data sharing:

- In order to articulate science, rural development and education in Nicaragua, a national seminar and workshop were held with massive participation from a total of 12 NGOs, 8 governmental organizations, 8 universities, 6 international centers, and 4 international cooperatives. The focus themes were developed around the work in the Nicacentral region, which is part of the Sentinel Landscape.
- Projects such as CATIE/MAP Noruega have worked in the NHSL and collected a lot of data in eight municipalities corresponding to the Nicaraguan part of the NHSL (where plots 4, 8 and 13 are located). This database has data on families (decision-making, food security), farms (land uses, tree richness and densities, yields), value chains, and organizations and platforms working in the area. Data and methods can be shared.
- Various CGIAR Centers and CRPs are operating in various sections of the NHSL. An alliance between CIAT, CATIE and CIRAD has started a process to put everybody in contact and keep them well informed.
- CATIE is involved in the preparation of various project proposals in alliance with colleagues from Bioversity International, CIRAD, CATIE and others. More research will be conducted in the NHSL. More integration between ICRAF and CATIE is also taking place.
- Exchange students from universities in Nicaragua, Honduras, Colombia and France also participated in Sentinel Landscape activities.

The diversity of the partner feedback reflects the different backgrounds of partners in each site; with some having a much stronger research network and others a stronger governmental and development network. This presents opportunities for collaboration to develop a research and intervention platform to share information about the landscape, expertise accumulated in other projects or gained by other organizations, and sources of information to delineate projects and interventions. There is a clear interest in systems to monitor deforestation, in opportunities to align new initiatives with existing monitoring efforts in the landscape, and in capacity building for local organizations.

CATIE within its role in FTA continued playing a key role as facilitator and leader in the platform or network 'Science, Rural Development, Policy and Education', a multistakeholder initiative (the university system, the government, the private sector, NGOs, donors, etc.) under Nicaraguan Council of Science and Technology-CONICYT-Vice Presidency of Nicaragua. The platform meets according to an agenda agreed among members and includes activities at both the national and local level. Currently, new international members have also joined the platform. An iconic protected area within the NHSL, el Macizo de Peñas Blancas has adopted a climate-smart development approach, and a local platform was created to organize the various stakeholders involved (farmers, small tourism operators, universities, etc.).

CATIE/MAP Noruega´s project developed a Climate Smart Territory (CST) inside the NHSL Nicaragua (CST-Peñas Blancas) which continues working in the site.

CCAFS/Bioversity International has been working in NHSL since 2012 with the establishment of two plots for long-term monitoring of the climate change effects on agriculture and peoples.

International students: Seven exchange students from two universities in Colombia (Universidad del Tolima and Universidad de Nariño) produced a report and research in NHSL.

CATIE developed theses in the Sentinel Landscape

- CATIE theses: One post-doctoral researcher and 41 master's-level students developed their research in the NHSL between 2012 and 2017 (see Annex 1; documents available at www.paisajecentinela.org).

Presentations, reports and other resources

- As part of the activities to support other landscape teams, the Sentinel Landscape Nicaragua-Honduras team traveled to Peru in order to share the methodology, experiences, and lessons learned from the application of the LDSF. Three presentations were done on the importance of Sentinel Landscape monitoring sites, the use of the LDSF methodology, challenges and solutions. Preliminary data analysis was conducted on the newly collected data, including infiltration capacity curves. All the participants were able to use the materials and equipment so that they were able to train other members of the local teams.
- CATIE-FTA published a detailed study of the contribution of both fruit and timber trees in small farms and homegardens in the most heavily populated area of Nicaragua: la Zona de los Pueblos. The publication can be downloaded at http://bco.catie.ac.cr/boletines/es/.
- The CATIE/MAP Noruega project has produced a range of tools and farmer resources on alternative agricultural practices related to a range of crops and livestock (e.g. coffee, cocoa, livestock, silvopastoral systems, backyard gardening and staple cereals). Distribution has focused on farmers and agricultural extension services. All documents are available at: http://map.catie.ac.cr.

Publications, data and other information were published and widely distributed to national organizations, producers and universities.

Meetings and workshops

- Sentinel Landscape Data Analysis International Workshop, CATIE, March 2014. The workshop engaged participants from the eight SL initiatives working around the globe under widely different biophysical and socioeconomic contexts. The objective was to analyze the data and methodology for both biophysical and socioeconomic baselines, as developed in NHSL. Presentations and workshop documents are available here:
  - https://www1.cifor.org/fileadmin/subsites/sentinel-landscapes/document/SL_Data_Analysis_Workshop.pdf
  - https://www.slideshare.net/ForestTreesSentinelL/using-systematic-field-surveys-to-assess-the-effects-of-land-use-on-soil-health-across-diverse-landscapes
  - Biophysical and socioeconomic baseline studies, and their relevant databases have been presented and shared in the NHSL Nicaragua through a series of seminars for technical staff in NGOs and governmental organizations from Matagalpa, Jinotega and Carazo. A knowledge-sharing event was funded by the MAP project to share the main findings from the baseline studies with farmers and other local stakeholders in Matagalpa, part of the NHSL.
- Lead by ICRAF and CATIE, a mini-symposium entitled 'Los Arboles en Fincas: su Presencia y Contribución a las Familias Rurales' was carried out. CATIE Costa Rica held an international workshop on the use and integration of existing databases to answer key research questions for the SL program (Turrialba, Costa Rica 10–11 November 2016). The objectives of this workshop were: (i) to discuss the analysis of baseline data across the SLs regarding the six central research questions; (ii) to explore the contents of the various databases available for the NHSL and the feasibility/potential of combining various sources of data to address the central research questions; and (iii) to discuss what is possible in terms of writing integrated papers. The document

is available at: https://www.youtube.com/watch?v=Dv97YUHuJTc.

- As part of the activities to support other SL teams, the Sentinel Landscape Nicaragua-Honduras field coordinator Norvin Sepúlveda and technical assistant Noel Ulloa traveled to Peru in order to share the methodology, experiences and lessons learned about the application of the LDSF.
- In coordination with the national platform 'Articulating Science, Education and Rural Development', four workshops were developed on themes such as climate change, the importance of trees outside of the forest, trees for multiples uses, the importance of livestock in greenhouse gas (GHG) emissions and for their reduction.

Stakeholder discussion

A stakeholder discussion on science and development was convened to help set up a relevant research agenda and secure science-based innovations to support sustainable development processes in Climate Smart Territories (TCI) in Nicaragua (Nicacentral). This event engaged more than 120 representatives from 12 NGOs, 8 governmental organizations, 8 universities, 6 international centers, and 4 international cooperatives, with the main objective of articulating science, rural development and education in Nicaragua in 2015. In addition, CATIE has supported the creation of a TCI in Peñas Blancas, part of the NHSL. The TCI is a new way of conceiving social organization for the management of ecosystem services on a territorial scale, integrating the interests of different actors and sectors within a shared vision. The integration represents the main objective of the TCI and seeks to optimize the sustainable, equitable and competitive production of the ecosystem goods and services of the territory.

Based on the Phase 2 proposals, through the CGIAR process of country-level integration across Centers and CRPs (formerly called 'site integration', now called 'CGIAR country collaboration'), 10 CRPs have identified or plan to link activities in Nicaragua which are anchored in 5 CGIAR Centers – Bioversity International, CIAT, ICRAF, IFPRI, CIMMYT and CATIE. The goal of site integration is twofold: (i) high level CGIAR engagement with the national government to scale up innovations; and (ii) knowledge management among Centers and CRPs to improve the coordination and efficiency of CGIAR activities. Nicaragua is considered a priority country by CCAFS, FTA and Livestock CRP. Most, if not all CRPs have a close working relationship with Nicaraguan Institute of Agrarian Technology (INTA) and other national and local partners as well as agriculture-focused universities and international NGOs. For example, CCAFS and partners play a catalytic role in bringing together CGIAR and national actors around climate change and FTA (with a strong role for CATIE), using a landscape perspective on ecosystem services and integration of trees in farming systems. Livestock has a value chain focus, integrating sustainable intensification by linking farmers to markets. In general, the collaboration spans national, regional, subregional and local levels with joint research for development undertaken by CGIAR and scientists from National Agricultural Research Systems.

7 Databases and data analysis

Biophysical: Key indicators measured as part of the biophysical field surveys include tree and shrub density, woody and herbaceous cover, diversity of woody species, land use, and land use history, in addition to soil health, erosion prevalence and soil infiltration capacity. The various datasets generated as part of the Sentinel Landscape initiative are shared through Harvard Dataverse. The LDSF data are currently available in Sepúlveda (2016). The data have been used to identify priorities of agricultural activities for proposed projects in El Tuma La Dalia. In addition, the data have been presented in national workshops on soil restoration and use.

Further, an online tool to explore all of the LDSF data collected in the Sentinel Landscapes, including the four LDSF samples in the Nicaragua-Honduras SL, is available at: http://landscapeportal.org (Figure 7).

Open access database

- CATIE agroforestry databases available in: http://thedata.harvard.edu/dvn/dv/CATIE.
- 18 legacy datasets compiled and archived in: http://thedata.harvard.edu/dvn/dv/N-H-SL.
- 10 years of databases on coffee agroforestry in Nicaragua in: https://dataverse.harvard.edu/dataverse/CATIE.
- 126 spatial datasets compiled and archived in: http://thedata.harvard.edu/dvn/dv/SL.
- CATIE-FTA has developed a web page: https://paisajecentinela.org/NicaraguaHonduras, where several documents have been uploaded.
- GAVILAN forest dynamics model is finished and is available at: https://www.catie.ac.cr/gavilan.
- Information about Sentinel Landscapes is in Nicaragua FB: www.facebook.com/catienicaragua.

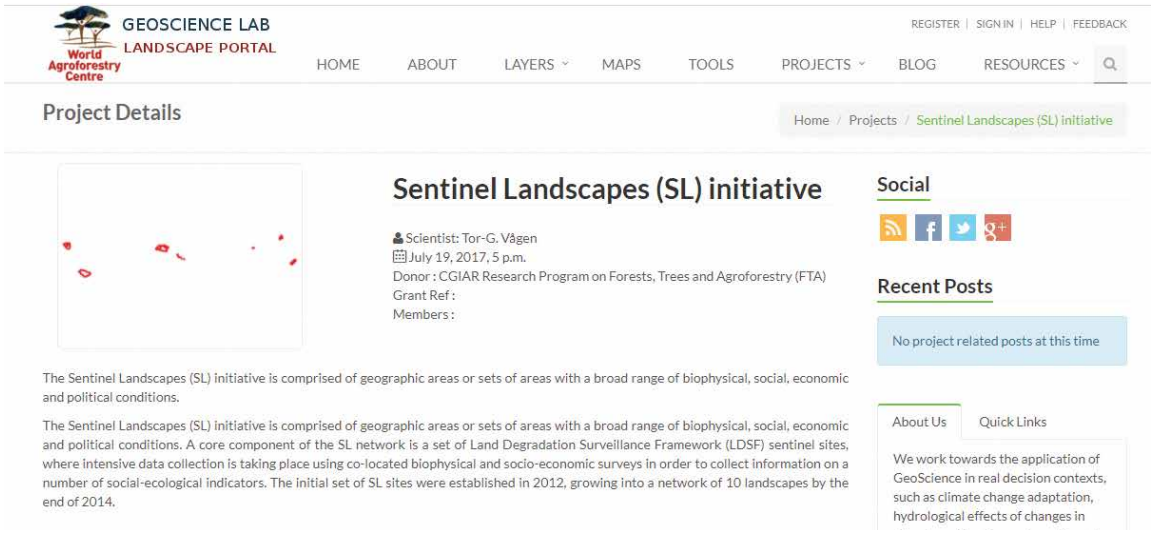

Figure 7. Screenshot of the front page of the online tool: SL Explorer: http://landscapeportal.org/projects/1

8 Data collected directly by the NHSL initiative

Data collected in the NHSL helped in identifying some trends in land cover/uses within a landscape mosaic of land-use intensity, as well as to link these trends with socioeconomic factors. Also, attributes or metrics related to ecosystem functioning were observed and demonstrated; e.g. the benefits of having trees in the landscape to reduce the prevalence of soil erosion. In the following subsections, we present the main results of the baseline study of the NHSL initiative.

8.1 Cultivated area

Plot-level observations were recorded at each of the 160–1000 m^2 plots per site. A generalized linear mixed-effects model was used to estimate the area under cultivation at each 10,000 ha site. In El Tuma-La Dalia, more than 50% of the site was cultivated, while estimates of cultivated area were less than 25% for Columbus Mine and Rio Blanco, and less than 5% for Rio Plátano. Major crops at El Tuma-La Dalia were coffee and staple cereals; in Columbus Mine they were maize, cassava and rice; and in Rio Blanco livestock, corn and beans were predominant. The graphic below shows the percent of cultivated area per site. Rio Plátano is still forest, and thus is not cultivated (Table 3).

The land use relationship between crops, pastures, and forests differs in each site. In El Tuma-La Dalia, shade-grown coffee is the main crop, accounting for up to 70% of the cultivated area. Rio Plátano is the site with the highest proportion of forest, at 70%, followed by Columbus Mine at 28%. Rio Blanco is predominantly a livestock site, with 70% of the area under pasture

Table 3. Percentage of cultivated area, grassland and forest cover in the LDSF

Site	Cultivated %	Grassland %	Forest Cover %
El Tuma	59		18
Columbus Mine	12		28
Rio Blanco	11	70	6
Rio Platano	10		70

8.2 Linking metrics

Tree density and erosion prevalence in cultivated and semi-natural areas: Average tree density was 543 trees ha^{-1} and 266 trees ha^{-1} in Columbus Mine and El Tuma-La Dalia, respectively (Figure 8). Note that the LDSF used the Food and Agriculture Organization of the United Nations (FAO) Land Cover Classification

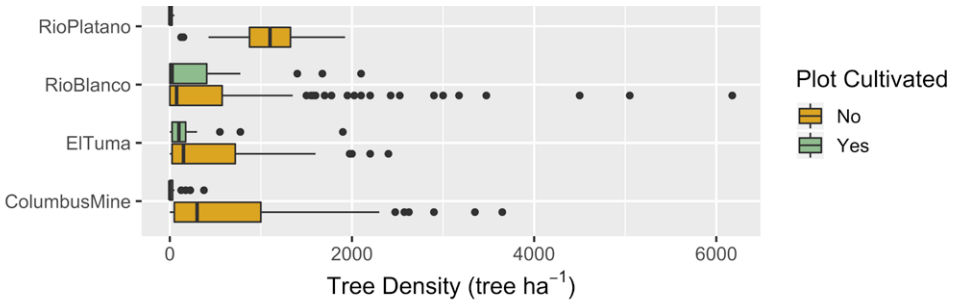

Figure 8. Tree densities in cultivated and non-cultivated plots for each of the four sites

System, which uses the following definition of a tree: "woody vegetation that is taller than 3 meters". In cultivated areas, this number decreased for both sites. Figure 8 illustrates how erosion prevalence and tree density are linked, in both cultivated (1) and semi-natural (0) areas in the two sites. Erosion prevalence was highest in areas with low tree densities (Figure 9).

8.3 Infiltration capacity

Infiltration was measured in three plots per cluster, for a total of 48 plots per site, using a single ring infiltrometer. Average infiltration capacity was modeled using non-linear mixed effect models. Infiltration was higher in plots with trees (1) compared to plots without trees (0), as shown below. Further, infiltration was higher in non-eroded plots (0), compared to eroded plots (1) (Figure 10), reflecting the relationship between tree density and erosion prevalence mentioned above.

8.4 Soil analysis

All soil samples were air-dried and ground to pass through a 2 mm sieve locally. Sub-samples were shipped to the ICRAF Soil Plant Spectral Diagnostics Laboratory in Nairobi, Kenya for further analysis. All soil samples were analyzed for Mid Infrared Spectroscopy (MIR) absorbance at the ICRAF laboratory. Thirty-two reference samples from each site were subjected to traditional wet chemistry analysis. These wet chemistry data were used to develop calibration models to predict soil properties on the whole dataset using the MIR spectra.

Soil texture (sand, silt and clay content) was measured using a Laser Diffraction Particle Size Analyzer (LDPSA) from HORIBA (LA950) after shaking each soil sample for 4 min in a 1% sodium hexametaphosphate (calgon) solution, at the ICRAF laboratory. Total nitrogen and organic carbon were measured by dry combustion using an Elemental Analyzer/Isotope Ratio Mass Spectrometry (EA-IRMS) from Europa Scientific after removing inorganic carbon with 0.1 N HCl, at the ISO- Analytical Laboratory located in Crewe, Cheshire, UK. Soil pH and exchangeable bases were analyzed at Crop Nutrition Laboratory Services in Nairobi, Kenya.

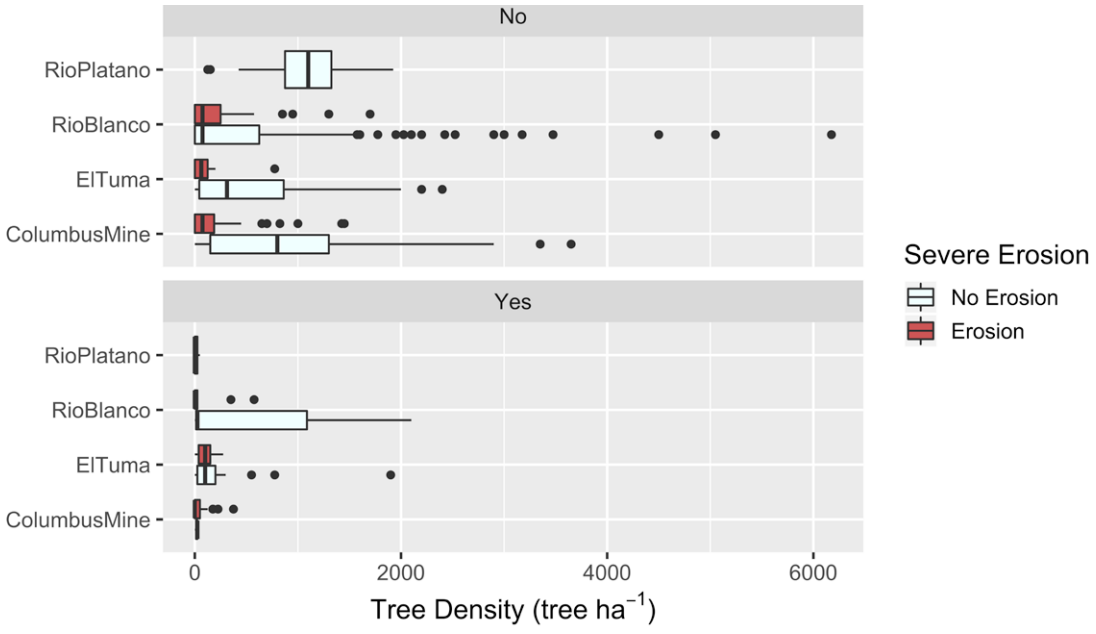

Figure 9. Comparing tree densities in severely eroded plots vs. non-eroded plots in cultivated (1) and non-cultivated plots (0), in El Tuma-La Dialia and Columbus Mine LDSF sites

Note the higher tree densities in non-eroded plots, especially in the non-cultivated (0) plots

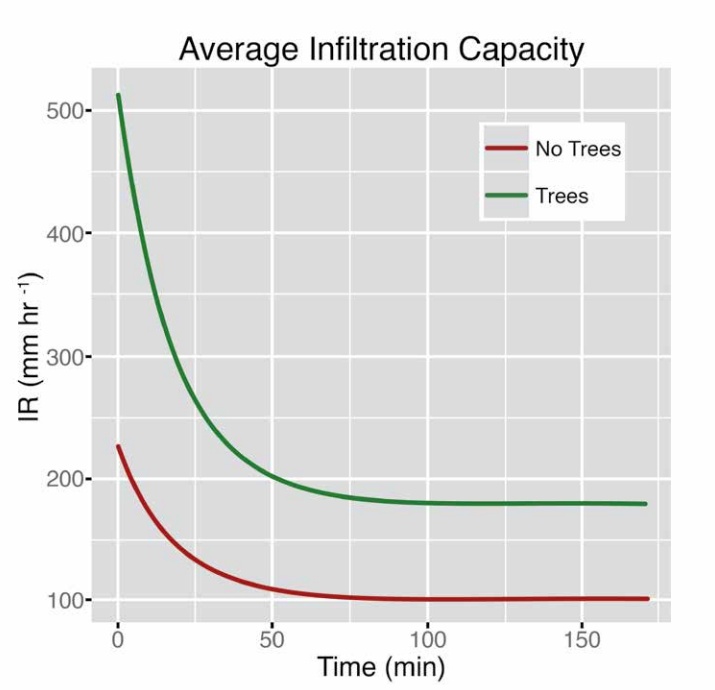

Figure 10. Infiltration rate in presence of trees (1) and no trees (0)

Note: the higher infiltration rates in the presence of trees

8.4.1 Mid Infrared Spectroscopy (MIRS) Prediction data

Overall prediction results were good. R^2 for pH was 0.961, and 0.896 for soil organic carbon, 0.933 for sand and 0.931 for clay. Figure 11 shows the measured values vs. the MIR predicted values for pH, SOC, sand and clay. The remaining graphics and analysis are conducted using the predicted results.

