A dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science* (MSc) in Environmental Forestry of the University of Wales

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Abstract

There is increasing concern for the condition of biodiversity and water resources worldwide and a need to articulate ways in which both can be effectively conserved. The challenge is achieving conservation while still meeting the production demands of agricultural systems, which are becoming greater with increasing population. Agroforestry has been proposed as one form of land use which may provide some resolution.

For many countries coffee is an extremely important export crop and covers an extensive land area. This is the case in Guatemala, where biodiversity is also under severe threat and an adequate water supply a serious issue. Coffee therefore represents a land use, that if able to promote biodiversity and water conservation, could have a significant impact on these issues for the country as a whole, and potentially world wide if practices are applicable else where. The most benign form of coffee cultivation is considered to be multi-strata coffee agroforestry, where the greatest number and variety of trees are grown with the crop.

In order to be able to make broadly applicable recommendations for the cultivation of coffee however, more knowledge is needed on the behaviour and characteristics of tree species and their impact on these two issues. This study documents local knowledge of trees used within multi-strata coffee agroforestry systems in the River Hato watershed, El Progreso department, Guatemala. At the head of this watershed is a protected area of cloud forest, the Sierra de Las Minas Biosphere Reserve, notable for its biodiversity and as a source of 62 rivers that feed the River Montagua valley below.

Comparison of local knowledge with scientific knowledge revealed a high level of complementarity, with each knowledge system also providing added individual detail that did not contradict the other. There were areas of knowledge where science was able to be more explicit, but general processes were well understood by local informants. There were also areas of knowledge that could not necessarily be denied or supported by science but that present interesting ideas and could provide a basis for further investigation.

The synthesis of both knowledges enabled an increase in understanding of the processes involved in biodiversity and the water cycle and the role of particular tree species or groups of species. It is suggested that multi-strata coffee agroforestry systems do exhibit a high level of biodiversity and can contribute to the regulation of water flow. In addition, they may be able to aid in the protection of the cloud forest reserve from deforestation and enhance its ability to increase water yield.

Using the synthesis of knowledge, recommendations are made of ways in which biodiversity and water conservation can be improved, the role of local knowledge is considered, and areas of further research identified.

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List of Abbreviations

ADIPSA	Asociación de Desarrollo Integral Progresista San Agustín Acasaguastlán
ANACAFE	Asociación Nacional del Café
CATIE	Centro Agronomico Tropical de Investigación y Enseñanza
CIRAD	Centre de coopération Internationale en Recherche Agronomique pour le Développement
FAO	Food and Agriculture Organisation
FDN	Fundación Defensores de la Naturaleza
ICRAF	International Centre for Research in Agroforestry
INAB	Instituto Nacional de Bosques

1. Introduction

1.1 Introduction

The issues of biodiversity and water conservation are becoming increasingly important both at a worldwide level and more locally. Answers are being sought to questions such how biodiversity and water conservation can be improved while coping with increasing demands for land and population growth. The deterioration of both of these services has been linked to land use change characterised by a decline in tree cover. Agroforestry systems provide a potential method of meeting agricultural needs but at the same time preserving some measure of tree cover (Sinclair 1999, Nair 1989).

Coffee agroforestry systems are considered to be particularly significant worldwide because of the area of land they cover and the contribution they make to world trade and the economies of many developing countries. There are differences in methods of cultivation however, and multi-strata systems are seen as being more beneficial. There is potential for existing, more simplified coffee systems to increase their complexity and potentially improve biodiversity levels and water conservation, but more information is needed in order to make explicit recommendations, particularly surrounding individual tree species.

There is great interest in the contribution that the local knowledge of coffee farmers already practising multi-strata systems can make to enhancing our understanding of the factors affecting biodiversity and water conservation and the influence that different tree species and types have. This study investigates local knowledge of the trees used within multi-strata coffee agroforestry systems located in the River Hato watershed, El Progreso department, Guatemala. This area is considered to be particularly relevant to the research as the range in altitude means that there are many life zones present. The Sierra de Las Minas Biosphere Reserve is also located at the head of the watershed and it is an area where water availability is of particular concern.

1.2 Overview

This chapter looks at the importance of biodiversity and water conservation worldwide and for Guatemala, the influence of land use and multi-strata agroforestry systems, the role of coffee cultivation and local knowledge, and details the aims and objectives. Chapter 2 outlines the methodology and provides a brief description of the study area. Chapter 3 presents the main findings of the research, and Chapter 4 compares these findings with scientific knowledge. Chapter 5 discusses some of the main issues that arose and Chapter 6 makes some recommendations and suggests further lines of research. Chapter 7 draws some general conclusions.

1.3 Context

1.3.1 Biodiversity and water conservation as ecosystem services

Biodiversity and water conservation are both issues that are currently at the forefront of international focus. Their importance was recognised at this level at the United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro in 1992 (Williams et al. 2001), and consolidated in a number of international conventions, particularly the Convention on Biological Diversity (UNCBD). 2005-2015 is also the international decade 'Water, source of Life' (IARNA et al. 2006).

Both have been recognised as ecosystem services, which can be defined as those goods and services provided by nature that permit our survival. Water, and the river and wetland systems that it comprises, contributes to human wellbeing by supplying water for various uses, providing a habitat for fish, and also regulating climates and floods (Millennium Ecosystem Assessment 2005). Concern has arisen at the high level of degradation suffered by these systems which have caused a worldwide lack of drinking water, the effects of which impact disproportionately on the poor in low-income countries (ibid., IARNA et al. 2006),

Biodiversity is valued on a number of different levels; the Millennium Ecosystem Assessment (2005) embraces all of these, from an 'intrinsic' appreciation that values it as and for itself, to a 'utilitarian' acknowledgement of the many products that it provides us with, to its 'serependic', or future potential value (Swift et al. 2004). Increasingly it is being suggested that it may also have a 'functional' value in providing a regulating and supporting service to ecosystems.

In this sense then biodiversity occupies a unique position where it is being suggested that it has a direct relationship with the continued provision of all other ecosystem services (Swift et al. 2004). If this is the case, the fact that it is under threat, with the current extinction rate estimated at 1000 times the typical planetary rate (Millennium Ecosystem Assessment 2005; Williams et al. 2001), is certainly of great concern.

The posited relationship revolves around the understanding that as all species have roles in ecosystem processes that contribute to its efficient functioning, any decline in biodiversity may disrupt these processes and hence the sustainable provision of ecosystem services, including water conservation (Swift et al. 2004). It has yet to be substantiated empirically (Myers 1996; Swift et al. 2004), with some suggesting that as species can be classified into functional groups only one or two species per group may be needed (Balvanera et al. 2006; Swift et. al 2004; Vitousek and Hooper 1993), and others drawing attention to the importance of guilds of organisms that work together (Swift et al. 2004). But whether there is some measure of redundancy inherent in ecosystems or not, the threshold is unknown (Myers 1996) and biodiversity continues to decline, so erring on the side of caution seems advisable.

1.3.2 Biodiversity and water resources in Guatemala

Although Guatemala occupies less than 0.5% of global land area, it possesses between 7-10% of all known life forms and 17% of all land species together with Belize and the states of south Mexico. Of 25 regions, it has the second highest diversity of species, and endemic species. This high biodiversity is due to its broken topography and diverse microclimates, as it lies between the neoarctic of North America and the neotropics of South and Central America and the Caribbean. However, it is also one of the most threatened biodiversity hotspots in the world. (IARNA et al. 2006). The Sierra de Las Minas Biosphere Reseve is the second largest protected area in Guatemala and is noted for its high species diversity, with 2000 species having been recorded, including endemic species, which number at least 70 (ibid.). The range in altitudes from 250 to 2,600 m asl from the River Montagua at the bottom of the valley to the Sierra also means there is a great number of micro-environments and biodiversity (Ellis and Taylor 2007).

The volume of water flowing within Guatemala is more than enough to satisfy demand, but there are problems with providing a sufficient supply where it is needed at particular points in time. The main limitations are seasonal and geographic, with supply issues during the dry season and particularly in the departments of Zacapa and El Progreso, where this research is located (see the map in Figure 1, section 2.2 for their location in Guatemala). The greatest demand for water is for irrigation, particularly within these departments that lie within the watershed of the River Montagua. (ibid.)

1.3.3 Influence of land use and multi-strata coffee agroforestry systems

One of the main causes of biodiversity decline and water ecosystem degradation is land use change, where the trend has been the conversion of land to the agriculture of annual crops with no tree cover, simplifying and intensifying ecological systems (Bennett et al. 2005). Within Guatemala general poverty and inequality have increased, and along with a growing population there is an increased demand for land, creating pressures for the utilisation of marginal land, deforestation and increasing water withdrawal for irrigation (IARNA et al. 2006, Millennium Ecosystem Assessment 2005). The annual deforestation rate is 1.43%, which is four times that of Brazil, and twice that of Mexico (FAO 2007, IARNA et al. 2006).