8.4.2 Soil health indicators

Soil texture has implications for water holding capacity and cation exchange capacity, among other properties. Average sand content was low across the four LDSF sites (15% for both top and subsoil). Columbus Mine and El Tuma-La Dalia had the lowest average sand content (10%), while Rio Blanco and Rio Plátano had the highest sand content (23% and 17% respectively) (Figure 12). Also, note the narrow distribution of sand content in both top and subsoil for El Tuma-La Dalia, while both Rio Blanco and Rio Plátano had wide distributions of sand content (more variability). Unlike the sand content, clay content varied greatly between sites. Average topsoil clay content was 57% and the average subsoil clay content was 61%. Columbus Mine and El Tuma-La Dalia had the highest overall clay content (69% and 64%, respectively) and Rio Blanco had the lowest (42%) (Figure 13). Rio Plátano has the highest macronutrient content, and Rio Blanco the least. Average pH value was 5.9 across the four sites. Río Pláltano and Coloumbus Mine had the lowest pH values (acid) (Figure 14). Micronutrient analysis shows that the contents were higher in plots with more diversification (El Tuma-La Dalia, agroforestry-coffee) than those with less diversification (Rio Blanco, livestock).

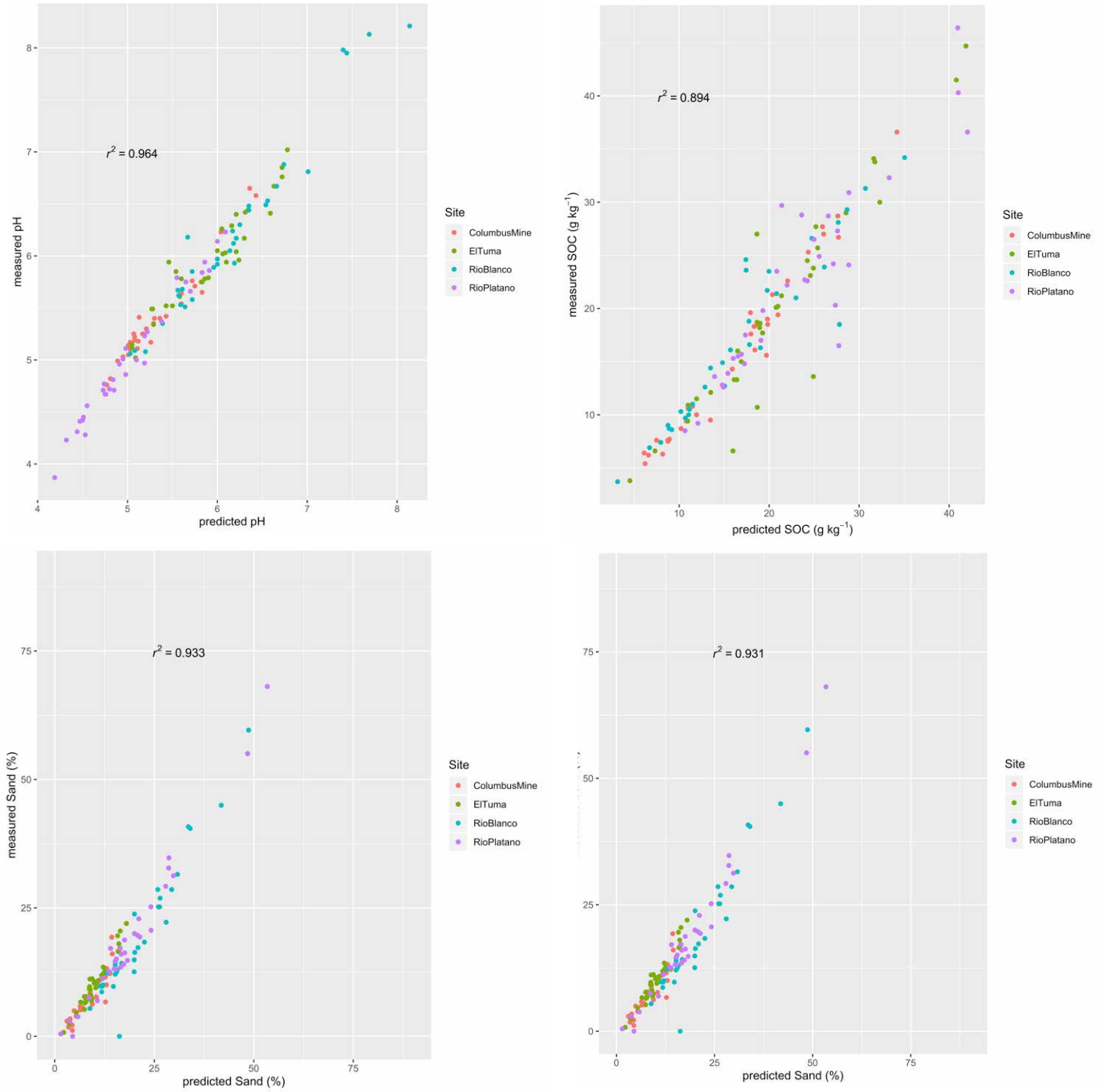

Figure 11. Prediction results for pH, SOC, sand and clay

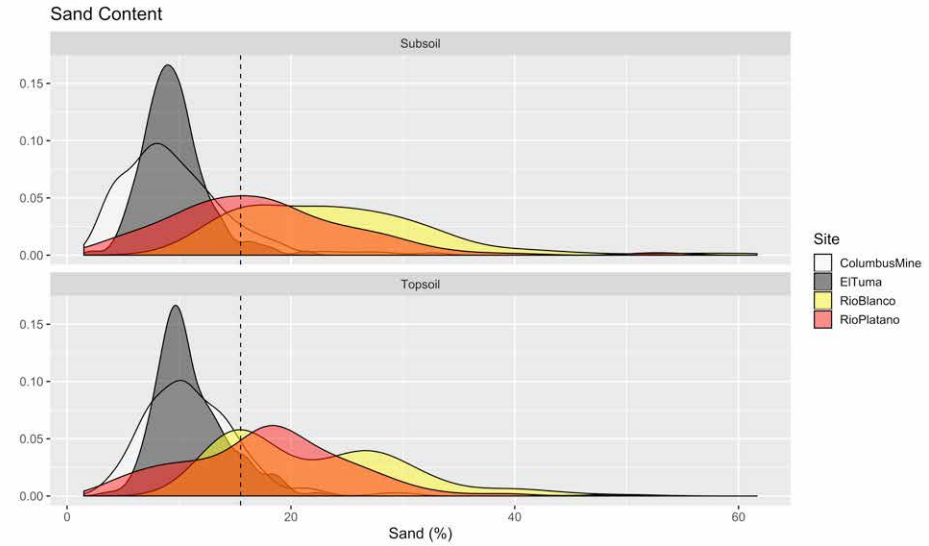

Figure 12. Sand content in top (n=619) and subsoil (n=623) samples for the four LDSF site

Note: Vertical line indicates the average sand content (15.5%)

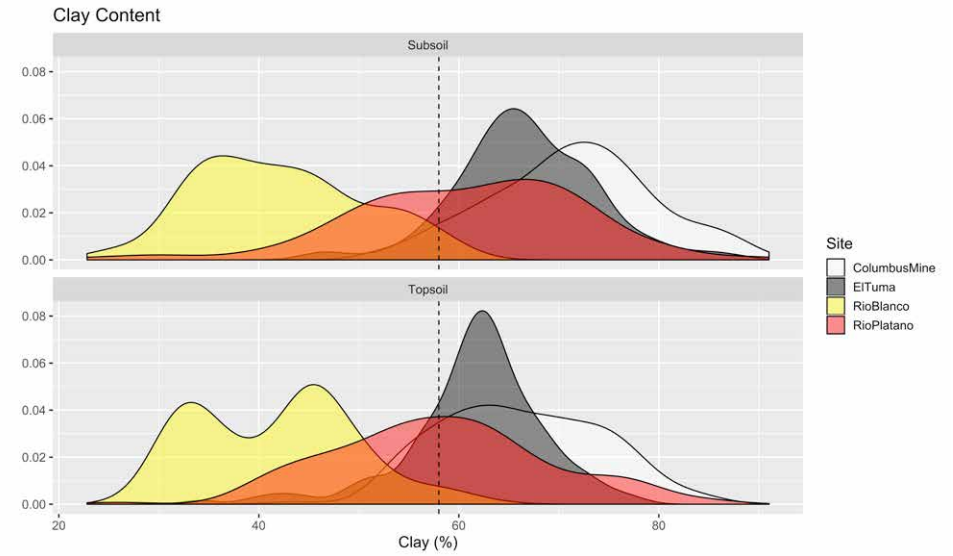

Figure 13. Clay content in the top (n=619) and subsoil (n=623) samples the four LDSF site

Note: Vertical line indicates the average topsoil clay content (57%)

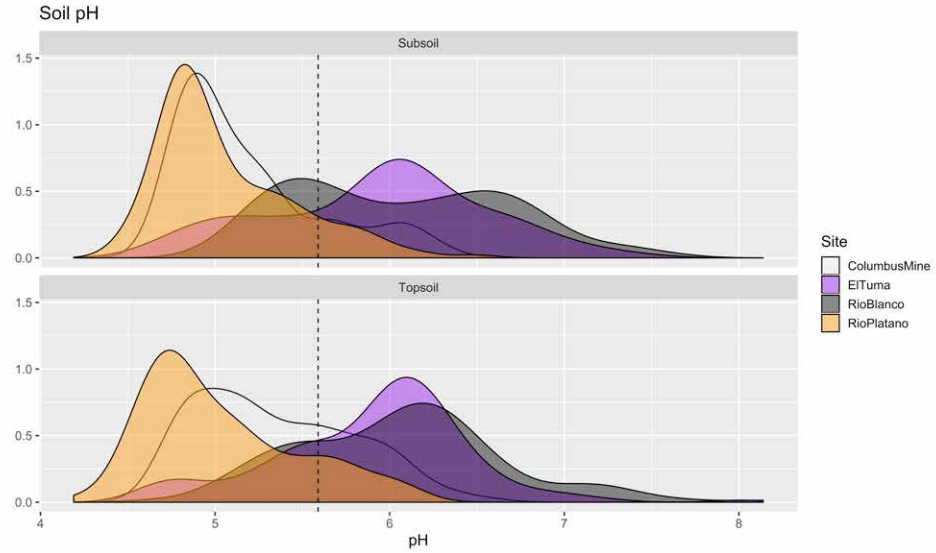

Figure 14. Soil pH values in top (n=619) and subsoil (n=623) samples

Note: Vertical line indicates the average pH value (5.59)

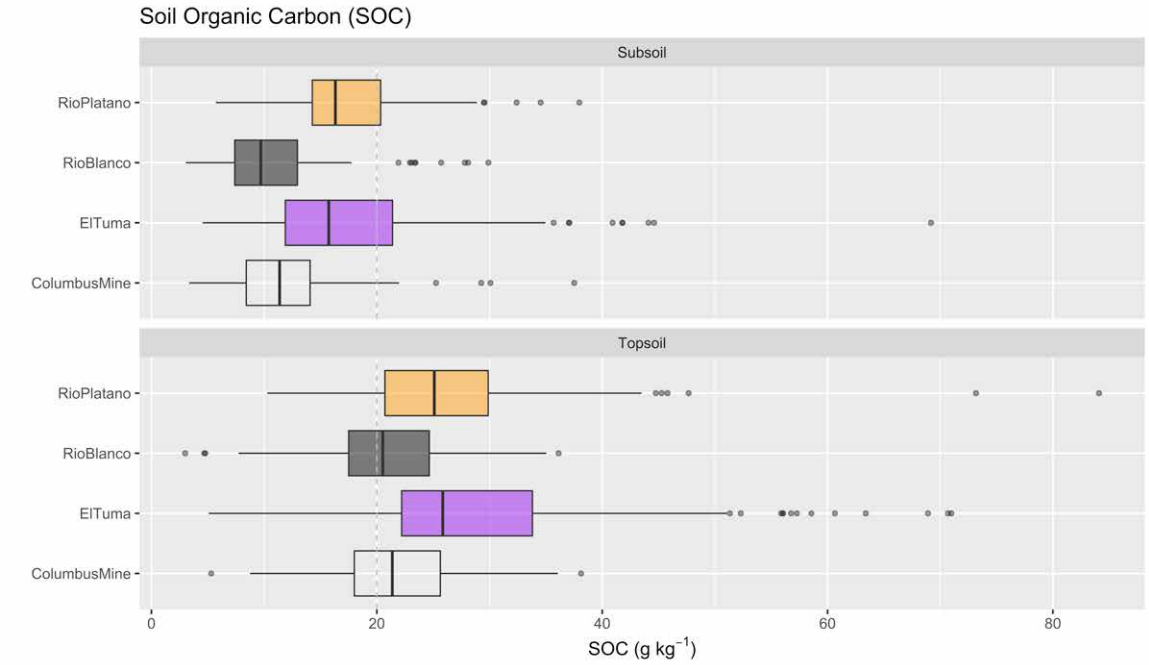

Figure 15. Boxplots of SOC in the top (n=619) and subsoil (n=623) samples for the four LDSF sites

Note: Vertical line is at 20 g kg^{-1}, a threshold for agricultural productivity

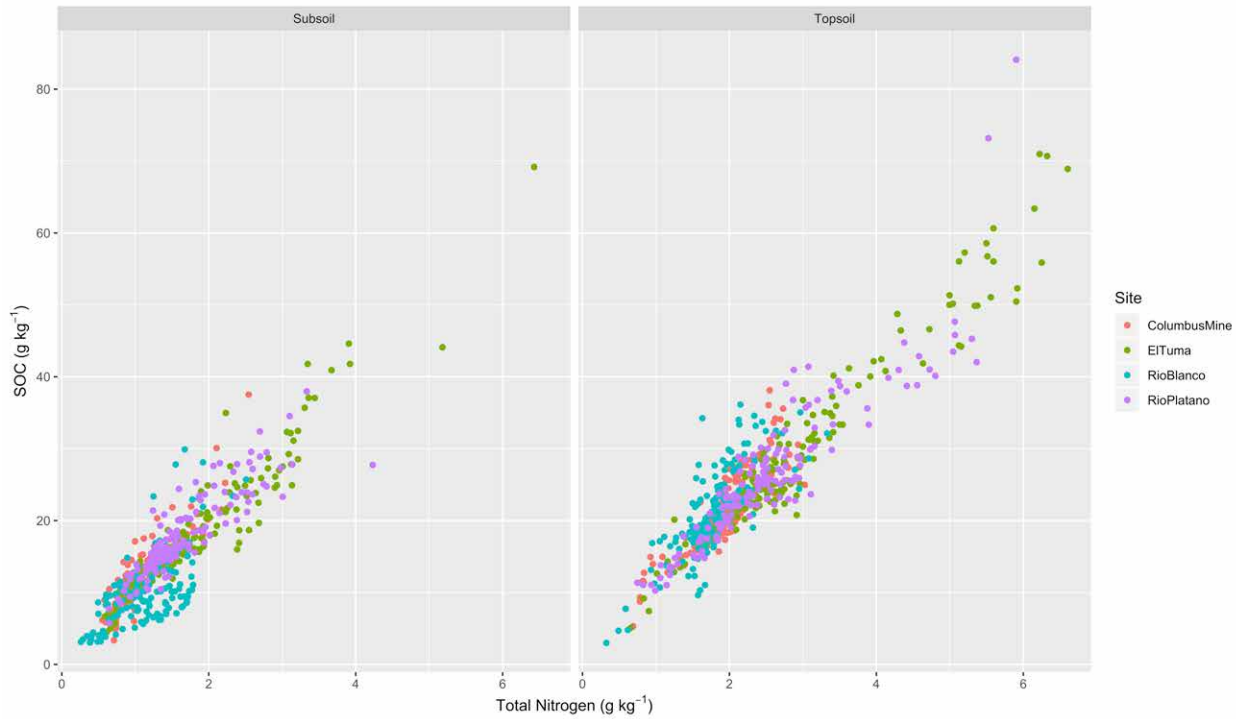

Figure 16. Carbon: Nitrogen ratio across the four LDSF sites

Soil organic carbon (SOC) content was low across all four sites (Figure 15). Average topsoil SOC content was 24.8 g kg^{-1} and average subsoil SOC content was 14.5 g kg^{-1}. El Tuma-La Dalia and Rio Plátano had the highest topsoil SOC (29.8 and 26.6 g kg^{-1}, respectively). Figure 16 also shows that El Tuma-La Dalia had the greatest variation in top and subsoil SOC, while the other sites had less variation. The next analysis should look at the influence of land management and vegetation cover on SOC content.

Exchangeable bases are important macronutrients for plant growth. Note that Rio Plátano is below the critical threshold and that the El Tuma-La Dalia site has the highest variation and content of exchangeable bases (Figure 17).

8.4.3 Principal component analysis (PCA) on four sites of the Sentinel Landscape

The first two dimensions explained 41% of the total variance of the data (26.10% and 15.21% for the first axis and second axis, respectively). Calcium (CA in ppm), cation exchange capacity (CEC) (meq/100 g), Boron (B in ppm), Potassium (K in ppm), and pH are the variables that best explain dimension 1, whereas in dimension 2 clay is the variable that better described this axis; sand and silt are negatively correlated to this axis. This means, for example, that soils with higher CA and CEC values have lower S and Al values or vice versa. The variables in dimension 2 are related to the texture of the soil. Based on the PCA analysis there was no correspondence of the variables with specific sites (Figure 18).

Land health and erosion, pH and organic content maps have been published at: http://landscapeportal.org/. For a detailed description of the methods used to generate this map see Vågen et al. (2016) (Figure 19 and 20).

A remote sensing-based dataset using the Terra-i vegetation and monitoring system (www.terra-i.org) was developed, including detection of deforestation and calculation of deforestation rates for the NHSL and administrative districts within it.