Tree cover has been closely linked to increased biodiversity and the regulation of water flows (Pérez-Nieto et al. 2005; Bruijnzeel 2004), so in order to increase it and deal with the demand for agriculture simultaneously, attention has been increasingly focused on agroforestry systems, particularly complex, multi-strata systems to enhance biodiversity that are characterised by a diverse vertical structure (Monro et al. 2006, Bandeira et al. 2005, Davidson, S. 2005, McNeely 2004, Somarriba et al. 2004, Greenberg et al. 1997, Gallina et al. 1996, Swallow et al. 2006). Coffee in Central America has typically been cultivated in such systems beneath a diverse mixture of shade trees (Monro et al. 2006, Davidson 2005). These are often referred to as traditional/rustic systems or traditional polyculture systems, and have been historically practiced by small farmers (Faminow and Rodriguez 2001). Within this study they will be referred to as multi-strata coffee agroforestry systems.

1.3.3 The coffee market

Coffee is the second leading commodity after petroleum in world trade (Castro et al. 2005), and Central America was the second most productive region globally prior to 2002 (ibid.). Within this region, Guatemala has the largest area under production and the second highest yield after Costa Rica (Varangis et al. 2003). While there have been pressures to decrease shade and increase inputs in order to increase yield since the 1970s, the coffee crisis of 2000, caused by a production surplus that resulted in severe price drops, has led some farmers to sell shade trees, clear surrounding forest or switch to more intensive crops like sugarcane in order to maintain their livelihoods (Castro et al. 2005, Varangis et al. 2003).

The area still cultivated as a traditional, multi-strata system remains significant, at 45% of the area under cultivation (Varangis et al. 2003), but due to these pressures there is a need to promote the retention of multi-strata practises and increase its economic viability for farmers. Differentiated markets, such as fair trade, organic or 'bird-friendly' coffee that require certification but confer a price premium are increasingly being viewed as a possible solution (Monro et al 2006, CIRAD 2005, Castro et al. 2005, Varangis et al 2003, Szott 1999). CAFNET, to which this study will contribute, is a recently initiated project that seeks to conserve natural resources through improving the remuneration for producers by payment for environmental services such as biodiversity and water conservation (CIRAD 2005). It is currently working in three regions worldwide, including Central America and Guatemala.

1.3.4 Local knowledge

Agroforestry however is a relatively new discipline and there is still much that has not been fully investigated or recorded; ICRAF for example, was only established in 1977 (King 1989). There are therefore gaps in our understanding of agroforestry systems in general (Walker et al. 1995) and more specifically of multi-strata coffee agroforestry systems (Montagnini et al. 2005). Local people are increasingly being recognised as having detailed ecological knowledge (Soto-Pinto et al. 2007; Thapa et al. 1995), and have been advocated as having a vital role to play in addressing these gaps (Hunn 2006, Millennium Ecosystem Assessment 2005, Joshi et al. 2001, Blaikie et al. 1997).

Recently an appropriate methodology was developed for the systematic collection and recording of local knowledge (Sinclair 2001). Up until then its systematic use was constrained by dissent over its nature and the manner in which it should be treated. Some argued that different aspects of local knowledge are inherently interconnected and so cannot be separated, and as it is value and culture-bound it cannot be used and communicated independently of its context (Scoones and Thompson 1994). In the past as scientific knowledge was valued over local knowledge (Blaikie et al. 1997), there were also concerns it would be distorted in interpretation to fit into a framework of western scientific rationality (Scoones and Thompson 1994).

Systems thinking however has been able to conceptualise knowledge more palpably. A system is defined as a group of components that interact with each other for a common purpose as a unit (Sinclair 1999), where each part is seen in relationship to each other part and to the whole (Doyle 1990). While recognising the influence of the social and cultural matrix, these are viewed as parts of a whole, which means that one part, ecological knowledge, can be articulated and described separately. Rocheleau (1987) also shows that such a conception is recognisable to local people themselves, and Amanor (2002) describes local ecological knowledge as a 'science of the concrete' or an 'art of the locality' (p. 126) that, as it is conscious, can be articulated. Similarly Hunn (2006) characterises what he terms ethnobiological knowledge as 'firmly grounded in concrete encounters of human minds with the natural world' (p. 156). Studies have also described how farmers use their own observations and experiments to evaluate and update their own knowledge (Millar 1994, Richards 1994).

By collecting and recording local knowledge it can be synthesised with what is known scientifically to increase our overall understanding of multi-strata coffee agroforestry systems and enable better recommendations to be made for the conservation of biodiversity and water. The idea is to create a holistic body of knowledge that is accessible to practitioners worldwide and that can be continually updated with new knowledge as it is discovered and documented (Walker et al. 1997). This is a fundamental part of the CAFNET project, and the local knowledge collected will be synthesised across the three regions, allowing useful knowledge that is documented in Guatemala to inform recommendations that are made elsewhere and vice versa (CIRAD 2005). Even beyond the duration of the CAFNET project it is foreseen that this body of knowledge will be of use to other practitioners where it is relevant to other areas and communities (Thapa et al. 1995)

1.4 Rationale for research

The rationale for the research is that more knowledge is needed on the interactions within coffee agroforestry systems and particularly those characteristics that affect biodiversity and water conservation, in order to advise on ways in which these processes can be improved. Local knowledge has been identified as a valuable resource that can be utilised in this respect, particularly with regard to agroforesty as a relatively new discipline.

The decline in biodiversity and water resources are concerns worldwide, but they are of particular relevance within the River Hato watershed. Multi-strata coffee agroforestry is also practised here, making it a highly suitable location for this study. It is foreseen that the research will contribute to a body of knowledge to inform CAFNET and enable the project to improve the livelihoods of coffee farmers in this region in a sustainable way through payment for environmental services including biodiversity and water conservation, but will also stand on its own and enable recommendations to be made in other regions as appropriate, serving as a repository of combined knowledge that can be accessed widely and added to.

1.5 Objectives

- Document local knowledge of the tree species used within multi-strata coffee agroforestry systems and their influence on biodiversity and water conservation.
- Make a comparison with scientific knowledge, identifying knowledge gaps in both types of knowledge.
- Evaluate this knowledge in relation to biodiversity and water conservation within the River Hato watershed, El Progreso department, Guatemala.
- Make some recommendations on the ways in which biodiversity and water conservation can be improved using the information gained from the evaluation of knowledge.

2 Methodology

2.1 Introduction

Fieldwork was carried out in eastern Guatemala in the department of El Progreso for approximately 10 weeks, from the beginning of June until the beginning of August. A Guatemalan NGO, FDN, as co-ordinators of the CAFNET project within the country and responsibility for the administration of the Sierra de Las Minas Biosphere Reserve, facilitated the research.

After an initial two week stage of orientation and scoping, semi-structured interviews were conducted with informants and knowledge entered into a knowledge base. The methodology outlined follows closely that detailed in Sinclair and Walker (1997), and Walker and Sinclair (1997), making use of AKT5 software in the development of the knowledge base.

2.2 Location of research

The area within which the research was to be undertaken, the River Hato watershed, had been previously chosen by FDN as suitable for the CAFNET project. The watershed is located in the department of El Progreso and is one of many watersheds that feed into the River Montagua. The proximity of the watershed to the Sierra de las Minas Biosphere Reserve, the range of microclimates present, and the lack of organisation of coffee producers within it were factors contributing to its choice. Figure 1 shows the location of the watershed in relation to the Biosphere Reserve and within Guatemala.