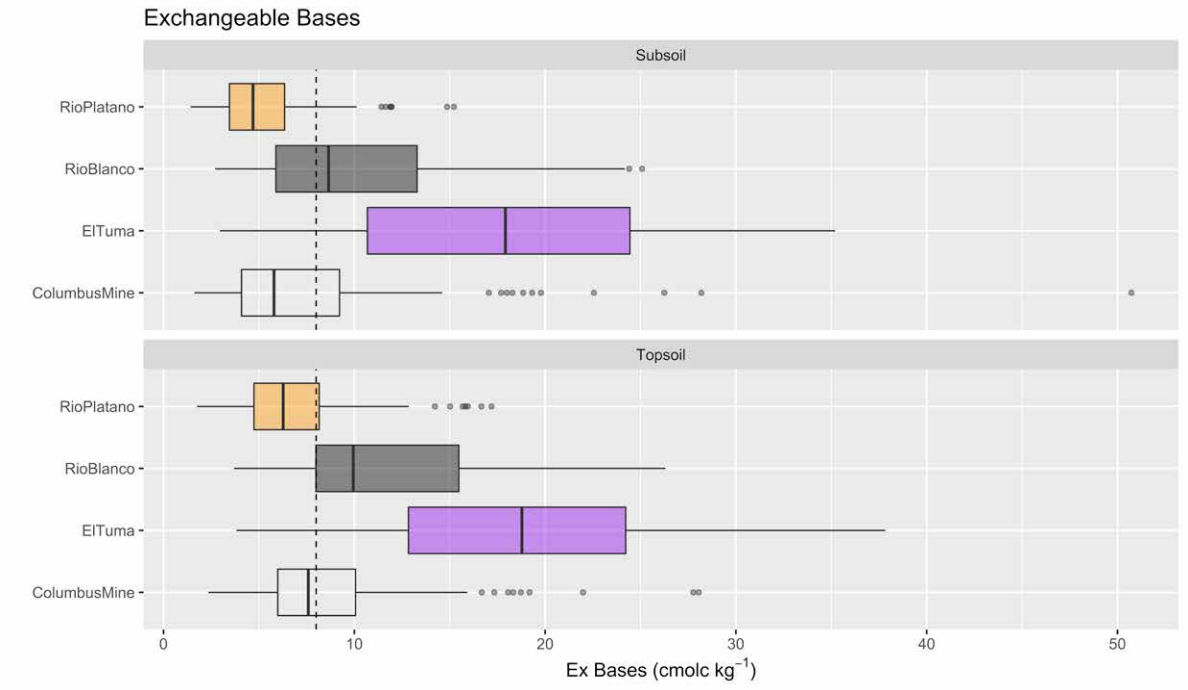

Figure 17. Exchangeable bases top (n=619) and subsoil (n=623) samples across the four sites

Note: The vertical line indicates the minimum threshold for agricultural productivity (8 cmolc kg^{-1})

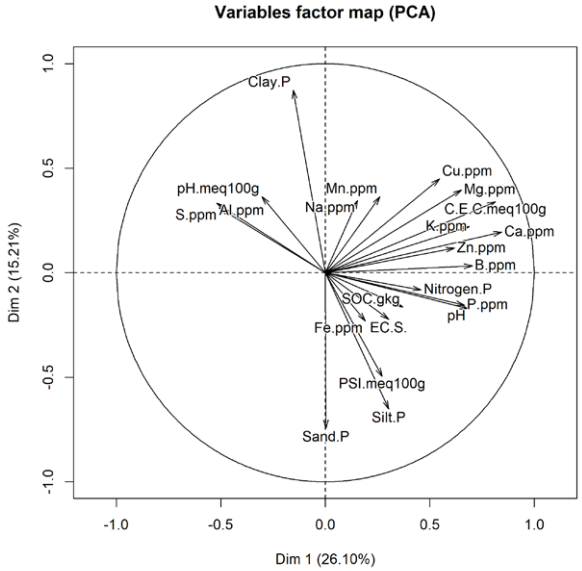

Figure 18. Principal component analysis of soil chemical and textrure variables on four sites of the NHSL

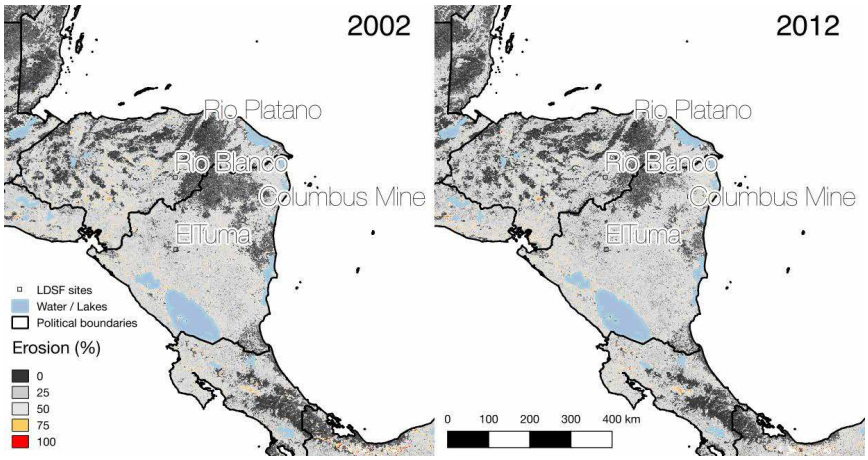

Figure 19. Estimated soil erosion prevalence in the Nicaragua/Honduras Sentinel Landscape for 2002 and 2012 at 500 m resolution

Figure 20. Screenshot of El Tuma-La Dalia erosion maps on the http://landscapeportal.org

8.5 Household surveys

The Exploratory Guide on Constructing Socioeconomic Indicators for the Sentinel Landscape Project: The Case of the Nicaragua-Honduras Sentinel Landscape, was written by Chiputwa et al. (2016). The basic underlying objective of this manual is to provide conceptual and practical guidelines on how to construct various livelihood indicators using household survey data from the SL project. The livelihood indicators illustrated in this manual provide a summary of the social, economic, demographic and livelihood strategies among the sampled households and can be used as a first step to explore differences across sampled villages and sentinel sites, as well as at the landscape level. The indicators covered in this guide are organized into the following broad measures: (i) household asset ownership; (ii) household farm dependency, income diversity and poverty; and (iii) household food security and nutrition diversity. In order to make the analysis reproducible, all analyses in the manual are conducted using R Statistical Software and the write-up was done using typesetting programs R Markdown and Latex. All R codes used in this manual are available on the Sentinel Landscape website.

Except for Rio Blanco, household size is similar across the NHSL sites (2.5–7.5 ha) (Figure 21), while Rio Platano has lower median and IQR ranges (both lower and upper) compared to the three other sites. Respondents were asked whether they usually hire any labor to help with either cash crops or food crops. The responses were recorded as a dummy variable (Figure 22).

Farm size in Rio Blanco is higher than other sites, because of the land use (livestock), meanwhile, in El Tuma-La Dalia farms are the smallest size (coffee, corn and beans) (Figure 23).

8.5.1 Farm under cultivation

Farm under cultivation is represented as the area of land that is under cultivation and is computed as the proportion of farmland that is dedicated to the cultivation of annual, perennial crops and/or annual crops integrated with perennial crops (Figure 24).

8.6 Trees on farms

This indicator shows the proportion of farmers that practice agroforestry on their farms. Trees are very important in NHSL, with fruit trees the most important species. However, this indicator does not shed any light on tree density, diversity or richness (Figure 25).

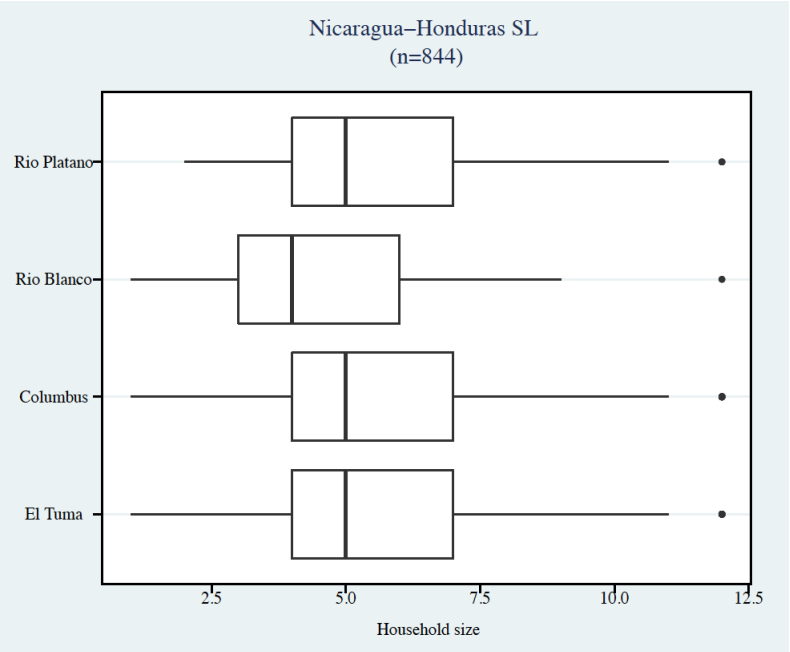

Figure 21. Household sizes across the sites

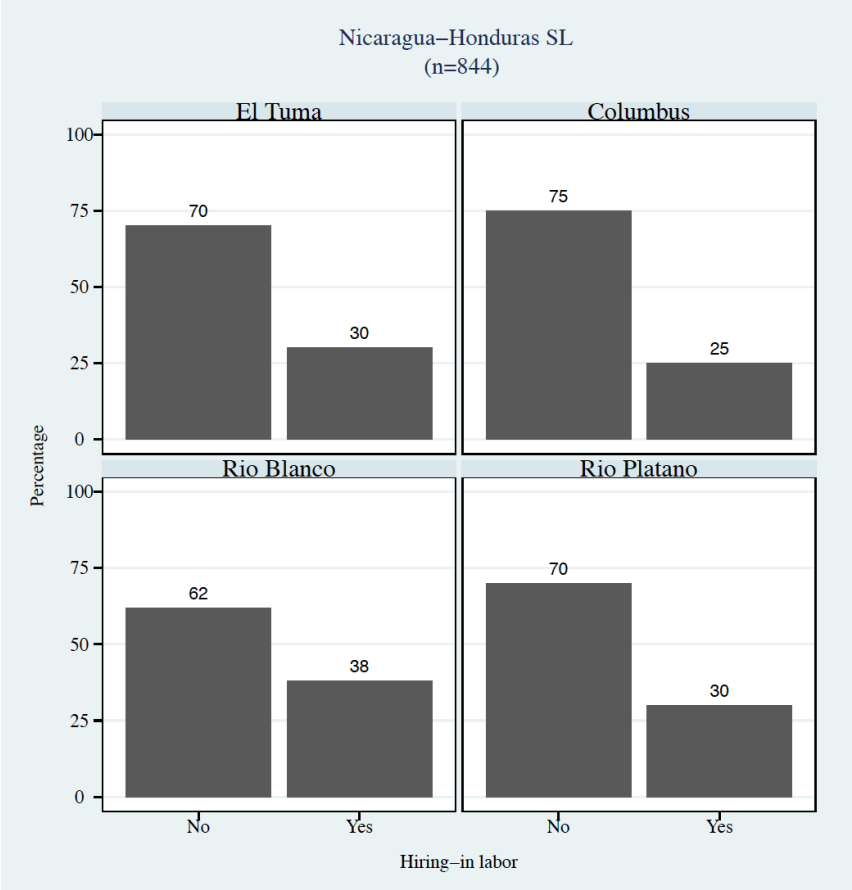

Figure 22. Proportion of households hiring-in labor

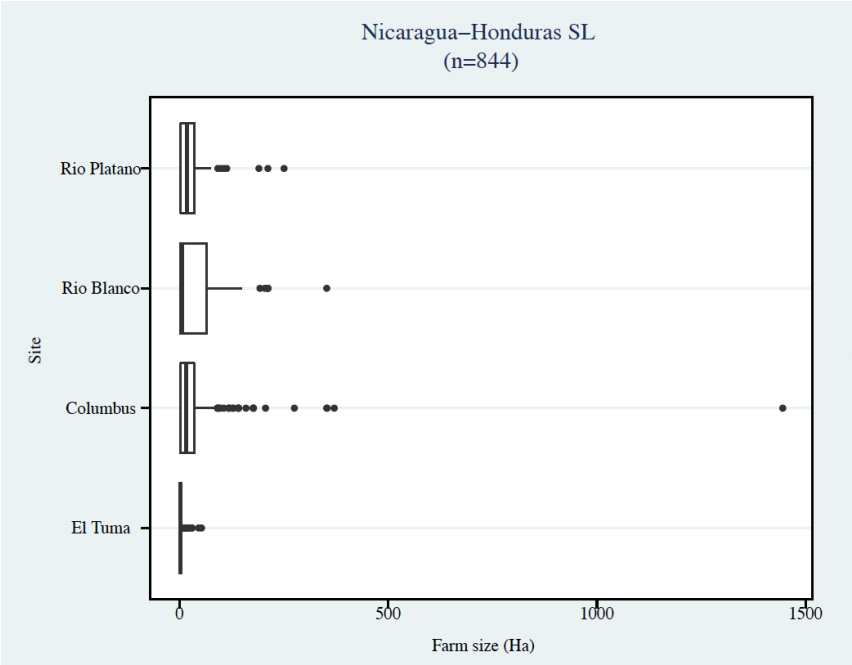

Figure 23. Farm sizes across the sites

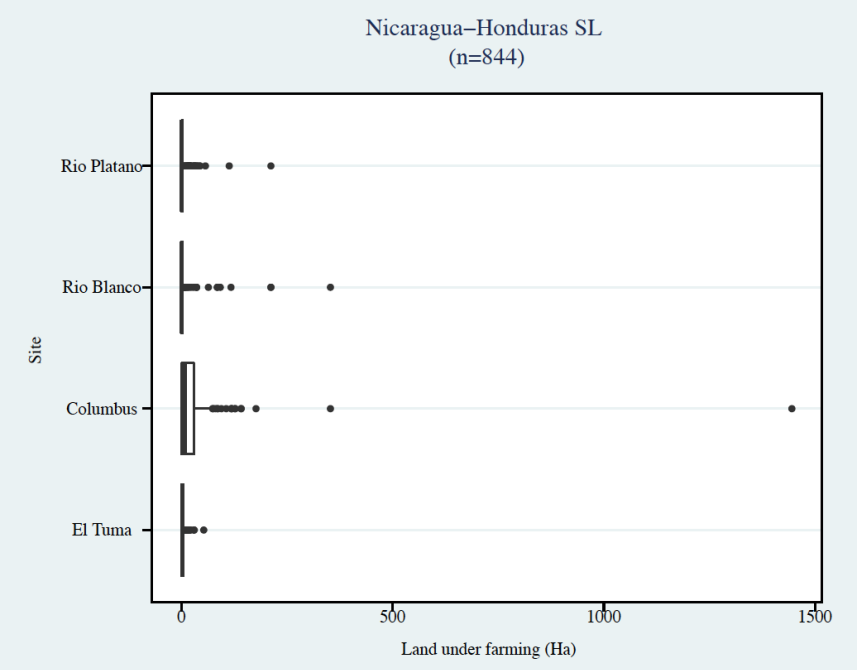

Figure 24. Land under farming across the sites

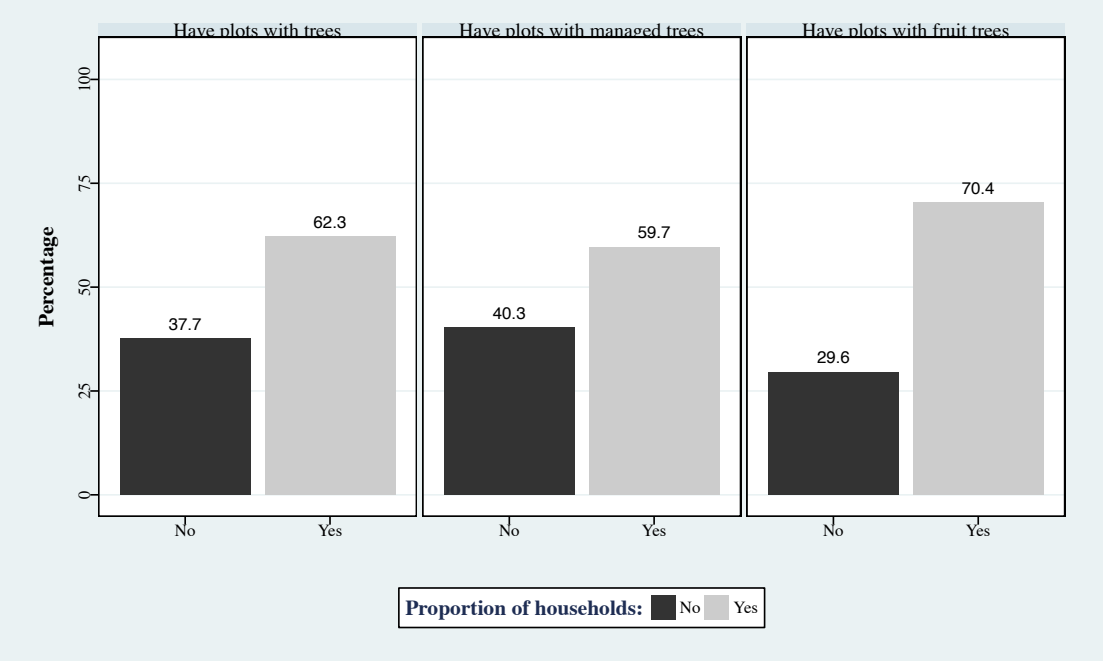

Figure 25. Trees on farms

8.7 Tropical livestock unit (TLU)

The Tropical Livestock Unit (TLU) is a common unit that describes livestock numbers across species to produce a single figure weighted according to the species type and age using the 'Exchange Ratio' concept. Livestock is considered an important source for the supply of energy, food, and support for agricultural production. Among rural families in different parts of the world, livestock is also a store of wealth. The more livestock a household owns, the wealthier they are considered in society. Figure 26. shows the TLUs across the NHSL sites.

8.8 Progress out of Poverty Index (PPI)

The Progress out of Poverty Index (PPI) is a poverty measure of the likelihood that a household falls below a certain threshold, developed by the Grameen Foundation. Households are asked a set of 10 questions covering socio-economic characteristics and asset ownership, and each item has a corresponding score. In the end, each household will have one summed score that will be converted into a likelihood score in terms of a percentage, which denotes the likelihood of a household falling below a given threshold. For this exercise, we use poverty thresholds at the internationally recognized USD 1.25, USD 2.50 and the USAID Extreme levels, which are nationally adjusted at the 2005 Purchasing Power Parity (PPP). Figure 27 shows the PPI values across the NHSL sites.

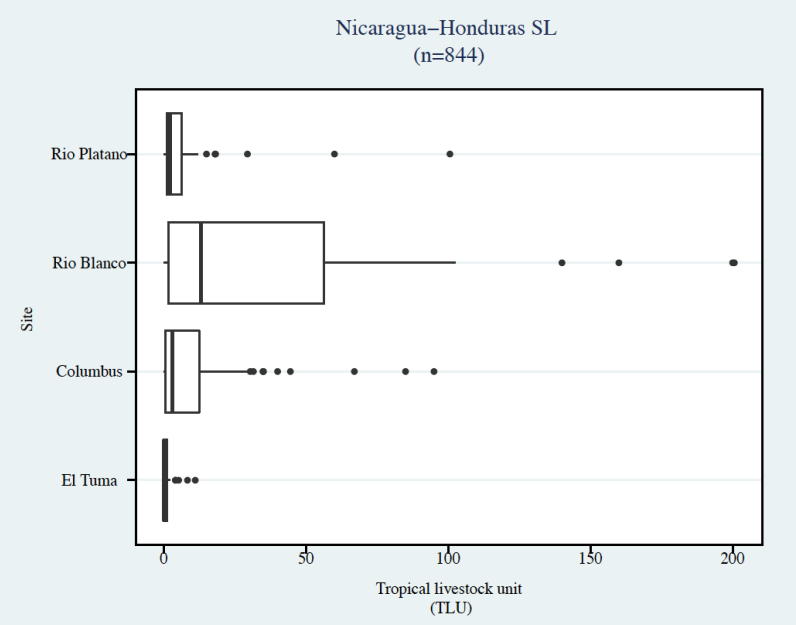

Figure 26. Tropical livestock units across the sites

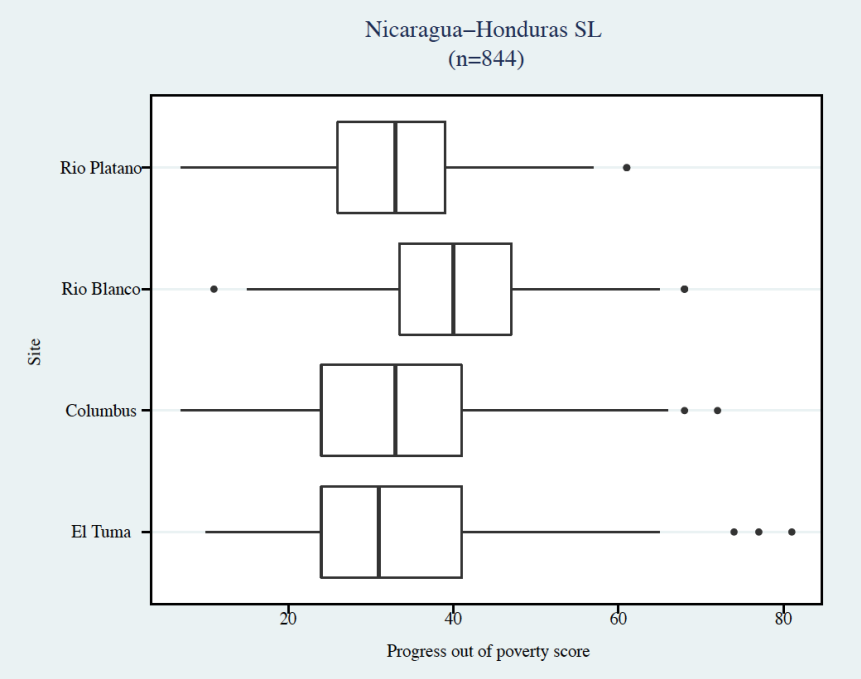

Figure 27. Progress out of poverty score across the sites

9 Other studies and data mobilized in the NHSL, coming from CGIAR organizations, CRPs and other partners

Thirty-eight master's degree theses have been developed in NHSL. They are listed in Annex 3 and are available at: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/JLAMS1&version=DRAFT.

Many publications have been produced in collaboration with partners and collaborators (see Annexes 1 and 2).

Approximately 20 female community leaders were trained by the Mesoamerican Agro-environmental Program (MAP) to strengthen their knowledge on the approach to Climate-Smart Territories and the use of tools for analysis, reflection and understanding of vulnerability to climate change and its implications for men and women (CATIE-MAP 2016). The report and information can be obtained at: https://catie.ac.cr/publicaciones-catie/.

ICRAF, CATIE and Bioversity International produced a climate change atlas for Central America (de Souza et al. 2017). The atlas provides habitat suitability maps for 54 species that are widely used in Central America for shade in coffee or cocoa agroforestry systems. The 54 species represent 24 fruit species, 24 timber species and 6 species used for soil fertility improvement. Suitability maps correspond to the baseline climate (1960–1990) and 2050 climates predicted for Representative Concentration Pathways (RCP) 4.5 and 8.5. Habitat was classified as suitable in future climates if a minimum of 12 out of 17 downscaled Global Circulation Models predicted suitable climates. Details of the methodology of ensemble suitability modeling with the 'BiodiversityR' package are provided in the atlas. The atlas was developed to support climate change-oriented initiatives for diversification and conservation of forest genetic resources across Central America. Farmers, scientists and technicians can use the atlas to identify suitable and vulnerable areas for shade species and develop strategies for climate change adaptation. The atlas is available at: https://www.worldagroforestry.org/news/climate-change-atlas-central-america.

A Farmer Field School (FFS) program was implemented involving 4,913 families (Trifinio and Nicacentral), leading to the adoption of agroforestry innovations (100% of families established at least one woody species in their patios). 141 field schools were developed by the program. These families have strengthened their knowledge and practical skills, and shared with members their decision to plan and carry out actions to diversify production in their homegardens, communal sites, vegetable gardens and farms. These actions aim to improve food and nutritional security, diversification of the family diet, and agro-ecological crop management in yards and farms alternatives. In addition, a first meeting between promoters of FFS was conducted in Honduras with partner organizations. Information can be obtained at: https://catie.ac.cr/publicaciones-catie/. Tools for practices of agricultural systems (coffee, cocoa, livestock silvopastoral, backyard, basic grains) have also been produced (Sánchez et al. 2015).

The Mesoamerican Managed Forest Observatory was formally constituted.

The methodology for developing a Climate Smart Territory in Nicaragua was developed.

Volumetric tables and guidelines for best silvicultural practices and estimation of standing value and volume of teak *(Tectona grandis),* Melina *(Gmelina arborea)* and *Eucalyptus camaldulensis* plantations have been developed and disseminated.

The development of small- and medium-forest enterprises for the management of secondary forests in Nicaragua, Guatemala and Costa Rica have been facilitated (more than 12 concept proposals have been presented and three are in the economic feasibility phase).

Estimates of GHG emissions were made jointly with farmers in Honduras and Nicaragua.

10 Results: Role of trees in the NHSLs

The results of the NHSL have been documented in a set of theses, all shared through: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/JLAMS1&version=DRAFT (Annex 3).

In the NHSL territory, 39 theses were developed, contributing to understanding of the temporal and spatial dynamics of trees and forests in an SL. Most of the research conducted (28 theses) is related to governance and models needed to optimize the use of natural resources (forest and trees included) and the drivers and processes linked to the presence of trees and forest in a landscape, 14 for each research question. The remaining 11 theses shed light on the stock of trees and forests in the landscape and on farms, and the effect of changes in the provision of environmental services.

These theses used NHSL data in conjunction with other data, as per the sections above.

Summarized here are the main findings and highlights of these studies, mapped to the original NHSL research questions: (i) Q1: What are the drivers and processes that determine/influence the presence of trees and forests? (ii) Q2: What is the magnitude of the stock and rate of change of the presence of trees and forest in the landscape and on farms? (iii) Q3: What are the consequences of changes in trees/forests in landscapes/farms on the provision of environmental services? and (iv) Q4: What new concepts and models are needed to optimize the presence of trees and forests in landscapes/farms to secure a sustainable provision of ecosystems.

10.1 Q1: Drivers and processes determining/influencing the presence of trees and forests in the landscape

Thesis: Analysis of the agricultural management practices effect on coffee rust (*Hemileia vastatrix*) impact in two coffee-growing areas in Nicaragua

- **Context:** Coffee rust is a major problem in Latin-American coffee-producer countries. Estimated yield losses due to coffee rust infestation can varied between 20% and 80% at farm level, with huge variations in incidence, severity and losses between affected areas. In Central America, recent outbreaks of the disease were reported during the 2012–2013 harvesting season. Nicaragua was the least affected country by the outbreak, with an incidence of 37% and estimated yield losses around 10%.

- **Challenge:** Reports of the incidence and severity of the disease brought to the attention of researchers and coffee growers that the incidence/severity of losses vary greatly among farms, even in areas reported as highly impacted by the disease. These differences in the response to disease outbreaks are related to agricultural management practices in coffee farms. Villarreyna (2013) studied the relationship between coffee management and coffee rust incidence in two municipalities of Nicaragua. The purpose of the study was to identify the practices that could reduce the incidence and severity of coffee rust and improve the

body of knowledge at farm level on how to cope and live with coffee rust in the face of climate change.

- **Methodological approach:** 58 coffee farms located at an altitude of 800–1200 m, in a zone heavily affected by coffee rust in 2012–2013 were selected. Half of the coffee farms presented a high incidence of coffee rust, and the other half had a low incidence of coffee rust. Pairs of farms in close proximity were formed to make comparisons between coffee farms.

- **Highlights:** There was a relationship between agricultural management practices and the level of incidence of coffee rust in the affected areas. Coffee farms were grouped into three categories of agricultural management practices: high, medium and low. Coffee farms with high agricultural management practices had low coffee rust incidence, while coffee farms with low agricultural management practices presented higher incidence and severity of coffee rust. Estimates of losses in productivity for farms with high management practices were only 1.5 qq/ha in comparison to 14 qq/ha reported for coffee farms with low management.
  - Coffee farms with high agricultural management practices included the following strategy:
    - Fertilization (foliar and on the ground) twice or more in 2011 and 2012.
    - Fungicide application: twice or more in 2011, more than three applications in 2012. The main products used were systemic. The first application was planned infor the first semester of the harvesting season.
    - The majority of farmers did coffee rust monitoring, regulated coffee shade at least once a year, and planted tissue management.
    - Also, coffee farmers in this group received technical assistance (> 10 visits per year), training (four4 per year), havehad access to funding and havehad estimated coffee incomes around USD 15001,500/ha.
  - Coffee farms with low agricultural management practices applied the same practices but at a lower frequency,; for example, the first application of systemic fungicide in the second semester and at the age of 18 years. Coffee farmers in this category did not receive support in training or technical assistance and lack, lacked access to funding and havehad less income from coffee sales.

The list of variables likely explaining the differences in the coffee rust effect on coffee farms, according to the hierarchy analysis, were related to plant nutrition. That is,, i.e. application of foliar nutrients (B, K, N, Mn, P and Fe) and soil fertilization with B and K; fungicide application in 2011 and 2012, coffee rust monitoring, shade regulation in 2011 and 2012 and access to training, technical assistance and credit.

Thesis: Economic and financial analysis of agricultural farms located in the north-central area of Nicaragua and the role of the family unit in the decision-making process

- **Context:** The agriculture sector is a major component of the Nicaraguan economy. In 2010 this sector generated USD 1.890 million in incomes. 80% of the farms are small-medium in size. Livestock, cash crops and permanent crops occupy 40% of the territory.

- **Challenge:** Poverty is a recurrent problem in Nicaragua, and rural areas are the most vulnerable to this situation. Given the fact that agriculture is a big player in income generation, more information about the economic benefits of agricultural activities areis needed to improve the management and decision-making processes on farms. Toruño (2012) documented the incomes and production costs incurred by the main agricultural activities practiced in farms of the municipalities of El Cua, Waslala, Matiguas and Muy, Muy, Nicaragua. Also, the role of the family unit in the decision-making process was acknowledged.

- **Methodological approach:** 14 farms distributed in four municipalities of

Nicaragua were selected to monitor and record the production, incomes generated by sales, consumption and change of inventory of the main agricultural activities. Interviews and land -use maps were carried out to complement the data on income generation and to record the participation of different members of the family unit on on-farm activities. Selected farms were representative of the main land- uses registered in the four municipalities. Farms sizes varyvaried between 2.7 and 137.7 ha.

- **Highlights:**
  - *Agricultural activities:* Between 4 and 15 farm activities were recorded, including non-agricultural activities. All 14 families cultivated maize, and had livestock and patios on their farms. 12 families cultivated beans, nine families cultivated coffee and rice, and six cultivated cacao, cassava and horticultural crops (vegetables). Banana and fruit cultivation, beekeeping, and vermiculture were practiced by five or fewer families. On average, agricultural activities contributed in 2011 to 93% of the total farm gross margin of the 14 families. Coffee was the crop with higher production costs per ha (Nicaraguan Cordoba NIO 29,356/ha equivalent to USD 1328/ ha [14]) followed by "other cash crops", including cassava, vegetables, fruit, and banana cultivation, representing NIO 10,217 (USD 462/ha). This was followed by rice, beans, cocoa, and livestock activities with NIO 9,460 (USD 428/ha); NIO 8,359 (USD 378/ha); NIO 5,534 (USD 250/ha) and NIO 4,242 (USD 192), respectively. Farm labor was the category that resulted in higher costs (on average 69%), followed by inputs (23%) and "other costs" (8%). The latter includes depreciation and product transportation to the market, among others. Crops with higher gross margin per ha, in order of importance were coffee [NIO 50,117/ha (USD 2268/ha)]; "other crops" [NIO 11,809/ ha (USD 534/ha)]; cocoa [NIO 11,746 (USD 532/ha)]; livestock [NIO 3,517/ ha (USD 159/ha)]; and basic grains [NIO 2,371 (USD 107/ha). This pattern is explained by yield productivity, prices and incurred costs. Based on the results of the financial analysis, families with larger areas dedicated to coffee cultivation and livestock had better farm outputs (increase in incomes and produce by unit). Also, the majority of farms could cover, based on the incomes generated and familiar benefit indicator, the wages of each member of the family unit. The decision-making process varied according to the kind of activity, amount of income generated or investment, costume, land and other goods ownership, who managed the farm activity, overall knowledge of the activity, and negotiation skills. For example, men were in charge of the on-farm decisions that required more investment or generated more income, whereas women could participate in a farm activity when the activity made lower returns.

Thesis: Contribution of cacao agroforestry systems to rural economy and nutrition in Waslala, Nicaragua

- **Context:** Nicaragua has great potential in terms of agricultural production. However, 2.4 million people live in poverty, and between 25% and 35% of its population is undernourished. Cacao enterprises not only produce cacao, but they also provide beef and pork meat, coffee and corn. Several studies acknowledge the benefit of cacao enterprises to the well-being of rural families in Waslala, Nicaragua and these enterprises are recognized as one of the main means to meet family needs.

- **Challenge:** Cocoa smallholder farmer´s livelihoods are dependent on on-farm activities. However, little is known about the economic and nutritional benefits fromof a cocoa agroforestry system. Sáenz (2012) investigated the botanical composition of cocoa agroforestry systems and their produce, and how these systems contributed to nutrition and family finances.

14 1US = NIO 22.30 as of March of 2011.

- **Methodological approach:** 37 cocoa farms were studied in Waslala, Nicaragua. In each farm, the cocoa shade canopy was inventoried. Semi-structured interviews were completed to obtain information on the quantity and frequency of fruit consumption yielded from the cocoa shade canopy. Also, a financial analysis was carried out to determine the contribution of cocoa agroforestry systems to net farm income.

- **Highlights:** A total of 4434 individuals distributed in 143 species and 40 families were inventoried. Woody plant density was estimated at 107 plants ha^{-1}. Fruit trees represented 43% of the total of individuals inventoried, followed by timber trees. The most frequent species were *Inga* spp, *Cordia alliodora, Bactris gasipaes, Cedrela odorata, and Mangifera indica*.

  The nutritional analysis of fruit trees inventoried showed that five groups of fruits can be formed as a function of nutritional traits. Group 1 includes 17 fruit species, which have the higher contents of vitamin A in comparison to the other groups; some examples are *Citrus* spp, *Manilkara zapota, Pouteria sapota, Mangifera indica, Bixa orellana, Carica papaya, Persea americana*). In Group 2 there is only one species (*Mammea americana*) characterized by a high content of vitamin A. Group 3 is formed by *Bactris gasipaes* and presents higher content of zinc and iron. Group 4 grouped species with a higher content of protein and carbohydrates (e.g. *Cocus nucifera, Tamarindus indica, Artocarpus communis*). Group 5 is formed only by *Guava* spp., and presents high content of vitamin C.

  Greater diversity in fruit trees is associated with an increase in functional diversity. According to net income and familiar benefit (net income + benefit-in-kind) estimates, cacao farms are a source of both cash income and in-kind benefits.

Thesis: Balance of GHGs, tree diversity and their effect on carbon stocks in different land uses of dual-purpose cattle farms in Sico and Paulaya valley, Honduras.

- **Context:** Livestock production contributes to climate change, and it has been linked to deforestation processes and losses of biodiversity in the tropics. It is recognized as a great contributor to anthropogenic GHG emissions.

- **Challenge:** It is imperative that the livestock sector address its environmental footprint. Experiences from several countries in the tropics show that silvopastoral systems can contribute to mitigating GHG emissions of the sector through the implementation of good management practices. Rodríguez-Salguera (2017) estimated the GHG emissions of dual-purpose cattle ranching and the relationship between tree species diversity and carbon storage in the main land uses practiced in cattle farming in Honduras.

- **Methodological approach:** 30 dual-purpose cattle farms were selected for the study. A semi-structured questionnaire was applied to characterize the prevailing farming system and the biophysical characteristics of the farms to determine GHG emissions annually using Tier 1 and Tier 2 approaches of the Intergovernmental Panel on Climate Change (IPCC) guidelines. Tree species diversity and their carbon storage capacity were estimated in four land uses: scattered trees in pastures (STP), live-fences (LF), hydrological conservation areas (HGC) and forest (F). Carbon storage capacity estimates were done using a generic allometric model. The balance of GHG net emissions was estimated using the information generated in the previous steps (GHG emissions and carbon fixation rates estimates).

- **Highlights:** *GHG emissions by the numbers:*
  - Dual purpose cattle farms in Honduras emitted 4,397.7 Mg $year^{-1}$ of CO_2e. Milk cattle is responsible for most of the emissions.
  - On average, emissions of GHG per ha were 3.9 Mg ha^{-1} $year^{-1}$ of CO_2e.
  - GHG emissions per farm were 146.6 Mg $year^{-1}$ of CO_2e.
  - About 65% of dual-purpose cattle farming emissions were in the form of CH_4 by enteric fermentation, and 23% was in the form of N_2O produced by manure deposition.

- Emission intensity (i.e. emissions per unit of product) is estimated at 2.3 kg CO_2e per kg of milk produced.
- Most of the cattle ranching farms presented a positive balance of net GHG emissions; only four farms had a negative net balance. The range of net GHG emissions was between 31.1 and -109.1 Mg year^{-1} of CO_2e.

Tree species diversity and carbon storage

- 4,585 trees were inventoried in total, of which 1,816 were recorded on LF, 1,768 on STP, 757 on F and 244 on HCA.
- 248 species were recorded in the four land uses. STPs were the most diverse land-use with 158 species, followed by F (140 spp), HCA (92 spp) and LF (27 spp).
- Forest and HCA were the land uses with the higher value of carbon storage (172.2 Mg C ha^{-1} and 143.4 Mg C ha^{-1}, respectively) followed by LF (77.8 Mg C ha^{-1}) and STP (5.6 Mg C ha^{-1}). LF and STP were statically different in terms of carbon storage.
- There was no relationship between tree diversity and carbon storage capacity in the four land uses. However, the number of individuals per hectare had a positive effect on C storage.

Finally, unit animal (UA ha^{-1}) and milk production (kg ha^{-1}) were the variables better explaining the emissions per unit of land. Farm size, presence of F and HCA and vast extension of grassland influenced net GHG emissions.

Thesis: Assessing farming livelihoods, nutrition and use of the agrobiodiversity with a gender approach into the sustainable development of four communities of the municipality of Waslala, Nicaragua.

- **Context:** Analysis of the options available for agro-ecological diversification of farms to minimize the risks and uncertainty to changing climatic conditions is essential for rural development sustainability. Smallholder farmers in the north of Nicaragua have farms ranging in size between 1 and 5 ha, and produce and commercialize between one and eight agricultural products.

- **Challenge:** There exist several factors influencing the degree of diversification of farms, such as agroclimatic conditions, market access, labor availability, seed availability, history of the community and culture. However, little is known about the effect of agricultural activities on the composition of the farms and the diversity of commercialized produce on income generation at the family level and on women's incomes, and the contribution of this diversification on nutrition. Here we present the results of the agrobiodiversity found on farms and how this diversity can be taken into account for the promotion of better practices and to improve the nutritional status of the community

- **Methodological approach:** Communities were selected based on the following criteria: low economic and nutritional status, market access and potential of yield improvement. A participatory approach was developed to carry out the research that included interviews of local organizations (four in total) to collect information related to nutrition, income generation, main livelihoods of the community, market access, etc. Also, interviews at the farm level were conducted to assess the livelihood of the household. Next, an agrobiodiversity analysis was conducted through focus groups to generate a database of the plant species produced, consumed, commercialized and bought at the community level.

- **Highlights:**
  - The livelihoods of the communities were: agricultural activities, sales of produce, forest product extraction, paid labor and off-farm activities (school teachers, food preparation, etc.). Grains, legumes roots, and tubers were produced in almost every farm, especially, yucca, malanga, maize and beans. Fruits, medicinal plants and herbs were the groups of plants with higher diversity in the communities.

The most frequent fruit species were: pejibaye, naranja, mango, banana and guayabo. Vegetable cultivation was also reported in most of the communities studied. Chayote, baby corn and ayote were the preferred vegetables for consumption.
  - Maize and beans were the staple foods of the communities. Roots and tubers were also part of the daily diets.
  - Poultry, pigs and cattle were also part of the portfolio of agricultural activities on the farms. Pigs and cattle were for sale only. Hens were for both consumption and sale.
  - Cocoa and coffee were the cash crops of the farms and their communities.
  - Trees were also common around the farms; 55 tree species were recorded.
  - Household labor was divided among all members of the family unit. Youth, women and men had different roles, adjusted according to the agricultural activities. There were some crops that were only managed by women, which was the case for malanga and medicinal plants. Commerce was in the hands of the men. Women were in charge of taking care of the household, children, food preparation, cleaning, and management of resources. Youth and children helped their fathers with ongoing activities on the farm.
  - Most of the families reported a lack of access to enough farm equipment to take care of maize, beans and cacao cultivation.

Thesis: Tree diversity and carbon storage in two sites with different degrees of intensification of land- uses in Nicaragua.

- **Context:** Deforestation and forest fragmentation caused by agricultural commodity production is a recurrent situation in the tropics. These changes in the landscape matrix have a negative effect on species diversity and the structural complexity of the vegetation surrounded by agricultural areas.

- **Challenge:** In human-induced landscapes, it is common to find arrangements of land- uses with tree cover, for example, secondary forest, scattered trees on pastures and/or cash crops. 'Trees on farmsfarms' are now part of the agenda of research institutes aiming to investigate the contribution of trees to the provision/maintenance of environmental services. Caicedo Albán (2016) studied the contribution of agroforestry systems to climate change mitigation through carbon capture and storage in aboveground biomass and tree diversity in two sites.

- **Methodological approach:** To evaluate the variation in taxonomic diversity and C stocks in agroforestry systems with a different state of agricultural development, 45 farms at each site and for six land uses were selected. The six predominant land uses sampled were: coffee plantations (CP), cacao tree (CC), hedges (H), staples grain (GB), pastures (PA) and home gardens (HG). Tree individuals with a diameter at breast height (dbh) ≥ 9.9 cm (≥ 4.8 cm in the case of *Citrus sp*.), were recorded. The aboveground biomass and stored C in the shade canopy (trees and palms) were estimated by allometric equations. The components of alpha and beta diversity were evaluated through various metrics.

- **Highlights: Tree diversity**
  - 171.6 ha in 344 plots were evaluated at the two sites. A total of 16,579 individuals of 235 woody species spread over 160 genera and 54 families were recorded. 183 woody species were identified in El Tuma-La Dalia and 195 in Waslala.
  - The composition and richness at the landscape level differed by sites and land use. In the El Tuma-La Dalia site, CP and H were more diverse and equitable than in Waslala, but the pattern reversed for CC, PA and GB, which were more diverse and equitable in Waslala than in the La Dalia site. The home gardens did not differ in diversity and equity between the two sites, showing intermediate levels among all land uses.
  - The floristic similarity between the two study sites was 60%, having 144 shared species. There was higher species richness in Waslala than in El Tuma-La Dalia. Accumulated species

richness, species richness per (ha) and diversity at plot level (Shannon, Simpson) differed only by land use.

Carbon storage

- CF had the highest C stored rate in aboveground biomass per hectare and was similar to CC and H, while GB had the lowest C stored in aboveground biomass.
- PT and PA showed intermediate values of stored C.
- Density and basal area of individuals had a strong impact on biomass, and therefore the stored C.
- The path analysis evaluating the effect of species richness and abundance of individuals on the stored C showed significant correlations ($p < 0.05$) for all land uses. The relationship between C stored in aboveground biomass and species richness of the shade canopy depended on the kind of land use.