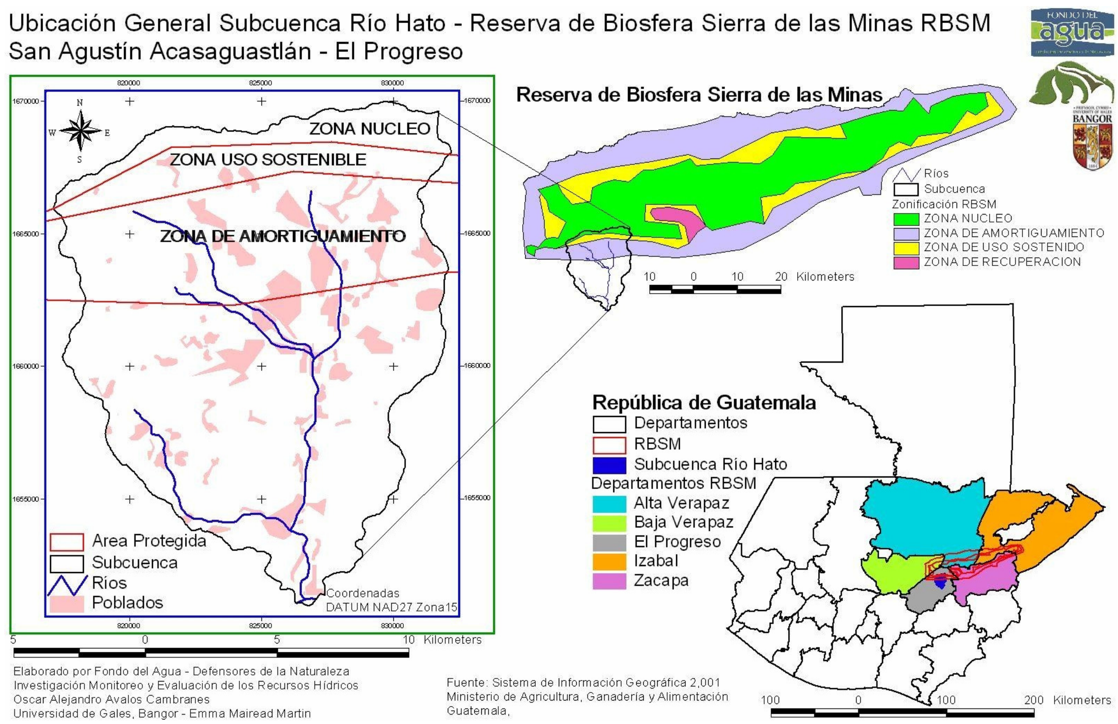


Figure 1: Map showing the location of the River Hato watershed in relation to the Sierra de las Minas Biosphere Reserve and within the department of El Progreso in Guatemala

2.3 Scoping and Definition

2.3.1 Reconnaissance and Scoping

The initial objectives were to become familiar with the area and communities in order to make problem definition more locally relevant. The methodology also requires the definition of potential informants into strata according to possible differences in knowledge to ensure all facets of knowledge are adequately covered.

Informal discussions were held with employees of FDN at one of their regional offices in the municipal centre of San Agustín Acasaguastlán, at the base of the River Hato watershed in the valley of the River Montagua, to gain an understanding of the distribution of communities within the watershed. Meetings were also held with a local non-profit organisation, ADIPSA, which has involvement in organic coffee production in area. The ADIPSA employees were also from the municipality, many living in rural areas and owning coffee farms themselves in the watershed.

A drive was also made around the watershed from San Agustín with the support of FDN, and informal interviews held with two coffee farmers in two communities.

The research was conducted during the rainy season, which starts at the end of May and finishes at the end of October, and it was made clear early on that transport would be very difficult at that time of year. Typical journey times up into the rural communities where coffee is produced were up to four hours there and back, and up to an hour between communities. The availability of transport was also an issue. In addition, the distribution of households within the majority of the coffee communities is quite scattered and ADIPSA advised that communal meetings could only be organised for a Sunday, when many people attend mass.

Due to these constraints, it was not possible to hold communal meetings to further define the domain and possible stratification of informants before interviews needed to take place in order to fit in with time constraints. However, further discussions were held with ADIPSA and it was also possible to interview another coffee farmer who had come into San Agustín for the day. Use was also made of census information held at the municipal building giving detailed breakdowns of land use and community make up.

2.3.2 Definition and choice of strata

It became evident that while biodiversity would clearly remain a key focus area, the availability of water was also highly important for this watershed. It was therefore decided that the research and interview questions would centre around these two issues.

The possible factors affecting differences in knowledge were discussed. Ethnicity was not considered to be an issue as the population on the south side of the River Montagua valley are all 'ladinos' (mestizo). It also became clear that there was no separation in labour activities in relation to coffee between men and women; in male headed households women generally had no association with coffee apart from at labour intensive times of year during the harvest, and in female headed households they undertook the same work as their male counterparts.

From reconnaissance it became clear that there were more likely to be differences in knowledge between coffee farmers and workers, with the former more involved in the management of coffee and the latter actually undertaking labour activities such as pruning, weeding and harvesting. Workers also frequently live in communities lower down the watershed and might be employed by a number of coffee farms over the course of a year; it was posited that due to this they might observe processes differently in the light of comparison with different environments.