Thesis: Effect of Hurricane Felix on seed-bat dispersals assemblage in the North Caribbean of Nicaragua.

- **Context:** Extreme climate events, such as hurricanes, have a negative impact on natural resources, infrastructure and communities' well-being, with huge economic and environmental losses. The estimated severity of the damage by Hurricane Felix to forest cover in the north Caribbean of Nicaragua was around 1,170,000 ha.

- **Challenge**: Forest recovery capacity depends on a combination of factors such as natural regeneration ability, seedlings banks found on the ground, and dispersal agents. These factors help in the structural recovery of the disturbed area. Bat guilds are one of the main seed dispersers and pollinators of the Neotropic. Here we described how hurricane-induced disturbance affected bat assemblage in a tropical forest, specifically, composition and richness of frugivorous bat, and the contribution of bats as disperser agents. Also, the association between palm diversity and the canopy-dwelling, frugivorous bat community is studied (disturbed vs. undisturbed).

- **Methodological approach:** The study was carried out in two types of forests according to the state of hurricane-induced disturbance: (i) heavily affected forest patch (>75% of the trees fallen, existence of pioneer seedlings and sprouting), and (ii) minimum disturbance (forest not affected by hurricane Felix, existence of 40 trees ha-1 with diameter > 60 cm).

- **Highlight**: *Bat composition and richness*
  - 19 bat species were found in the two types of forests: 9 species in the disturbed forest and 10 in the undisturbed forest. Bats belonging to Phyllostimidae and Verpertillionidae families were the most abundant.
  - *Carollia perspicillata, Carollia brevicauda, Artibeus lituratus, Chiroderma villosum, and Artibeus phaeotis* were the species with the most relative abundance in the perturbed forest (all of them frugivorous).
  - *Carollia perspicillata, Carollia castanea, Carollia brevicauda* (frugivorous), *Micronycteris brachyotis* (insectivorous) and *Uroderma bilobatum* (frugivorous) were the species with the most relative abundance in the undisturbed forest.
  - There were differences in terms of richness and abundance of bats in disturbed vs. undisturbed forest. In the first, a higher richness and abundance of bats were recorded than in the undisturbed forest.
  - According to rarefaction curve analysis, the likelihood of capturing a new bat species is higher in the undisturbed forest vs. disturbed forest.
  - According to functional traits (feeding habits and biometrics), four groups were identified:
    - Group 1. Identified as pioneer dispersers. Bats are small in size. They feed on seeds encased in ear-like structures. Three bat species belong to this group: *Uroderma bilobatum, Carollia castanea and Carollia brevicauda*.
    - Group 2. In this group, bats are small in size and feed on seeds that are in berry or ear-like fruits. The species

that comprise this group are, *Carollia perspicillata* and *Artibeus toltecus*. This group disperses seeds from pioneer and late species.
- Group 3. Formed by bats that are medium in size (i.e. *Chiroderma villosum, Platyrrhinus helleri* and *Artibeus phaeotis*) and feed on seeds that are in berry-pulp-like fruit. This group disperses seeds from late forest species.
- Group 4. Formed by bats that are large in size (*Artibeus lituratus* and *Artibeus jamaicensis*) and feed on seeds that are in berry-pulp-like fruit. This group is believed to be able to disperse seeds larger in size and from shade-tolerant species.

Palms and bat community

- A total of 10 palm species were recorded in both types of forests. The most abundant species in the disturbed forest were *Geonoma congesta, Reinhardtia gracilis, Asterogyne martiana* and *Geonoma deversa*. The most abundant species in the undisturbed forest were *A. martiana, Prestoea decurrens, G. congesta,* and *Bactris hondurensis*.
- Disturbed forests recorded higher palm species (9) and abundance in comparison to undisturbed forests (1).
- Undisturbed and disturbed forests were statically different. Undisturbed forest presented lower values of Shannon Index and lower abundance and richness of species and higher values for Simpson Index in comparison to disturbed forest.
- Sites with higher diversity and richness of palms are expected to have a lower richness of bats.
- In 12 palms of three species were roosts were set up. All of them in disturbed forests. Only in one of the roosts were seeds belonging to *Inga* spp.

Thesis: Evaluation of silvopastoral systems to increase livestock productivity in the dry corridor of Matiguas, Nicaragua

- **Context:** Livestock is a heavy player in the economy of Nicaragua. It is estimated that 12% of the country's GDP comes from the livestock sector. Generally, livestock is managed in extensive cattle production systems with low productivity and which have a tendency to increase the cattle population. Innovations and shifts in paradigms by cattle-ranchers are crucial to improve the management of grasslands. Silvopastoral systems are land uses that sustainably integrate pastures and woodlands to improve the productivity of the livestock systems.

- **Challenge:** Shade tree projection is an ongoing issue in the design of silvopastoral systems. The interaction of tree shade canopy and the herbaceous component of the system have been documented elsewhere, especially in terms of hydric stress, and availability and quality of the pasture. However, little is known about the effect of shade tree canopy (light transmittance and distribution) on pasture. Ayestas (2014) supported the decision-making process related to adequate density and tree species being established/managed in pasturelands. This information will help the design of sustainable silvopastoral systems in the region.

- **Methodological approach:** A tree inventory was carried out in 10 dual-purpose cattle farms with different land uses with tree cover. The selection of pastureland followed these criteria: presence of trees, contrasting conditions of tree structure and density and pasture productivity, grazing capacity in both the dry and raining seasons and similar managing conditions related to periods of grazing and non-grazing of the pastureland. The percentage of occlusion of the canopy was estimated using different methods/instruments.

- **Highlights:**
  - 2,419 trees (dbh > 5 cm) belonging to 47 species and 21 families were recorded in 25.5 ha. The most frequent type of flora in the pasturelands evaluated was *Paspalum conjugatum* for both seasons. Tree spatial arrangement in the pasture was

as follows: on 12 pastures, trees were arranged randomly with a neighboring index of 0.98. Six pastures had a dispersed spatial arrangement with a neighboring index of 1.41 and seven pastures had a cluster spatial arrangement with a neighboring index of 0.85.

- Three groups based on shade tree cover were formed: high, medium and low shade tree cover. The availability of pasture was statically similar in the three groups. There was an effect of shade tree cover over pasture availability for both seasons. Two models were fitted to predict pasture availability seasonally:
  $PA_{kgDM/ha}$ dry season = $51.63+3.97_{sc} - 0.13_{sc}$
  $PA_{kgDM/ha}$ rainy season = $239.15+ 4.84_{sc}+ 0.14_{sc}$
  Where:
  PA: Pasture availability
  DM: Dry matter
  SC: Shade cover (%).
- Tree density that can be accommodated in pasturelands according to seasonality is between 65 and 115 trees ha^{-1} without compromising pasture productivity.
- There was no difference in milk production simulation in relation to tree shade cover.
- Species that projected heavy shade were: Adelia barbinervis, Ficus spp., Simarouba amara, Cassia grandis. The species that projected a wider cover for the dry and rainy seasons were: *Guazuma ulmifolia, Albizia saman, Enterolobium cyclocarpum, Cassia grandis, and Lonchocarpus miniflorus*.

Thesis: Socioeconomic factors influencing tree presence on farms located in the Sentinel Landscape –Nicaragua

- **Context:** Trees on farms are valuable resources in the livelihoods of the rural poor. Great efforts have been made to document their role in agricultural areas in terms of coverage. However, more efforts are required to investigate the decision-making process behind the presence of trees on farms, especially in the context of deforestation and agricultural frontier expansion.

- **Challenge:** Halting deforestation processes in the tropics while promoting landscape restoration are key elements of the agenda of governments and aid/funding agencies, especially as they are seen as processes contributing to the achievement of sustainability of natural resources management. In the Sentinel Landscape in Nicaragua, the socioeconomic factors that influence the presence of trees on farms were evaluated (dos Santos Moreira, 2017).

- **Methodological approach:** This study was developed in two municipalities of the Caribbean north of Nicaragua. A participatory approach was developed, including semi-structured interviews of the families of the selected farms, focus groups, and participant observation to document the possible factors determining tree presence on farms.

- **Highlights:** There was a strong relationship between local livelihoods and trees, how farmers' perceptions influence tree farming on farms, and the relationship between security over land tenure and the presence of trees on farms. It is concluded that farmers attribute values, uses, and symbols to trees, according to their cultural, social, political, economic and environmental context.
  - There were several factors that influence the presence of trees on farms: the identity as a farmer; the attachment to family traditions; the worldview that trees are living beings and divine; the fundamental role that tree products play in the supply of wood, firewood, and fruits to families; the aesthetic and economic values that trees confer to the farms; the financial capital they represent as standing timber; and the ecosystem services provided by trees, as perceived by farmers.
  - The strategies and objectives of farmers in cultivating trees respond to the perceptions and needs generated by the context in which they live. For example, they choose the trees to be cultivated, the resources they are going to use, and define the

distribution of trees on the farm, according to the way they perceive them in their context. If farmers considered that some species are better than others (i.e. provide better shade, good quality wood, produce fruits, or to conserve the water), they will assign more resources and a privileged location in the farm. If a tree can alleviate some family needs, then the farmer decides to harvest it and take advantage of its financial capital. If there are trees that have emotional value, they are preserved. If they perceive them as living beings, they avoid cutting them.
  - Farmers cultivate trees regardless of formal security over land tenure.

Thesis: Climate change impact on coffee (*Coffea arabica*) agroforestry system productivity in Costa Rica and Nicaragua.

- **Context:** Assessment of climate change effects on coffee productivity has predicted negative outcomes for coffee cultivation. This is why the use of analytical tools such as crop simulation models is imperative in providing alternatives to manage coffee cultivation under changing climate conditions.

- **Challenge:** Crop modeling has proved to be useful in forecasting productivity under different conditions and management. CAF2007 is a basic dynamic process model for coffee agroforestry systems that includes coffee plant physiology and its response to different growing conditions. Integrated into a plot-scale model of the coffee plant and tree growth, it can simulate management practices such as spacing, thinning, pruning and fertilizing and coffee production rates under two management options: shaded coffee or full sun. The model requires calibration to reduce uncertainties in each simulated site and requires further validation of the obtained results. In this study, the CAF2007 model was calibrated within 12 plots located under three agro-ecological zones (Ovalle Rivera 2015).

- **Methodological approach:** The model was calibrated on 12 sites located in Costa Rica (8 sites) and Nicaragua (4 sites). Different management practices (i.e. fertilization, pruning, tree type, coffee under full sun, thinning) were included in the model (inputs). Outputs of the model were validated using data from a plot in Nicaragua (Hammonia coffee farm). The parameters to run the model are 104, of which 70 are calibrated. The plots were located in three agroecological zones: Zone 1 with a dry-cold climate, Zone 2 with a cold-humid climate and Zone 3 with a hot-humid climate. A simulation of climate change effects on coffee productivity was carried out on three calibrated plots (the previous step of the study); one plot in Nicaragua was managed in full sun conditions and conventional practices and two shaded plots in Costa Rica were managed under the shade of *Terminalia Amazonia* and *Erythrina poeppigiana* and medium conventional practices.

- **Highlights:** An annual temperature increase of 5°C will affect annual production of both systems, shaded coffee and full sun coffee. Coffee system plots growing in full sun conditions will reduce their productivity by 40%. A reduction between 18% and 27% is expected in shaded plots of *Terminalia amazonia* and *Erythrina poeppigiana*, respectively. Lower precipitation will affect positively or negatively coffee yield depending on the local conditions and the reduction of rain. For example, in one of the plots managed in full sun and growing in a hot-warm climate, a reduction in annual precipitation of 763 mm will decrease yield productivity by 76%. Meanwhile, a plot located in a site where annual precipitation values are above the optimum for coffee cultivation, a reduction in precipitation can have a positive effect on productivity. An increase of CO_2 levels can have a fertilization effect on the coffee plants increasing estimated average yields. *Climate change scenarios for coffee yields*: In a simulation of coffee yields managed under the canopy of *Terminalia Amazonia*, medium conventional practices and using the climate scenario of the global circulation model MIROC5 with CO_2 levels of 380 ppm and RCP 8.5, coffee yields will be

reduced by 18% and an increase in yield in 10% is expected with an increase of CO_2 levels of 541 ppm.

Thesis: Drivers of land-use change and carbon storage capacity along a gradient of human-induced landscapes in Nicaragua

- **Context:** Deforestation in the tropics can be explained by proximal and underlying causes. The first group includes agricultural expansion, infrastructure development and timber extraction. The latter is related to the synergies among economic, technological, social, demographic and institutional variables. Research focus in terms of land uses and land cover changes is on the improvement of monitoring systems, forest transition processes/drivers and the modeling of future scenarios using multi-temporal analysis.

- **Challenge:** The use of radar remote sensing in the last few decades has demonstrated its usefulness in highlighting the rapid decline of forest in the tropics. Recent studies have proved the capacity of remote sensing, especially ALOS PALSAR, to estimate the distribution and quantity of aerial biomass in different kinds of forests, including forests under heavy clouded conditions. Even if the approach has gained some momentum in forest monitoring, its application is still limited in the tropics, due to the cost and lower geographical cover area. Here, an estimation of biomass and carbon stock in a coniferous forest and a tropical broadleaf forest using radar remote sensing data is presented. Also, drivers of tree land cover and land-use changes in a gradient of modified landscapes are analyzed using spatial modeling techniques.

- **Methodological approach:** The current study was carried out in Nicaragua in seven municipalities belonging to three ecological zones. The study area is hypothetically located along a gradient of human-induced activities that can be accommodated in the forest transition curve to explain the dynamics of deforestation/degradation of tree cover. A model forecasting land-use and tree land cover change over time (e.g. 2030) was built using Dinamica EGO software. A series of biophysical variables and land-use/tree cover maps for 2000, 2008 and 2014 were used in the modeling process. Images from ALOS PALSAR for 2008 and 2009 were analyzed using L band wavelength and the HV polarization technique to predict aboveground biomass and carbon stocks in two types of forests.

- **Highlights:** Dinamica EGO software permitted the successful modeling of land-use changes for 2030 in three agroecological zones of Nicaragua. This process also provided the annual transition rates of the land uses and the weights assigned to each of the variables included in the modeling process. There was evidence to support the existence of a forest transition curve in the area of study and a lower rate of forest recovery was observed. The forest transition curve begins with the presence of forests in Puerto Cabezas and Rosita, diminishing its presence towards the municipalities of Waslala and Siuna. The forest in these municipalities is being replaced by pasturelands. The recovery phase of the curve at a slow pace is located in some areas of Rancho Grande, El Tuma-La Dalia, and San Ramón. It seems that the presence of vast coffee agroforestry systems influences the increase in forest cover. There was a direct relationship between forest cover loss and pastureland increase. Forest cover loss was a consequence of migration during the agrarian reform and the increase of population.

  The results of the current study suggest that L band from ALOS PALSAR successfully predicted aboveground biomass for both coniferous forest (at any tree density) and broadleaf forest (density above 160 trees/ha). A strong relationship between aboveground biomass and the coefficient of retro-dispersion of HV polarization demonstrated that this methodology is a viable alternative to estimate aboveground biomass. Three factors influence the correlation between radar signal and aboveground biomass estimation: tree density, forest homogeneity/heterogeneity and topography. For example, in broadleaf

forests it was found that with a higher tree density in 0.5 ha plots, a higher correlation with retro-dispersion coefficient of the radar signal is expected.

Thesis: Socioeconomic potential of secondary forest management: Tree cases from Central America

- **Context:** Tropical secondary forests are defined as those resulting from human disturbance (i.e. logged forest and forest fallow). Secondary forests are extensive in the tropics. In Central America, the extension of secondary forests (broadleaf and pines) is 6 million ha. Several studies have highlighted their potential of management and their contribution at the socioeconomic level. However, little is known of the economic potential of secondary forests in Central America.

- **Challenge:** In Central America, there have been experiences in the management and harvesting of secondary forests in several locations. This represents an opportunity to document the economic potential of secondary forests to landowners and the influence of forest legal frameworks and policies in their management.

- **Methodological approach:** This study was carried out in three countries of Central America. The cases selected for the study were based on the recommendations of key stakeholders of the forestry sector in the region. Semi-structured and open interviews were conducted with relevant key informants from each of the cases selected, to gather relevant information about secondary forest management. Also, secondary information such as forest management plans, laws, decrees and regulations were reviewed. The economic-financial sustainability of the activity was evaluated using Internal Rate Return, Net Present Value, cash flow values, and sensitivity analysis for each case.

- **Highlights:** Only the case in Costa Rica was profitable; that is, all the costs, including legal requirements, were covered by the activity. In Nicaragua and Honduras, the cases studied presented negative profitability indexes (the income generated by the activity did not cover all the incurred costs). The higher costs were due to legal requirements that need to be met in order to manage and harvest the secondary forest. The same regulation and processes apply for mature forests and for secondary forests, leading to a long and exhausting process negatively affecting the profitability of the activity. Also, low timber prices in the national market influenced the negative profitability of the activity. However, landowners found that management of secondary forests is a way to protect the properties from illegal occupation, as well as income generation and family labor hiring.

Thesis: Agroecological practices to increase productivity and food security in home gardens in Central Nicaragua

- **Context:** Agroecology is the field that combines agricultural practices and ecology to solve the most pressing issues around food production. Identification and implementation of agroecological practices bring about numerous social and productive benefits.

- **Challenge:** Implementation of agroecological practices in home gardens can improve the biophysical and socioeconomic conditions of the system and aid in securing food for the family. Studies on the effectiveness of agroecological practices in home garden production are limited. In this study, the agroecological practices found in home gardens were documented and prioritized based on the screening of the suitability of these practices to increase productivity and nutrition.

- **Methodological approach:** Thirty home gardens were characterized, and agroecological practices were prioritized to secure sustainable production. Each practice was evaluated based on criteria developed by farmers, practitioners and researchers, such as agronomic and economic feasibility, adoptability and their potential contribution to climate-smart systems.

- **Highlights:** According to the characterization of the home gardens, 42 crop species, 28 fruit plants, and 10 animal species were recorded. The majority of home gardens (85%) did not include agroecological practices in their management system, such as crop rotation and crop association, seed storage and the use of beneficial plants or organisms. Four agroecological practices were prioritized (higher score), two practices related to fertilization management: compost application and vermiculture and the other two practices were about pest management, based on a botanical extract from *Gliricidia sepium* leaves in combination with either *Psidium guayava* leaves, garlic or chile. However, the validation experiments established to evaluate the effect of the four practices on carrot and cabbage performance (crop height at 30 and 60 days after being sowed, and weight at 100 days after harvesting), indicated that the practices were statistically similar to a control. The reasons why the practices did not yield differences were crop mortality (90% of carrots and 30% of cabbage loss) due to excessive rain and floods.

Thesis: Economic assessment of silvopastoral systems and good livestock practices to improve climatic resilience of small-scale milk farms in the municipality of Olanchito, Yoro, Honduras.

- **Context:** Honduras, like other Central American countries, is vulnerable to the effects of climate change. Livestock is a dominant production system across rural Honduras, and especially in Olanchito municipality, Yoro. Traditionally, cattle ranchers in Yoro put in place several silvopastoral systems (SPS) and other best agronomic practices (BAP) and infrastructure measures (BIM) to make livestock a more sustainable and profitable activity in the long term. However, the role of SPS, BAP and BIM as effective and resilient climate change mitigation/adaptation strategies has not been fully assessed country-wide.

- **Challenge:** There is a lack of up-to-date data/information regarding the suitability, reliability and economic feasibility of SPS, BAP and BIM as effective measures for climate change mitigation and to elucidate whether livestock is resilient enough to overcome future climatic scenarios.

- **Methodological approach:** Dominant SPS, BAP and BIM were documented via participatory workshops conducted at different elevation areas (high, medium and mountainous) across the municipality. Semi-structured interviews were used to gather information regarding SPP and BAP measures implemented at the farm level in order to identify and prioritize aspects of productivity, adaptation and mitigation actions. A comparative economic analysis was also done to assess the financial and environmental performance of ranked SPS, BAP and BIM among farmers' typologies (small and medium) and elevation area (high, medium and mountainous).

- **Highlights:**
  - A total of 22 practices were identified and implemented by > 20% of producers with an age of use > 5 years.
  - A subset of 10 practices was prioritized by farmers including cutting pastures, improved pastures, live fences, genetic improvement, clean milking, division and rotation of paddocks, silage, adequate space for agricultural products, milking rooms and water crops.
  - Half of the sample in this study was ranked to further perform the economic assessment among farms.
  - Economic assessment by typology showed that all farms (n=17) were profitable. However, best practices performed better for small farms, as is evidenced in the net flows that were higher compared to medium farms.
  - Financial analysis by agroclimatic zones showed positive values across farms and practices, yet those located in middle areas had a higher net present value per hectare and a moderate capacity for re-investment.
  - Financial analysis by type of practice showed that farms with SPS were the most profitable with greater net gain/ha, higher financial performance and high capacity for re-investments.

10.2 Q2: Magnitude of the stock and rate of change of the presence of trees and forest in the landscape and on-farms?

Thesis: Carbon storage and household benefits in small coffee farms in Nicaragua

- **Context:** Arabic coffee represents 63% of the worldwide coffee market and is of upmost importance in the economy of several tropical countries, especially in Central America. In Latin-America, 90% of coffee is produced under the shade of trees. Several studies have pointed out the importance of coffee agroforestry systems in the livelihoods of coffee farmers and businesses and in the provision of ecosystem services (i.e. biodiversity conservation, carbon storage, and water and soil conservation).

- **Challenge:** Understanding the synergies and trade-offs of ecosystem services (such as coffee production, tree benefits, carbon storage, food production and water management) is key to improving their management. There are qualitative models that show the synergies between carbon storage and coffee profitability, where it is possible to obtain high profitability and carbon storage if the selection, planting and management of shade trees is optimized. In this study, the relationship between two key ecosystem services: agroforestry production (estimated as household benefit) and carbon storage (regulation) in coffee farms with different shade compositions, was studied.

- **Methodological approach:** 27 coffee farms were evaluated and grouped according to the type of shade systems. C1: sun-grown coffee; C2: coffee + musaceae + leguminous trees; C3: coffee + leguminous trees + timber trees; and C4: coffee + leguminous trees, timber trees+ fruit trees and musaceae. Carbon storage in the aboveground biomass and the yields of agroforestry produce (coffee, fruits, bananas, timber and firewood) were estimated. The value (income and self-consumption) of coffee agroforestry was estimated using three economic indexes: net cash flow, net income and household benefit.

- **Highlights:** Carbon storage capacity varied from 7.8 Mg/ha in open sun-grown coffee systems to 35 Mg/ha in coffee agroforestry systems with diversified shade canopy. Trees stored 74% of the carbon (19. 6 Mg C/ha) of the system, followed by coffee plants with 19% (4.9 Mg C/ha) and musaceae with 7% (1.9 Mg C/ha). Agroforestry produce contributed positively to net cash flow, net income and household benefits. Coffee was the product that provides the most revenue in comparison to other agroforestry produce. The latter is an important component in household benefit estimation (self-consumption). Two of the coffee systems studied (C3 and C4 coffee agroforestry systems) could provide both ecosystem services, indicating synergy between the two environmental services.

Thesis: Contribution of trees on farms to the livelihoods of rural families from two contrasting sites of Nicaragua

- **Context:** Rural development is essential to both improve the quality of life of the rural population and for natural resource conservation. Agroforestry is a sustainable alternative for rural development and it is a conspicuous element in the agricultural landscape. Recent estimation of agroforestry extension is 1 billion ha. Trees on farms can contribute to subsistence farmers' strategies to face climatic or socioeconomic eventualities and can supply important goods to meet farmers' demands.

- **Challenge:** Socioeconomic studies are important to quantify the share of agroforestry systems in the profitability of the farming system. This study assessed whether the contribution of trees on farms varies in two sites (La Dalia and Waslala) with contrasting agricultural histories, market access and population densities, and history of land tree cover.

- **Methodological approach:** 90 farms were studied, 45 farms per contrasting site. On each farm, five land uses were evaluated: cacao, coffee, pasture, home gardens and staple crops. Four groups of variables

were recorded: tree diversity and density, basal area, tree production (timber, fruits and firewood) and the economic benefits (sales and household benefit) supplied by trees.

- **Highlights:** Study sites were similar in terms of tree diversity and density, but differences were found in the economic benefits provided by trees. A total of 261 tree species were recorded in both sites (160 species were shared), 202 species in La Dalia and 220 species in Waslala. In terms of land uses, coffee was the land use with the highest tree diversity (197 spp), followed by pasture (189 spp), cacao (169 spp), home gardens (152 spp) and staple crops (138 spp). The most important species in terms of their abundance, frequency and relative dominance were: *Cordia alliodora, Mangifera indica, Persea americana, Citrus sinensis, Platymiscium dimorphadrum, Inga oestediana, Psidium guajava, Cedrela odorata, Guazuma ulmifolia,* and *Tabebuia rosea.* At the plot level, the land uses with higher tree diversity were coffee and cacao agroforestry systems, whereas staple crops were the land use with the lowest value in tree diversity. Coffee, cacao, pasture and staple crops showed higher similarity in botanic composition (70–90%) while home gardens was the land use with a higher ecological distance (30–50%). Coffee and cocoa agroforestry systems recorded the highest tree density (138 and 79 trees/ha, respectively) and staple crops the lowest (30 trees/ha).

  The tree products with a higher frequency of use by families on both sites were timber, fruits, firewood and posts. Fruit and firewood were the produce harvested by almost all the interviewed families (97%). Therefore, these products had a larger share in the household benefit estimate. The household benefits of tree produce were higher in coffee and cocoa agroforestry systems (USD 268/ha/year and USD 242/ha/year) followed by pastures, home gardens and staple crops. At the farm level, household benefits can reach up to USD 550/ha/year. This study demonstrated that tree produce is an important strategy of rural families to improve living conditions through food security and saving.

Thesis: Contribution of home gardens to food security and nutrition of families working with the Mesoamerican Agroenvironmental Program in Trifinio and north-central Nicaragua

- **Context:** Climate change, low income, lack of access to good education and poor natural resources management, among other issues, threaten food intake and the nutritional quality of foods. Climatic events, such as droughts, are a recurrent phenomenon in Central America. Therefore, the development of strategies to adapt to these threats are of importance to protect people and communities that live under these conditions.

- **Challenge:** Diversification of food production, the introduction of trees on farms, and crops resistant to drought are part of the strategies introduced to fight changing climatic conditions. The current study determined the diversity of food produced on home gardens and their contribution to the food security and nutrition of the families that rely on them.

- **Methodological approach:** 329 families were interviewed in 2013 to establish a baseline and in 2015 to monitor changes. The Shannon Index was calculated to determine food diversity in the home gardens. The food consumption score (FCS) was used to compare the nutritional quality of food consumption in 2013 and 2015 in Nicaragua and Trifinio.

- **Highlights:** Home gardens are a source of different types of foods for both groups of families (Nicaragua and Trifinio), whether for a few months or all year around. For example, vegetables rich in vitamins, folic acid and minerals were available for families in Nicaragua; but this was not the case in Trifinio, where this group of food was severely affected by the drought event in 2014. The richness of diet by food group had a better scenario in Nicaragua in comparison to Trifinio. This is due to the harshness of the environmental conditions in Trifinio. An increase in food richness in the leguminous group, which is a good source of protein, micronutrients and dietary fiber, was noted. The groups of foods such as meat and dairy

products were the most affected by drought. The quality of the diet measured at two different times, using the FCS index, showed that families in Nicaragua had a superior diet quality in comparison to the Trifinio group, the latter classified in the category of low consumption of food and low-quality diet.

Families in Nicaragua eat a higher number of food groups in comparison to the families in Trifinio; this means that families in Nicaragua have a more diversified diet and better food consumption.

Thesis: Density and diversity of nematodes in coffee agroforestry systems grown under the shade of bananas and leguminous trees in Jinotega, Nicaragua

- **Context:** The coffee sector in Nicaragua represents 3.5% of its gross domestic product (GDP), and green coffee is the country's eighth most exported product. Around 130,000 ha are cultivated with coffee, of which, 77,000 ha are under the shade of banana and timber trees. Bananas are planted as temporary shade in coffee agroforestry systems and are an important source of income for farmers, especially in times of low coffee prices.

- **Challenge:** Several studies have reported the effect of nematodes in coffee production. However, there are uncertainties about the relationship between banana cultivation in coffee and an increase in the density of nematodes in shaded coffee plantations. The current study examined nematode incidence in the coffee-banana system.

- **Methodological approach:** The study was conducted on 28 farms. Four systems were evaluated per farm: coffee-banana-legume (CBL), coffee-banana (CB), coffee-legume (CL) and coffee in full sun (C). Samples of soil were taken for nematode identification and physical-chemical analysis (% litter, % weed and % shade, and soil bulk density). Roots of coffee and banana plants were also examined.

- **Highlights:** A total of 11,663 nematodes were identified in the soil samples, belonging to 14 families and three genera. They were divided into four trophic groups: bacterivore, omnivores, fungivores, and phytonematodes. No significant difference was found among the different trophic groups between systems. Nematodes presented a high population density in both the roots of banana and coffee. *Meloidogyne* J2 had a higher density in the systems where bananas were absent (CL and C). The genus Pratylenchus in banana had a higher population density in the CB treatment, while *Meloidogyne* J2 in banana roots was higher in the CBL treatment. There was a significant positive relationship in bananas between root damage and the presence of *Meloidogyne* and *Helicotylenchus*, and total of nematodes found in banana roots.
  - The genus *Pratylenchus* in banana roots presented a negative significant relationship with *Pratylenchus* in coffee roots and a positive relationship with *Meloidogyne* in coffee roots. The phytonematodes in coffee and bananas roots, despite being of the same genus, exhibited different relationships with the physical and chemical characteristics of the soil, this could indicate that they do not belong to the same species.
  - The genus *Pratylenchus* in coffee increased in the CBL system, while in banana Pratylenchus decreases under that combination. The *Meloidogyne* J2 in coffee decreases when there are more bacterivores in the systems with a greater diversity of plants, while in banana *Meloidogyne* J2 increases in those systems.
  - Soil food web parameters were estimated and no significant difference was found between the different systems and indices of the soil food web, except for the ratio predator footprint and target prey on the CB system, which was significantly different from that of the other three systems.

Thesis: Dynamic of growth of *Swietenia macrophylla* and *Carapa guianensis* in a forest of the North Caribbean Region of Nicaragua, using dendroecological techniques: A contribution to sustainable forest management

- **Context:** Tropical forests in the Caribbean Region of Nicaragua are an important source for economic growth and well-being of the indigenous communities that rely on them to survive. Studies on anatomy, ring analysis and phenological relationship in tropical forests in Latin-America are limited, and fewer studies were found for the Meliaceae family with regard to the use of ring analysis to describe its growth and ecology.

- **Challenge:** Indigenous communities in the North Caribbean of Nicaragua require information regarding the growth dynamic of valuable species that would help them in the decision-making process in the short and medium term to improve forest management. This study describes a methodology using ring analysis as a tool to improve the sustainable management of two valuable forest species.

- **Methodological approach:** This study aims to contribute to community forestry management at two forest sites, Butku and Layasiksa, using a dendroecological approach that describes the growth dynamic of two forest species *Swietenia macrophylla* and *Carapa guianensis*, in relation to climatic factors. 18 *Swietenia macrophylla* trees and 42 *Carapa guianensis* trees were examined. The research established the dynamics of growth of both species, beginning with the validation of the annual rings.

- **Highlights:** 27 and 24 synchronized and correlated series were obtained for *Swietenia* and *Carapa*, respectively. These synchronizations provided chronologies and a ring width index that was afterwards correlated with precipitation and temperature. There was no significant relationship between diameter increment and temperature or precipitation. The environmental conditions of both sites were in the range of the conditions described for the species in the area of their natural distribution. In terms of soil conditions, the parameters evaluated for *Swietenia* had similar values as the ones established for the species by researchers. The soil growing condition for Carapa was similar to the conditions found for *Swietenia*.
  - Ring tree analysis of *Swietenia macrophylla* established a mean annual increment of stem diameter of 5.8 mm and of 4.8 mm for *Carapa guianensis*. Modeling of the pattern of diametric increment allowed the definition of rotation times and felling cycles. For *Swietenia macrophylla*, the harvest period is between 65 and 85 years, at which the tree can reach stem diameters between 40 and 65 cm dbh, respectively. For *Carapa guianensis*, the rotation and felling cycle is between 70–122 years, in which trees can reach stem diameters of 40–70 cm dbh.
  - The models developed based on tree ring width analysis demonstrated discrepancies with the minimum cutting diameters (MCD) established by technical standards. The MCD of 40 cm fixed by Nicaraguan technical standards for *Carapa guianensis* is not appropriate, because diameter estimations, based on biological criteria, desirable for harvesting are higher (50 cm). On the other hand, the MCD of 50 cm for *Swietenia macrophylla* is in the range considered biologically desirable.
  - The inter-annual variation in precipitation and temperature in the study area was not correlated with growth diameter of the two species, probably due to the short duration of the annual dry period.

Thesis: Estimation of carbon storage in aboveground biomass in three forest landscapes of Central America and its relationship with environmental factors

- **Context:** Most of the studies on biomass and carbon storage in different land-use arrangements in Costa Rica and Nicaragua do not consider the effect of environmental conditions on the biomass and carbon stocks of the ecosystems.

- **Challenge:** Tropical forest conservation and management are one of the nature-based solutions to reduce and capture

CO_2 from the atmosphere. Reducing emissions from deforestation and forest degradation (REDD+) is a financial mechanism available to developing countries to strengthen forest governance and forest conservation emissions reduction from deforestation. Costa Rica and Nicaragua have developed their REDD+ strategies. However, to design and evaluate these strategies, methodologies for measuring, quantifying and monitoring variation in carbon fluxes are necessary. Therefore, with this research, relevant knowledge on carbon storage and its relationship with environmental conditions was provided, using data from permanent and temporary measuring plots of three forest landscapes in Central America.

- **Methodological approach:** Three forests were selected, two in Nicaragua (Maderas and Mombacho volcanoes) and one in Costa Rica (Talamanca mountain range). The forests are located at different altitudinal locations. Eighteen measuring plots (0.25 ha) were established/monitored in volcanoes Maderas and Mombacho across an altitudinal gradient from 437 to 1,157 m above sea level (masl), and 27 permanent measuring plots across in Talamanca in an altitudinal gradient between 400 and 2,810 masl. All trees with a diameter and breast height (D) > 10 cm were measured. In Nicaragua, aerial biomass estimates were calculated using the equations of Chave et al. (2014), which include the use of variables D, wood density (ρ), and total tree height (H). In Talamanca, a combination of equations (Chave et al. 2005, Alvarez et al. 2012 and Goodman et al. 2013), which include the use of D and ρ, were used. Carbon was estimated using a factor of 0.5.

- **Highlights:** Three types of forests were identified in Mombacho volcano, similar to the Maderas volcano, based on the abundance of tree species recorded in the plots. Four types of forest were identified in the Talamanca mountain range. The relationship carbon and altitude can be positive or negative and is influenced by the frequency and severity of natural disturbances. Linear regressions suggest a negative linear relationship between carbon and altitude in the altitudinal gradients evaluated in Nicaragua, and between 440 and 1,120 m in Talamanca. However, a positive linear relationship between carbon and altitude was found between 1,400 masl and 2,810 masl in Talamanca.

  No relationship was found between edaphic variables and C in the Mombacho and Maderas volcanoes. In the Talamanca mountain region, a negative linear relationship between K, Ca, Mg and pH with carbon, and positive linear relationship between P and silt with carbon were found.

  In this study, no individual environmental parameter influenced carbon storage, but an effect of a set of environmental parameters over carbon was proved. In Maderas volcano the partition of the variance suggests a joint effect of the altitude above sea level and spatial variables on carbon variance, explaining a 25% variance of carbon. In Mombacho volcano, it was not possible to find an effect for most of the environmental variables studied. The partition of the variance only found a relationship with altitude. In Talamanca, a joint effect of the annual mean temperature, edaphic and spatial variables was found, which explains 3% of the C variance.

Thesis: Validation of GAVILÁN model: A tool for the management and research in tropical rainforests of Central America lowlands

- **Context:** Worldwide, around 510 million ha of forest are under the category of production for timber; in Central America, 2.1 million ha are in this category. Therefore, effective tools to plan optimal cutting rotation and population dynamics of a tree stand are essential in forestry governance and management.

- **Challenge:** The use of models to simulate different silvicultural interventions in forests has become a useful tool in the decision-making process of forest management. This type of technique reduces the time

needed for the elaboration of a forest management and harvesting plan. In this study, a model forest dynamic of *Pentaclethra* in a lowland rainforest of Costa Rica to support the sustainable forest management of this species was validated.

- **Methodological approach:** Gavilán is a model that is based on the theory of gap dynamic developed by Shugart (1984) and Botkin (1993) and builds on the approach of individual trees recognized as suitable for the simulation of more complex forests, and the effect of silvicultural treatment on stands and tree dynamics. In the model, five groups of species can be determined based on growth rate: very slow growth species, slow growth species, moderate growth species, rapid, and very rapid growth species. To validate the model, a database from six permanent measuring plots (PMP) was used. These PMPs were measured from 1993 to 2010. Gavilán can model the effect of silvicultural intervention and harvesting on regeneration, growth, mortality, future harvesting, diversity and composition of the forest.

- **Highlights:** The results confirm that the Gavilán model shows good performance and that it can be used for both long-term research and sustainable forest management. The model presented a low to medium percentage of error for basal area, number of individuals and mortality. Even though the model presented an atypical mortality rate in the first year, this result does not affect the overall accuracy and performance of the model as a tool for forecasting forest dynamics. The error associated with atypical mortality seems to be related to the underestimation of independent-density causes and an overestimation of the dependent-density causes of mortality. These measurements can be improved through the optimization of the parameterization of the model.

10.3 Q3. Consequences of changes on trees/forests in landscapes/farms on the provision of Environmental Servicesenvironmental services

Thesis: Catalysts and constraints in the provision of hydrological ecosystem services on cattle farms in a small watershed of the Bulbul River, Matiguás, Nicaragua

- **Context:** In Nicaragua, most watersheds are facing a drastic reduction of tree cover due to agricultural activities. Deforestation in Nicaragua is one of the biggest environmental issues. According to the World Forest Watch, Nicaragua has the second highest rate of deforestation in Central America. This issue has several negative effects on the provision of ecosystem services, for instance, water availability for human consumption/farming use as a result of sedimentation of water bodies.

- **Challenge:** In the municipality of Matiguás, rural populations depend on superficial water bodies to meet their needs for water. In this region, livestock is the most important land use; therefore there is a necessity to increase or maintain tree cover in pastureland as a means to secure hydrological ecosystems services to the community. The present study analyzed the feasibility of the provision of hydrological ecosystem services in silvopastoral systems.

- **Methodological approach:** 23 cattle farms were selected to establish the baseline of current land uses in the area of study. Based on an index of land uses for cattle-ranching proposed by Alpizar & Madrigal (2005), a set of improved land-use practices was proposed to increase the likelihood of the provision of hydrological ecosystem services (HES). Limitations and catalysts for the implementation of improved land-use practices were documented as a means

to identify possible incentives that could increase the likelihood of implementation of new practices on cattle farms.

- **Highlights:** The predominant land uses in cattle farms were silvopastoral systems (65%), in comparison to pasturelands with no trees (12%). Most cattle farms with scattered trees in their pastures have low tree density (66% of cattle farms, < 30 trees/ha). Forty-one percent of the cattle farms studied managed improved pasture in their pastureland. According to the hierarchical analysis, based on the contribution of the land uses on the provision of HES, the best practices identified to improve HES delivery were: (i) improvement of pasture, (ii) planting trees in pastures that have no trees, and (iii) increased tree density in silvopastoral systems.

  Farmers indicated that for them, the economic benefits perceived from agricultural activities are more important than the provision of ecosystem services by the farm. At the policy level, the formulation of a package of monetary incentives is imperative, especially for small cattle ranchers (< 15 ha and less than USD 1,000/ month of gross income). Also, in-kind incentives, such as inputs supply, are of importance for medium cattle-ranchers (< 25 ha and less than USD 4,000/month of gross income). The incentive package needs to be accompanied by an awareness campaign on the importance/value of natural resources management in the general well-being of the farm and community. In the case of large cattle ranchers (> 50 ha and USD 4,000/ month of gross income), they have a positive attitude to manage trees on their farms, as they recognize the importance of the trees in the provision of benefits (economic growth/ in-kind goods).

Thesis: Hydrological analysis under a scenario of climate and land-use changes in the watershed of the river Compasagua, Nicaragua

- **Context:** Recent studies on the effect of climate change in Nicaragua determined that water availability will be diminished by 2100 by 63% if the business-as-usual model persists in the decision-making process of stakeholders. On the other hand, the quality and quantity of water are affected by agricultural activities (land-use change).

- **Challenge:** Understanding historic scenarios of land-use changes is key to acknowledge the link between socioeconomic processes and natural resources management. The use of technologies such as remote sensing and stochastic models, provides reliable tools for the forecasting of future land-use changes. In this study, changes in land use and climate change in the Compasagua watershed, Muy Muy, Nicaragua and their impacts on the components of water stability and erosion were evaluated.