Reconnaissance also revealed that distinctions could be made between small and medium coffee farms due to possible differences in the composition and diversity of tree species used with coffee, with small producers likely to retain a greater diversity to supplement their income and for subsistence, therefore having different knowledge. While the majority of the coffee farms in the watershed were conventional, i.e. made use of fertilisers, there were also some organic coffee farms. The absence of chemical inputs and consequent possible differences in management also made stratification along these lines seem reasonable.

Lastly, while most coffee farms were located in the communities at the highest altitudes in the watershed, some coffee was produced in coffee farms lower down that experience a warmer and drier climate. Again, differences in composition of tree species and management of coffee were likely.

Strata groups were therefore based on potential differences in management and tree species composition, and differences in interaction with coffee (see Table 1 for a summary). As workers are only found on medium farms, there are no small or low altitude organic farms, and all the low altitude coffee farms are small, these groups could not be additionally split according to size.

Table 1: Summary of strata groups

Strata	Reason for stratification	Communities
Small farmers (conventional)	Possible differences in tree species composition and management	Las Parcelas El Carmen La Hierbabuena
Medium farmers (conventional)	Possible differences in tree species composition and management	Las Parcelas El Carmen Los Albores
Workers	Differences in observations due to changes in environment	El Carmen Los Albores
Organic farmers	Possible differences in tree species composition and management	Las Parcelas Los Albores La Hierbabuena
Low altitude coffee farmers	Possible differences in tree species composition and management	El Terreplen El Cimiento

2.3.3 Choice of communities

While there are over 40 communities in the River Hato watershed, many of them with less than 200 people, the majority do not produce coffee as the altitude they are located at is too low for it to be produced successfully and to an acceptable quality. From a choice of approximately 10 communities in the coffee zone, four were initially chosen according to the sizes of the coffee farms they included, the presence of organic coffee farms and altitude to ensure that all strata were covered.

The logistical issues outlined above also affected choice. Due to transport difficulties, it was decided that week long stays would be made within one community at a time, with travel to coffee farms on foot. It was therefore important that communities were not too spread out to enable this. Choice was also dependent on whether it was possible to arrange communal meetings, facilitated by ADIPSA, at the beginning of each week in order to make introductions, explain the purposes of the research and arrange interviews for the week ahead.

It was initially anticipated that time allowed for five weeks of interviews in five different communities. After three consecutive weeks of interviews however a week with no interviews was needed to complete translations; the lack of electricity in La Hierbabuena had prevented the use of laptops to process information. Only four weeks of first interviews were carried out then, but it was also actually possible when based at two communities, Las Parcelas and Los Albores, to access some coffee farms that were part of another community on foot. Overall then, six different communities were visited in a four week period.

Time also permitted the return to certain communities in the last week to carry out any second interviews deemed to be necessary. Table 2 shows the basic time scale available for the research and the various stages of the study.

Table 2: Time scale and stages of research

Activity	**7/6**	**11/6**	**24/6**	**25/6 – 30/6**	**1/7 - 7/7**	**8/7 - 14/7**	**15/7 – 21/7**	**22/7 - 28/7**	**29/7 – 5/8**	**6/8**
Arrive Guatemala, meet FDN										
Arrive San Agustín										
Orientation and scoping										
Interviews: Las Parcelas (Los										

Balsamos) / El Terreplen										
Interviews: El Carmen										
Interviews: La Hierbabuena										
Completion of translations										
Interviews: El Cimiento / Los Albores										
Second interviews: Los Albores / Las Parcelas										
Feedback of preliminary findings to FDN										

2.3.4 Description of study sites

The six communities visited are in general located at the higher altitudes of the watershed within the coffee zone. However, two communities, El Cimiento and El Terraplen are notably lower and experience hotter and drier conditions as a result, at altitudes of just below 1000 m asl to approximately 1,300 m asl. The others were all higher than 1,500 m asl, with La Hierbabuena above 2000 m asl. In comparison, San Agustín Acasaguastlán, the municipal centre, is less than 500 m asl and experiences little rain even during the rainy season. Figure 2 shows a map of the River Hato watershed, showing the locations of the communities visited, and Table 3 shows how the quantity of rainfall and temperature vary with altitude.