- **Methodological approach:** Future land-use maps for 2030 were modelled using Markov chains and cellular automata to evaluate the matrix transition and change in trends in land use. The hydrological analysis was performed by applying the Soil and Water Assessment Tools (SWAT) built into the ArcGIS (version 10) software. For this analysis, 10-year period climate data (2000–2010) recorded by the Nicaraguan Institute for Territorial Studies (INETER) was used. The climate change models used were GFLDR30, ECHAM4, and HADCM3 simulated under a pessimistic scenario (A2).

- **Highlights:** The spatial dynamic analysis of land uses showed that changes in land use occurred during the periods of analysis. For example, a reduction in dense forest area of 31% occurred between 1981 and 2010. The highest change in land use was from open pastures to pasturelands with scattered trees: by over 700% of the area for the period 1981–2010. In the case of secondary forest, 43% of the area has been shifted to other land uses while the remaining 53% was maintained as forest, in the period 1981–2010.

  Comparing maps from 2010 with the projected map for 2030, the area of pasturelands without trees will be reduced by 37%, whereas pasturelands with scattered

trees will increase by 21%. Secondary forest will increase in area of 30%, while dense forest will decrease in area of 16%.

Notwithstanding that these changes in tree cover dynamics drive an improvement in the hydrological conditions from 2010 to 2030, it is still a sensitive issue because some hydrological components such as groundwater recharge, runoff and erosion are more sensitive to climate change than to changes in uses of the land. According to the simulation exercise, small changes in temperature and precipitation severely affect the amount of water produced in the watershed, between 49% and -25% compared to scenarios without climate change. When analyzing the impacts of climate change with the proposed management scenarios (best farming practices in the watershed, the ecologic and economic zonification-EEZ), it showed a decrease in sediment deposition by 39% based on the land uses forecasted for 2030.

According to this study, climate change will have the same impact with management scenarios (EEZ) and without management, but with the implementation of ZEE practices, better conditions for mitigating the effects of erosion and water risk production management can be obtained. Therefore, the design of strategies to mitigate climate change should be complemented with the management of water resource practices to aid in the adaptation to unfavorable climate conditions, such as a reduction in precipitation as predicted by HADCM3 and ECHAM4 models.

Thesis: Genetic diversity of *Cedrela odorata L.* in an agricultural matrix in the Nicaragua-Honduras Sentinel Landscape and its implication for forest restoration

- **Context:** Degradation of natural forests is an ongoing issue in tropical countries. Between 2010 and 2015, around 6.6 million ha of natural forests were lost annually. At the national level, Nicaragua reported annual losses of natural forest of 85,329 ha. As of 2008 forest cover was only 25% of the national territory.

- **Challenge:** As a result of deforestation processes, landscapes are a mosaic of land uses comprised of forest patches (original, secondary and riparian) inserted in a matrix of agricultural activities and pasturelands. Forest fragmentation causes isolation and negatively affects the patterns of genetic flux, structure, and diversity of a population. Valuable species such as *Cedrela odorata* are overexploited in their areas of natural distribution (found in areas outside forest patches), and could be an option to increase the gene flux and maintain the genetic variability of the remaining populations, as has been reported for other vulnerable, valuable forest species. This study examined the extent of genetic variation of *C. odorata* in a fragmented landscape.

- **Methodological approach**: 164 trees were sampled in an area of 50,000 ha. Trees selected were distanced at least 100 m from each other. The genetic diversity of *C. odorata* was studied based on 10 microsatellite molecular markers (simple sequence repeats-SSR). The genetic analysis was carried out in the Laboratory of Molecular and Cell Biology at the University of Life Sciences, Prague.

- **Highlights:** Overall, in the whole population a total of 189 loci were found, with an allelic richness of A = 18.90. The level of expected heterozygosity (He = 0.76 ± 0.01) was almost double than the observed heterozygosity level (Ho = 0.4 ± 0.04), indicating a deficiency in heterozygosis at the individual level in the studied population. Trees with dbh > 60 cm were more diverse (15.15 allele per loci) than trees with dbh < 60 cm (14.11 alleles per loci) with F_{ST} values of 0.03 and P = 0.01. Tree provenance (natural regeneration or planted trees) showed similar levels of genetic differentiation; however, trees from natural regeneration were more diverse than planted trees.

  Genetic differentiation analysis by land-use category showed small genetic differences in the population (F_{ST} 0.026, P = 0.001). The phenological analysis showed higher values for F_{ST} (0.052, P

= 0.001), indicating that the vegetative phase presented higher allelic richness than the reproductive phase (14.74 and 13.47 respectively). However, these genetic variations were small; therefore, neither land use nor phenological phases can influence genetic divergence in the population.

Three subpopulations of *C. odorata* were identified with different levels of genetic diversity. Subpopulation A and B were significantly more diverse than subpopulation C. Phenotypic and environmental variables that presented a similar tendency to the genetic traits were phenology and altitude. For example, subpopulation C had a higher number of individuals in reproductive stages, was located at a slightly lower altitude and showed the lowest genetic diversity values. Subpopulations A and B had an almost 50/50 ratio of individuals in reproductive and vegetative phases, and were located at a higher altitude and presented the highest levels of genetic diversity.

10.4 Q4: Concepts and models needed to optimize the presence of trees/forest in landscapes/farms to secure a sustainable provision of ecosystem services

Thesis: Local adaptation to climate change through territorial strategic planning in the community of Wasaka Abajo, Municipality of El Tuma-La Dalia, Matagalpa, Nicaragua

- **Context:** The rural population of Nicaragua is vulnerable to climate change. According to recent studies, Nicaragua is the fourth country affected by extreme climatic events in the last 20 years and it is also one of the poorest countries of Latin America. Most of its population (70%) rely on agriculture to meet their needs.

- **Challenge:** The community of Wasaka Abajo is facing the same challenges as the rest of the country. In the context of climate change, a rise in temperature and a diminution of precipitation is expected, with longer periods of dry days directly affecting soil properties (fertility). This situation will have a direct effect on agricultural activities, threatening the livelihoods of the community, which depends on the management of natural resources. This situation is aggravated by the socioeconomic conditions of the community, which is classified as affected by extreme poverty. As a result, it is imperative to design tools/methodology to develop local, participative strategies.

- **Methodological approach:** In this study, the process of strategic planning in the context of climate change is presented. This study followed the methodology of the 'Local strategy for sustainable development under the scenario of climate change (LSDCC)'(Imbach et al. 2015) [15]. The methodology has a participative and inclusive approach, and its focus is on the singularities of the community in the context of climate change vulnerability and its general socioeconomic-cultural-political conditions. The strategy is designed to create a mechanism whereby the prioritized projects are included in the agenda of local stakeholders and can benefit the most vulnerable groups of people.

- **Highlights:** Local stakeholders participated actively in the design of the territorial strategic planning of the community, and validated and analyzed the information of the community. The territorial strategic planning contains the vision of all stakeholders. The participation of stakeholders was essential in the decision-making process, as decisions were based on the necessities and priorities of the community. Through the process of planning, local stakeholders were empowered, and it is expected that they will take a protagonist role in the successful execution of the proposed strategic planning, as a tool to face any future challenge. The vision of the community was built on five key aspects: body water conservation, better access to education, implementation of good agricultural practices, waste management,

15 https://labmeh.catie.ac.cr/2016/03/03/la-construccion-de-estrategias-locales-de-adaptacion-al-cambio-climatico-una-propuesta-desde-el-enfoque-de-medios-de-vida/

and forest conservation. Based on the conditions and characteristics of the community, a set of strategic goals and actions were formulated to respond to the aspects important to the community.

Thesis: Legal and enabling conditions for the formation and functioning of watershed committees in Nicaragua

- **Context:** Water is essential for living and the development of countries. Distribution of enough water for the world is one of the main social objectives of the last decades. Population increase, climate change and mismanagement of natural resources have had a negative impact on the supply of water in Nicaragua. It is necessary to have a paradigm shift on the adequate management of water resources to secure sustainable development.

- **Challenge:** Watershed management is a compelling approach that uses water as a unifying element in the decision-making process of a territory. However, watershed management is not easily done – it requires a series of legal and regulatory conditions that would enable institutionalized and organized participation of the users and the general population in a watershed. This can be achieved through the creation of watershed committees, which integrate the key actors that share responsibilities in watershed management.

- **Methodological approach:** To analyze the enabling conditions for the creation of *watershed committees*, two case-studies were identified. The first case-study is related to the formation of the watershed committee of the Estelí River. In order to establish this committee, it was necessary to implement a methodological process proposed by the National Water Authority (ANA), the entity in charge of the formation of the river basin committees. This methodological process entailed three phases (acknowledgment of the watershed, creation and legalization, and operationalization of the committee). The second case study analyzed the experience of the FOCUENCAS II program in creating the committee of the Jucuapa River. An integral analysis of the National Water Act (Act N. 620) and the Regulation of the Act (Decree 34-2010) regarding the implementation and operationalization of watershed committees was also performed.

- **Highlights:** With this research, it was possible to validate the methodology proposed by ANA. The thesis is expected to be an official document, a guideline for the creation of watershed committees in Nicaragua. Based on the analysis of the current legal framework and the two case studies, the enabling conditions for the formation of watershed committees were: legitimateness and representativeness, watershed characterization, the necessity to form a committee, political willingness from municipality authorities, existence of a methodological tool to guide the process, closeness to the territory, skills and capacity analysis of the persons who would integrate the committee, equity, commitments from local authorities and shared responsibilities, sustainability and financial strategies, knowledge building, a co-management plan, decentralization or committee scale-up, appropriation of methodological tools, and establishment of short-term goals.

Thesis: Participative building of a sustainable development strategy under a scenario of climate change in the territory of Peñas Blanca Mountain, Nicaragua

- **Context:** Climate Smart Territories (CST) are sociogeographical areas where different actors manage the ecosystems services provided by natural resources to improve the well-being of the community, optimize land use and contribute to climate change mitigation. The CSA approach was the central strategy of the MAP/CATIE Noruega´s program.

- **Challenge:** Peñas Blanca Mountain is a protected area of great importance in terms of environmental services provision due, to the features of the area (highland). MAP considered this territory as strategic from the point of view of political, economic and social management. One of the strategies of MAP is to facilitate tools/approaches that could

promote good governance and territorial management. In this study, the process of strategic planning for development was implemented in the Peñas Blanca Mountain.

- **Methodological approach:** In the territory, a participative platform named Peñas Blanca group of territorial management (TG-PBG) was created in 2014. This group gathers different actors of three municipalities (Rancho Grande, El Cuá and El Tuma-La Dalia) interested in the proper management of the territory and the protected area. In coordination with this group, a team from CATIE facilitated the process of strategic planning as a tool to aid in the decision-making process and proper management of the territory. The process of strategic planning for development used the methodology of Imbach et al. 2015.

- **Highlights:** The strategic planning for development is a participative process that involves the analysis of all the dynamics presented in a territory. Through this process, it was possible to promote public discussions and awareness, and these had a positive effect on the involvement of local actors at different scales. The strategies built as a result of the participative process are complementary to the existent instruments/mechanisms (i.e. Management Plan of the Natural Reserve Peñas Blancas Mountain) to manage the protected area. Planning, research, and knowledge sharing are transversal themes that guarantee the accomplishment of a territorial vision.

Thesis: Development of a proposal of bio-protocol to the right to Free, Prior and Informed Consent of Indigenous Peoples for the community Sauni Arungka of the Mayangna ethnic group

- **Context:** Even though countries have recognized the rights of indigenous communities to autonomy, freedom of land, and freely enjoy their cultural, social and spiritual heritage, it is still a long road in the process of acknowledging their obligations, as states, to the indigenous communities. In the 1980s, Nicaragua recognized the rights to self-determination of indigenous peoples through the promulgation of the Autonomy Statute of the Caribbean Regions, which was ratified in August 2010 through Covenant 169. Also of importance is the Decree 15-2003 (Inter-Institutional Commission for the Defence of Mother Earth) and the demarcation and land-rights security of indigenous and Afro-descendant territories.

- **Challenge:** Among the rights promulgated and recognized for indigenous communities is the right to Free, Prior and Informed Consent (FPIC) of Indigenous Peoples, which is part of international and national legislation regarding indigenous rights. The goal of this instrument is to consult and seek approval from indigenous communities in the decision-making process when a project/activity/law/regulation will be developed on their territories and which could affect their culture, well-being and livelihoods rights. This instrument requires states to cooperate in good faith. It is imperative that indigenous communities know of this instrument of consultation so that their rights are not violated. In this study, the process of consultation to obtain (or not) an FPIC for a community from the Bosawás Biosphere Reserve was facilitated.

- **Methodological approach:** The facilitation process for the formulation of the bio-protocol to respect the principle of FPIC included the history and cosmovision of the indigenous peoples of the Sauni Arungka community, as well as the natural resources existent in the territory. Also, the governance structure for conflict resolution/deliberation was acknowledged. With this information, the steps required to facilitate the process of the consultation were determined.

- **Highlights:** The bio-protocol incorporated aspects of the legal framework at all levels (territorial, municipal, regional, national and international). The process of facilitation will help to make a reality the views and rights of the indigenous peoples through their own institutions and demands to the state (guarantee of the process of consent), the use of the bio-protocol, when certain circumstances or persons

require the consent of indigenous peoples to carry out a development activity in their territories. This document is the first instrument available for the Caribbean and the State of Nicaragua to consult and improve their relationships with indigenous peoples.

Thesis: Local strategy for sustainable development under a scenario of climate change in the indigenous territory of Wangki Awala Kupia, Waspan, North Caribbean Coast Autonomous Region, Nicaragua

- **Context:** Wangki Awala Kupia (WAK) is one of the eight indigenous territories that belong to the municipality of Waspan. The territory is now in the process of becoming an autonomous territory. The autonomy process means, among other aspects/rights, that indigenous government structures and other forms of organizations are consolidated, the borders of their territory are defined and there is legal recognition from the State. The WAK indigenous group has advanced in developing strategic territorial planning as part of its efforts to secure an autonomous territory.

- **Challenge:** Strategic territorial planning aims to be a guideline to achieve and maintain over time the development goals proposed by the members of a community/territory. These goals need to be defined by all members of the community respecting the self-determination of indigenous peoples, recognized in international and national treaties and laws, and based on the resources available in a territory, with a local perspective and considering the effects of climate change.

- **Methodological approach:** The applied methodology is an integration of strategic territorial planning for development and the analysis of current and future effects of climate change at local and territorial levels (Imbach et al. 2015). The LSSDCC for WAK territory followed four steps: (i) mapping of local actors (identification of stakeholders with presence and power of incidence in the territory); (ii) analysis of the territory to know the current situation and project future trends; (iii) analysis of current vulnerability to, and impacts of climate change, especially identifying the levels of exposition, sensitivity and adaptation capacity of the territory to climate change; and (iv) definition of the local strategy for sustainable development of the territory.

- **Highlights:** The LSSDCC contains 10 key strategic aspects for development, including social, cultural, economic and environmental aspects. The sustainable use of natural resources played a key role in the definition of the LSSDCC document. The implementation of the 10 strategic themes will involve a concerted effort of stakeholders to build a sustainable territory. The facilitation of a participative and inclusive process in a society with diverse ideologies requires a major effort to develop an open and productive dialogue. In the WAK territory, the process of good territorial management may be hindered or limited by political ideologies.

Thesis: Evaluation of the use of ecological cook stoves, analysis of production and use of biochar as a soil amendment on the yields of corn (Zea mays) in three municipalities of León, Nicaragua

- **Context:** Maize is one of the staple crops consumed and produced in Western Nicaragua. The area is characterized by a dry climate with low precipitation. The use of firewood for cooking is one of the causes of deforestation in the area. According to national authorities, climate change has exacerbated the dry conditions of the area, with recurrent drought events affecting the populations that rely on agriculture as a livelihood.

- **Challenge:** The use of biochar has positive benefits on chemical, physical and biological properties of the soil, e.g. pH, cationic exchange capacity (CEC), soil acidity, organic matter, and water retention conditions. Therefore, the use of biochar in dry areas is an alternative to soil water retention capacity assistance and sustained agricultural production. Biochar is also recognized as a method

for offsetting GHG emissions when it is sequestered in the soil. Biochar may be produced by small farmers adapting their cook stove systems. Biochar-producing stoves use traditional biomass to produce energy for cooking, leaving biochar as a by-product, which will then be applied to the soil to improve its conditions and finally increase crop yields. Also, with the improved cook stove, the pressure on firewood gathering can be diminished. In this study, the effect of biochar on corn yields, and the perception of farmers on the use of a biochar-producing stove in comparison to a traditional cook stove were investigated.

- **Methodological approach:** In the present study, the effect of biochar and poultry manure in three different soil texture classes (sandy loam, loamy-sand, and sandy-clay-loam) on maize yields was investigated. The following variables were measured: water-holding capacity measured as a percentage of water bulk, water infiltration rate, bulk density, pH, CEC, organic matter, nutrient contents (Ca, Mg, K, N from $N0_3$, P) and weights of baby corn and corn cob, plant biomass and corn cob yields. Improved biochar stoves were built and distributed among farmers, and comparisons were made between traditional stoves and the improved biochar stove through quantitative and qualitative analyses.

- **Highlights:** *Soil characteristics and water retention*
  - Soil can retain up to 18% of water when applying biochar, independent of the soil texture; pH increased to 7.36.
  - Biochar + poultry manure (15 t/ha) increased the value of macronutrient contents in the soil in Ca: 324 mg/100 g; K: 111 mg/100 g; Mg: 35 mg/100 g; N: 35 mg/100 g; P: 66 mg/100 g.
  - Values for bulk density diminished (0.82 g/cm^3) in the soils with sandy-clay-loamy texture.
  - Additionally, the biochar + poultry manure application improved the texture of the soil, and a better radicular growing system of the corn plants and an increase in corn yields and weight were recorded.

Improved biochar cook stoves
  - The thermic behavior of the improved biochar cook stove is similar to traditional stoves, reaching 340° in 60 minutes. The total cooking time of the improved biochar cook stove was lower. Wood consumption was the same in both cases.
  - Biochar yields from the improved biochar cook stove were 26%.
  - 78% of the producers/users feel very satisfied with the results of using biochar in their crops. The price and smoke emitted from stove were the barriers mentioned by users/farmers for the use of the improved biochar cook stove. However, time for cooking, aesthetics, the ease of preparing the wood to use in the stove, durability and the easy-to-use stove itself, were the features more liked by the users.
  - 100% of the users are satisfied with the use of the improved biochar cook stove, because now the stove has three cooking spaces and can cook up to three different foods at the same time.

Thesis: Territorial identity, a contribution to the process of governance: An analysis of the socio-institutional context in Peñas Blanca Mountain, Nicaragua

- **Context**: A territory is a socially constructed space, a result of historic, social and cultural processes that make it unique. Climate-smart territories (CST) are defined as a model that looks to transform the way people see their surroundings and the nature of their relationship with it. Each territory has an identity, defined by the condition of living in a determined locality.

- **Challenge:** Strengthening the process of territorial management is a key part of the environmental program of CATIE. This process seeks to support good practices in governance and the co-management of a territory. Here we present an analysis of the socio-institutional context existent in Peñas Blanca Mountain, Nicaragua.

- **Methodological approach:** A participative process was carried out that promoted a continuous observation of the reality to

transform it, and the inclusion of key actors of the territory. Interviews, life-stories, transects, participative observation, and local workshops were among the tools used to carry out the analysis.

- **Highlights:** Peñas Blanca territory is comprised of five sub-territories belonging to three municipalities. Each of the sub-territories has its own history of creation and colonization. The sentiment of belonging varies between ages; younger generations have a higher sense of belonging than older generations.
  - Local platforms working in Peñas Blanca have a high potential for environmental management and support the inter-municipal activities carried out in the territory. New themes can be ascribed to the local platforms instead of promoting new structures of the organization. Platforms at the municipal level do not focus their work only on Peñas Blanca functioning, but there is an interest in collaborating on shared topics such as water, food security, and alternative farming production to reduce the pressure on the remaining natural forests.
  - The mass media communication instrument available and most used by local platforms is the radio, such as Radio Bosawás, located in the municipality of El Cua. This media is not only used for the diffusion of news, but also to raise awareness on environmental issues, especially for farmers.
  - The Government of Nicaragua has laws, decrees and other instruments that favor the good management of natural resources. However, local offices have a low rate of activity implementation, and technicians have low levels of training or low coordination capacity.

Thesis: Impact of green credits financed by the CAMBio Project, in the establishment of silvopastoral systems in cattle farms in north-central localities of Nicaragua

- **Context:** Livestock occupies 70% of the agricultural area worldwide. This sector is the culprit of deforestation, biodiversity loss, soil degradation, and climate change. In Central America, 35% of the forests were converted to pastures. It is urgent to promote the adoption of good farm practices in cattle farms to reduce the negative impact of livestock production on the environment.