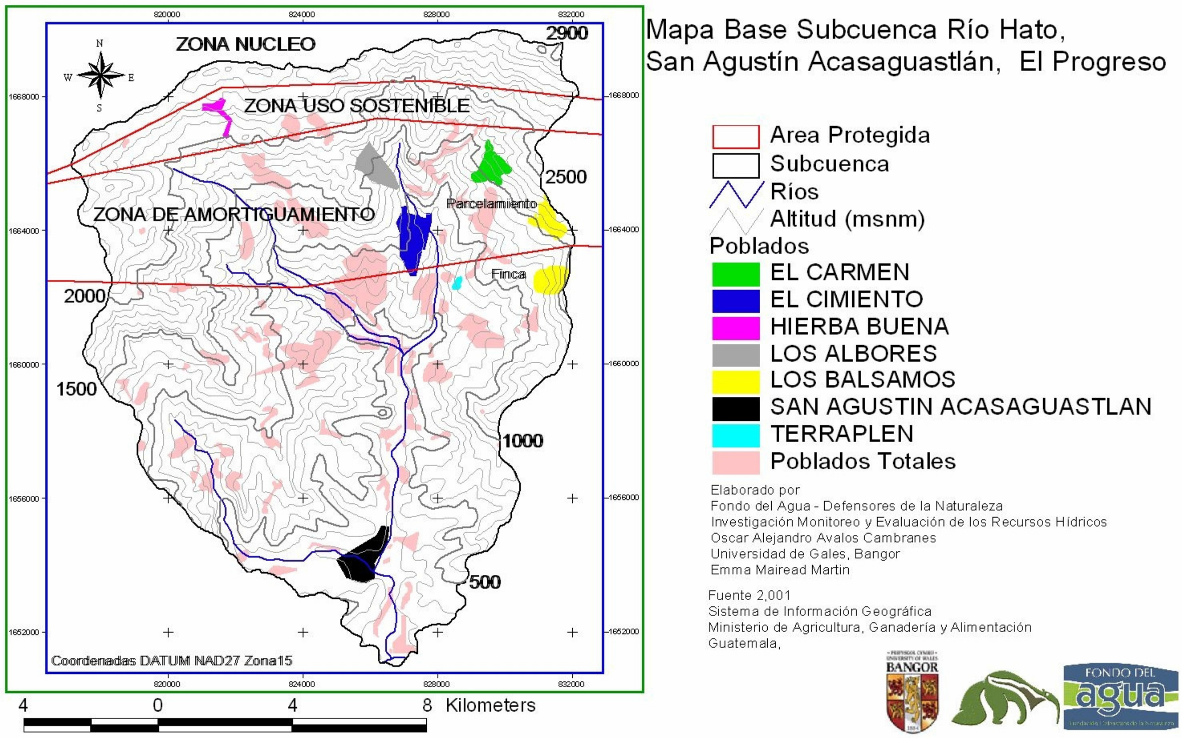


Figure 2: Map showing the location of 6 communities visited in the Rio Hato watershed. San Agustín Acasaguastlán the municipal centre and is at the lower point of the watershed.

Table 3: Characteristics of the different life zones in the River Hato watershed (adapted from information in Ortega 2003)

Unidad bioclimática	**Altitude above sea level (m)**	**Average annual rainfall (mm)**	**Temperature (°C)**
Monte espinoso subtropical	0 – 500	Menor de 500	24 – 30
Bosque seco subtropical	500 – 1000	500 – 1000	24 – 30
Bosque muy humedo subtropical frio	1000 – 1500	2000 – 4000	18 – 24
Bosque pluvial Montano Bajo subtropical	1500 – 2000	Mayor a 4000	12 – 18

The map also shows that parts of Las Parcelas, El Cimiento, Los Albores and El Carmen are all located in the buffer zone (zone de amortiguamiento) of the Sierra de Las Minas Biosphere Reserve, and La Hierbabuena in the sustainable use zone (zone uso sostenible).

2.5 Compilation

2.5.1 Key informant interviews

It is at this stage that key informant interviews are carried out and knowledge of the identified domains is recorded within a knowledge base. Ideally five key informants are selected from each strata; a purposively small sample to enable in depth knowledge to be recorded in the period of time available. In this case as interviews within communities and selection of informants took place on a week by week basis it was not practically possible to organise the ideal number of interviews from the beginning. Instead, informants from as wide a mix of strata as possible were interviewed each week. This was made easier by the knowledge gained about the communities in advance through ADIPSA and the census information, e.g. there were only organic farmers in three communities so in the others it made sense to interview more conventional small and medium farmers or workers. Likewise, in El Terraplen and El Cimiento, all farmers were included in the low altitude strata. Communal meetings were held on the first day of each week, arranged by ADIPSA, where the research was explained and its relevance to the farmers made clear. Most of the interviews for the following week were also arranged then.