- **Challenge:** Silvopastoral systems (SPS) have proved to be sustainable options for the intensification of cattle farms. However, cattle farmers require incentives to help them adopt SPS in their systems. Green credits are a kind of financial mechanism available for farmers integrating green practices in their farms. In this study, the impact of green credits promoted by the Central American Markets for Biodiversity project (CAMBio) and the technical assistance provided by Nitlapán in the adoption of silvopastoral systems in cattle farms was evaluated.

- **Methodological approach:** The limitations and lessons learned in accessing green credits were documented, through the analysis of the database of beneficiaries from Nitlapán and CAMBio. To analyze the impact of green credit in the adoption of SPS, 70 farms profiting from the incentive and 30 farms without incentives were randomly selected.

- **Highlights:** Credits were ranked as positive by farmers. 91% of the farmers indicated that thanks to the incentive they established silvopastoral systems in their farms. 89% of the farmers received Bio-premium (equivalent to 14% of the total amount of the credit), which is the measure of accomplishment of the commitments (SPS establishment).
  - 94% of the farmers have previous knowledge of SPS, a condition that favored its adoption. Technical assistance provided by Nitlapán had a positive effect on the adoption of SPS and the high success obtained.
  - With the adoption of SPS, farmers can obtain other goods and services from trees, such as firewood, timber, and shade for cattle, food and aesthetic benefits.

  - Farmers indicated satisfaction regarding the interest rate of the awarded credit; they believe that this credit had better condition terms in comparison to other credits they have received in the past.
  - There was a positive effect in cattle farming from the implementation of the CAMBio project. For example, an increase in tree cover was evident in the studied farms, as well as a reduction of natural pasturelands to improved pastures; an increase of forage banks was recorded. The Biodiversity Index of the cattle farms increased by 0.03 points, a direct effect of the financial mechanism.

Thesis: The social performance index for the prioritization of agricultural investment under the approach of climate-smart agriculture in two territories (Nicacentral and Trifinio) of Central America

- **Context:** Climate smart agriculture (CSA) is an approach that seeks to provide innovative solutions towards the goals of increasing yields, improving resilience, and promoting a low-emissions agricultural sector. The CSA approach also identifies holistic options promoting synergies, determine the barriers for the adoption of new practices, and integrates climate financing with business-as-usual agricultural investments.

- **Challenge:** A methodology for the prioritization of agricultural practices was developed by the CGIAR-CCAFS program to operationalize the CSA approach through the selection and ranking of investments portfolios. This methodology needs to be flexible and adjusted/adapted to the local conditions of each territory/country where it is applied. To do this, a participative and inclusive approach is put in place, so the document is a useful tool in the decision-making process for climate change mitigation/adaptation at all levels. In this study, the CGIAR-CCAFS-CATIE methodology was applied in two climate-smart territories of the environmental program of CATIE (MAP-CATIE) to contribute to the development of climate-smart territories (CST). The goal of the current study is to propose social indicators to accompany the set of indicators used in CSA prioritization. The expected result of this study is a catalog of CSA practices and investment portfolios available to small farmers.

- **Methodological approach:** Four steps are at the core of the prioritization process in the CSA methodology: (i) preliminary evaluation of practices, (ii) identification of the main CSA options, (iii) costs and benefits estimates, and (iv) portfolio definition. For the evaluation of agricultural practices in steps one and two, a list of indicators was defined based on the three pillars of the CSA approach. In step one, 12 indicators were used for the evaluation of practices which were established by experts, while in step two five indicators were used, defined and evaluated by local stakeholders.

- **Highlights:** The set of social indicators proposed were equity, bridging the generational gap, food availability, knowledge encouragement, agricultural experimentation, social relationships, and organizational strengthening. Of this set of indicators, the three best-ranked indicators were equity, food availability and knowledge encouragement.
  - 29 and 25 CSA practices were evaluated in Nicacentral and Trifinio, respectively. The CSA practices in Nicacentral with a higher social performance were design and establishment of coffee and cocoa agroforestry systems, design of home gardens (patios), seed selection and post-harvesting management of staple grains, scattered tree planting in pasturelands and the protection of water bodies. In Trifinio, the CSA practices with a higher social performance were preparation of organic fertilizers, chemical and biological inputs for pest and disease management in home gardens, seed selection, and storage of staple grains, agroforestry system establishment, and live fence establishment in pasturelands.
  - The evaluation of CSA practices with the proposed social indicators

supports the importance of innovation and product diversification as a strategy for adapting to changing climate conditions and as a vehicle to improve welfare, equity, and inclusion in CST territories.

Thesis: Land-use planning, normative policy proposal, and development profiles for the areas affected by Hurricane Felix in the North Caribbean Autonomous Region, Nicaragua

- **Context:** Land-use planning of a territory after a natural disaster, based on the degree of intervention and land-use capacity, is essential to secure adequate management of the affected areas and improve the environmental and socioeconomic conditions of the population living there. The Government of Nicaragua, through its ministries, has developed a series of programs for development and social projects to reduce poverty in abandoned and rural areas.

- **Challenge:** Hurricane Felix in 2007 hit the North Caribbean Coast Autonomous Region, affecting 1.2 million ha of broadleaf and coniferous forests. It was estimated that a large proportion of trees in these forests fell, and only a portion of them were harvested (removal of damaged/fallen trees) and used in the wood industry. The objective of the present study is to propose land-use zoning as a measure to restore the areas affected by Hurricane Felix. This zoning will be a consulting and planning tool in which the vision for sustainable development for the region is aligned with wood harvesting and forest restoration.

- **Methodological approach:** Using GIS software, future scenarios of land-use management were modeled. Cartographic and secondary information gathered through the review of policies and laws, as well as interviews with locals affected by Hurricane Felix and officials from governmental or non-governmental institutions, were essential to model and generate future land-use maps.

- **Highlights:** The desired scenario is achieved in 2032 and it includes areas of forest for harvesting purpose, an increase in the area of forest management/harvesting, and agricultural and pasture areas to support the people living in the region. The current area covered by protected areas is 8%; with the proposed zoning it will increase to 20%, including riparian forests and water body protection of interest for conservation.
  - The land-use proposal (zoning) contains five categories of management: (i) forest restoration and recovery (41%) for both production and ecosystem services provision; (ii) protection (20%); (iii) areas for forest logging (26.7%); (iv) agriculture and livestock production (12%); and (v) infrastructure and special areas (0.3%). Four strategic lines of action are defined in the proposal: planning and restoration of disturbed areas, forest management, organizational and individual strengthening, infrastructure development and basic services provision.

Thesis: The methodological proposal under the context of humane welfare and climate change for the elaboration of the Management Plan of Protected Areas in Nicaragua. Case study: Management Plan of the Natural Reserve Peñas Blanca Mountain, Nicaragua

- **Context:** 18% of the Nicaraguan territory is under a category of protection. 76 protected areas (PA) are registered in the National System of Protected Areas (SINAP) under nine categories of management. The main goals of PA creation are to provide ecosystem services and preserve natural and cultural heritage. The process of PA planning is through a management plan, which explains the guidelines for the administration and management of the PA and its buffer zone.

- **Challenge:** In the last decade, Nicaragua has initiated a process of strengthening the SINAP; as a result, 67% of the PAs have a management plan and 13% are in the process of consultation. The Natural Reserve of Peñas Blanca Mountain (NRPBM) management plan was drafted

in 2011 in collaboration with local and international organizations. However, an assessment of vulnerability in the area where the NRPBM is located showed that climate change threatens the sustainability of the PA. In this work, a methodological proposal was formulated to draw lessons learned in the process of conception of a management plan, and it was possible to update the initial management plan of NRPBM PA.

- **Methodological approach:** To develop the methodological proposal, a four-step approach was followed: (i) literature review; (ii) documentation of experiences through focus group and interviews; (iii) formulation of the methodological proposal (workshops/interviews); and (iv) validation of the methodology.

- **Highlights:** The elaboration of the management plan for the NRPBM (2011–2015) was made using the methodological framework for PA from The Nature Conservancy, due to the absence of a national methodological framework for the elaboration of a management plan for PA. The main barrier identified at municipal and institutional levels in the process of implementation of the current management plan of the NRPBM was the lack of recognition of the management plan as a tool for strategic planning. For example, municipalities did not take into account the NRPBM management plan when planning the environmental activities to be carried out at the municipal level.
  - The methodology proposed for Nicaragua explains clearly the approaches required for the strategic planning of PA: adaptation theory, ecosystemic analysis, and general human well-being. This proposal is accompanied by a toolbox that shows, step-by-step, how to update the management plan of the NRPBM to facilitate its application.

Thesis: Systematization of the process of governance of communal land in two indigenous territories: Wangki Twi Tasba Raya and AMASAU [Awastigni Mayangna Sauni Umani (Ancestral land of the Mayagnas of Awastigni)], North Caribbean Coast Autonomous Region, Nicaragua

- **Context:** Indigenous communities of the Caribbean region of Nicaragua have a long history of fighting for the recognition of their rights to land. International and national treaties and covenants acknowledge the rights of indigenous people to self-determination and territories. Nicaragua, with the promulgation of Law 145, gave indigenous groups the legal grounds to claim their historical territories and attain national recognition of their heritage and collective ownership.

- **Challenge:** Indigenous groups are demanding the protection, security, and permanence of their communal lands. This process means evicting third parties living in their historical lands and/or negotiating a peaceful living arrangement with non-indigenous groups based on the rules of the territory. The indigenous communities Wangki Twi Tasba Raya and AMASAU requested the support of the Foundation for the Autonomy and Development of the Atlantic Coast of Nicaragua-FADCANIC – Center for the development of the autonomy-CEDEA (a local non-governmental organization) to assist in the formulation of an internal procedures guidelines/book for the process of land sanitation. The present study documented the process of land rights clearance (demarcation) and its implications for the process of governance of communal lands.

- **Methodological approach:** An analysis of experiences through the reconstruction of the process and evolution of governance of communal land in two indigenous territories was carried out. This process of governance has been supported by two organizations at different intervals of time: Masangni, R.L. (Cooperative of Forestry Professionals -Masangni, R.L.) from 2012 to 2014 and CEDEA-FADCANIC (2016–2017).

- **Highlights:** The results of the systematization process showed that indigenous groups have a great interest in the formation of communal lands; this process reinforces the autonomy of

indigenous territories. These two factors represented a unique opportunity to advance in the recognition of indigenous rights. Collective ownership of the land has defined new rules in the community, with the formulation of a book of procedures that clearly gives the direct control of the land and natural resources to the communities Wangki Twi Tasba Raya and AMASAU.
  - One of the best practices identified in the process was the inclusive and broad participation of local actors, including women and men of different age groups that facilitated writing a draft.
  - The book of procedures has proved to be a useful mechanism for the containment of agricultural and livestock frontiers, especially regulating access of third parties to the territory.
  - Interference by political parties was identified during the process of drafting the guidelines of the procedure; these actors have a lot of influence and may distort the organizational potential of the communities and their territories to carry out the process of land ownership control and the implementation of new regulations to administer their territory and its natural resources.
  - The communal division is also observed. In this regard, mediation and conflict-resolution processes are recommended internally, highlighting their own potential and capacity through indigenous institutions.

Thesis: A proposal to adapt cacao cultivation to future climate change in Waslala, Nicaragua

- **Context:** Agricultural productivity in Nicaragua is highly affected by droughts, floods and erratic variations in climate. These climatic factors result in reduced annual productivity (total and partial crop losses), in addition to the negative impacts caused by poor agricultural practices (e.g. burning and other conditions such as low soil quality in marginal areas). This study analyzed the adaptive capacity and potential adaptation measures available to local cacao producers in Waslala, Nicaragua.
- **Challenge:** Cocoa is becoming a key crop for farm diversification and income generation, yet farmers are lacking tools and/or data to make informed decisions and better adapt cacao cultivation to climate change.
- **Methodological approach:** A total of 37 cacao grower families who are members of the Cooperativa de Servicios Agroforestales y de Comercialización de Cacao – Nicaragua (CACAONICA) were selected to collectively assess their adaptive capacity and resilience to climate change. A total of 47 indicators of adaptive and resilience capacity that could be applied by local families were selected from published literature. Best ranked adaptation proposals were discussed with farmers and technical staff within workshops.
- **Highlights:**
  - Cacao growers were grouped into three conglomerates according to their adaptive and resilience capacity to climate change.
  - A total of 28 recommendations for adaptation and resilience were proposed for growers with low adaptive and resilience capacities.
  - Growers in Conglomerate 1 would benefit from using natural resources in a more sustainable way, increasing soil conservation practices.
  - Farmers in Conglomerate 2 should foster shade canopy diversification to take advantage of a wider range of goods and services from cacao agroforestry systems.
  - Cacao growers in Conglomerate 3 should seek ways to depend less on hired labor, promoting more family participation in farm activities.
  - Active participation in CACAONICA activities is strongly encouraged; being organized will allow growers more opportunities for success and access to external resources/projects.
  - Current coffee-producing regions may be more suitable for cocoa production in the future. When communicated effectively, climate modeling and agro-meteorological information can

help farmers diversify or adapt cocoa cultivation to climate change.

Thesis: Ecosystem services recognized by the inhabitants of the buffer area of Peñas Blancas Mountain, in the Central North territory of Nicaragua

- **Context:** Awareness is important to promote or reinforce good practices and conservation actions that can make the sustainable use of resources efficient. However, it is important to identify the threats that condition or limit these actions to determine what joint management strategies or strategic lines citizens and other key actors can implement to achieve the integrated management of natural resources.

- **Challenge:** This work aims to identify which ecosystem services are recognized by the inhabitants who live in the buffer zone of the Peñas Blancas Mountain (PBM) and which factors such as land uses and other threats (pressures and anthropogenic and climatic causes that affect them) can impact the provision of such ecosystems services.

- **Methodological approach:** The sources of information for the identification of ecosystem services were: (i) field observations; (ii) a review of secondary information; (iii) open interviews of specialists and key actors; (iv) farmer workshops; and (v) global positioning system delimitation across the PBM reserve. For this study, three conservation areas or ecosystems were studied: cloud forest, water sources, and agroecosystems. The Planning Manual (CEN 2011) for the conservation of protected areas (PCA) was used, both to identify threats (pressures and sources of pressure), and to analyze them, obtaining a global hierarchical value to know the most critical threats to ecosystem services. Finally, through a cause-and-effect diagram, the relationships between the critical threats and the actors were identified and described, helping to decide which issues are needed to mitigate the pressures.

- **Highlights:**
  - The study explored, identified and characterized the goods and services received by people from three ecosystems: forests, agro-ecosystems and water sources.
  - The relevance of this study is that, given the social nature of ecosystem services, their recognition is vital to determine the ways in which the community establishes relationships that lead to establishing defined lines of action, effective and efficient, that contribute to solving the problems of biodiversity loss.
  - The recognition of ecosystem services is a necessity but not enough for conservation, due to the lack of awareness on the part of key actors of the greater impact on the ecosystem. Hence, any strategy to raise awareness of ecosystem services must be accompanied by a strategy of organization and structuring, which allows access to resources in an inclusive manner (by both large and small producers in the area), and is equitable and therefore more democratic.

11 Analysis of the SL process (what worked, what did not) and the future

What we have done/key accomplishments:

- Creation of socio-ecological research sites to engage in long-term work to accumulate data, comparisons and experiences.
- Characterization of the patterns of tree cover on farms and in the landscape, and the changes that occur (have occurred) between these different land use types. The objective was to understand why the changes occurred, the consequences of these changes at various scales (plot, farm and landscape) and trade-offs between socio-ecological vulnerability and efficiency of the system.
- Dataverse platform studied and databases on cocoa agroforestry in Central America located, evaluated and documented according to dataverse standards, available at: https://dataverse.harvard.edu/dataverse/CATIE. The data have been used by researchers and students for master's theses.
- Elaboration of a collection of bibliographic information on timber production potential in forest ecosystems and trees outside forests.
- Bibliographic databases (using Endnote software) about silvopastoral systems and fodder shrubs developed.
- Farmer Field School program in place to stimulate adoption of science-based agroforestry and agroecological innovations in 1,000 farms in the NHSL.
- Report on agroecological and agroforestry practices as options to modernize agroforestry systems. Farmer Field schools have also developed nutrition education sessions and practical alternative practices for food preparation. In addition, 38 groups have included gender issues for labor division.
- Central American network for long-term research on the dynamics of natural production forests formally constituted.

What has been difficult?

Due to lack of budget, it was not possible to establish a scientific committee of partners within the NHSL or to carry out further research activities defined for the NHSL, especially in Honduras, where CATIE, other CGIAR Centers and CRPs have fewer activities. Integrating FTA flagships, partner initiatives, and long-term socio-ecological monitoring in Tier 1 landscapes has been slow due to a lack of agreement and budget among CGIAR Centers and CRPs to work in a specific site of the NHSL.

The governance theme is a very difficult key issue, because it is a transversal topic identified as one of the main factors affecting land-use change and the opportunities to develop sustainable options for the use and management of tree-derived resources. Both in Nicaragua and Honduras, the boundaries of the territories of indigenous groups largely overlap with the territories of natural reserves. The migration of people from other areas of the country in search of land (even in forest reserves) triggers conflicts for land with indigenous groups living in these reserves. For these indigenous groups, conflicts over land and the low representation they have in the formulation of laws are seen as major threats to their livelihoods. Land tenure systems and land markets that promote the speculation and renting of land as a source of income are major problems in the NHSL. This problem will be exacerbated by demand for land for commercial productions systems (cattle ranching, coffee, teak plantations and

oil palm). Measuring the effects of climate change, particularly on water provision, and the relationship between these effects and non-sustainable land uses, was not possible due to lack of funds.

A key challenge relates to the development of new methods for a fast and accurate inventory/monitoring of trees and forest patches in farms. Options include the development of software-hardware devices using micro-drones, low-altitude photography, real-time identification of tree species, and properly tuned sampling schemes. There are a lot of difficulties in using these technologies in Central America due to the lack of legislation and regulation concerning the commercial (or research) use of sophisticated equipment. However, there is the potential for a tree inventory within the limits of large cattle or coffee farms. It is faster at this moment to rely on remote sensing than accurate technology for tree inventory, e.g. RapidEye imagery.

Most importantly, it has been challenging to establish an effective binational platform/ network with strategic plans to research and manage the NHSL. Organizational capacity is vital and very important, but the lack of budget has been a barrier to the development of an effective organizational structure.

12 Future of CATIE in NHSL

As a regional center, CATIE will continue its activities in the NHSL. Partners such as CIRAD continue the implementation of their STRADIV and FORECAST projects. A new ICRAF-CATIE-CIRAD-IUCN-University of Gottingen-University of Hanover initiative (the project 'Trees on Farms for Biodiversity Conservation and Livelihoods' under the International Climate Initiative [IKI] of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) started in May 2018 and will last five years. Potential sites of integrative work have been identified based on previous and ongoing CGIAR efforts (such as CCAFS Climate-Smart Villages [CSV] and FTA sentinel sites) and on priorities of the government (such as the Central American Dry Corridor). Some integrative work has already been done in El Tuma-La Dalia CSV between CCAFS and FTA regarding baseline surveys and implementation of agroforestry measures. CATIE aims to develop new research through master's and PhD theses in the NHSL to explore the research questions elaborated above and to promote the development of climate-smart territories as a tool to achieve sustainable and inclusive human well-being, as well as the support of effective integration of actions in education, research and innovation for development, in alliance with multiple public and private partners.

Leveraging the information from the Sentinel Landscape database, CATIE and partners can help promote some policy changes in land use and generate knowledge and technical instruments to quantify and promote both biodiversity in agricultural lands and the contribution of agricultural lands to wider biodiversity. Future work could also promote and enhance the importance of trees in livelihoods and environmental services. Published documents, studies and articles on agroforestry, trees and livelihoods in NHSL, as well as a consolidated national and binational research platform would also be suggestions for the future. Finally, appropriate implementation of the set-up requires significant efforts in capacity building. Several means have been identified to improve long-term place-based research. Therefore, capacity development of local actors needs to be included.

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WORKING PAPER

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This publication is part of the Sentinel Landscape network initiative established in eight sites around the world representative of widely different biophysical and socioeconomic contexts. Here we present and summarize the results of the research and baseline studies carried out in the Nicaragua-Honduras sentinel landscape that can be indicative of the humid forest ecological zone.

The CGIAR Research Program on Forests, Trees and Agroforestry (FTA) is the world's largest research for development program to enhance the role of forests, trees and agroforestry in sustainable development and food security and to address climate change. CIFOR leads FTA in partnership with Bioversity International, CATIE, CIRAD, ICRAF, INBAR and TBI.

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