All interviews were held in the field to better contextualise knowledge and take photographs, using a digital recorder to make translation and the formal expression of knowledge more accurate. They were semi-structured interviews where the interviewer adopted the role of student to encourage the informant to articulate knowledge more explicitly, and also avoid the 'Socratic dialogue' that can sometimes characterises interactions between extension staff and local people (Van Dusseldorp and Box 1993).

Ideally, multiple interviews are held with the same person in order to gain more in depth knowledge and enable any consistencies that arise to be resolved. There was only limited opportunity for this due to the week by week nature of the research and transport difficulties, however in the last week if was possible to return to two informants for a second interview. It was also possible to resolve many inconsistencies through interviews held with other informants.

2.5.2 Formal representation of knowledge

Interviews were translated from the recordings and converted into unitary statements as soon as possible after the interviews had taken place when the memory was still fresh. This was only found difficult in the third week when lack of electricity in La Hierbabuena meant that everything was done by hand, slowing up the pace of the work.

Unitary statements are the smallest possible statements of useful ecological knowledge, i.e. it can be used to answer a query or used in reasoning. They were entered into the database using the formal language of AKT that is so syntactically precise it leaves no room for ambiguity. Relationships that had been observed by informants were entered as causal statements, and conditionality was expressed using ‘IF’ statements.

In order to maintain the context of the knowledge and represent an ‘emic’ rather than ‘etic’ representation (Sinclair and Walker 1999, Thapa et al. 1995), all statements were attached to a source, containing the name of the informant, location of the interview and gender. Other information included strata, size of coffee farm, and how long the informant had been cultivating coffee for. Memos could also be added to any statement to give more local detail if necessary. Photographs were used to help define formal terms, to which synonyms were given where necessary, e.g. to include scientific names. Objects were also classified by creating object hierarchies to group together objects considered by informants to have similar characteristics.

To aid navigation through the database and view statements related to each other, topic hierarchies were also created.

Through turning speech into unitary statements and AKT language. ambiguities were more easily revealed and the meaning of any statement could be made very clear. Statements could also be analysed more rigorously and relationships between them explored in more detail using diagrams.

3 Results: Local knowledge of biodiversity and water conservation

3.1 Introduction

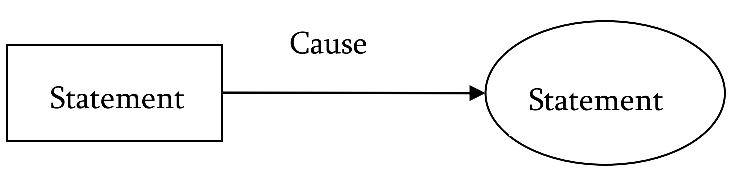
This chapter describes the main relevant points of knowledge gathered on the key areas of biodiversity and water conservation, and it is split into two sections accordingly to deal with each topic in turn. Within each section, the various factors identified as affecting biodiversity and water conservation are considered. Differences in knowledge between informants are also considered.

In order to amalgamate this information the 'boolean search' facility within the AKT program was used, which allowed the locating of statements that included relevant key words. From these statements diagrams were created, again using the facility within AKT, enabling the results to be presented in a manner that clearly demonstrates primarily causal relationships between factors (see Box 1 for notes on interpreting causal diagrams.) These causal diagrams form a key part of the presentation of the following results.

<u>**Box 1: Interpreting Causal Diagrams**</u>

The linking of statements

Each statement that the diagram includes is represented as a node. The shape of the node reflects the type of statement that was entered into AKT, but it is invariably rectangular or oval in shape. The direction of cause is represented as an arrow linking one 'node', i.e. statement, with another.



In order to understand the dynamics of the causal relationship various symbols are used.

Causal symbols

Firstly either a '1' or '2' is used to denote cause. It can be thought of as really encapsulating the world 'cause'.

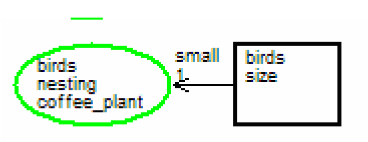
'2' is only be used when the terms 'increase' and/or 'decrease' are used together, e.g. an increase in fruit trees causes and increase in diversity of birds. A '2' would denote that this statement is '2-way', i.e. the same is also true for the opposite statement, that a decrease in fruit trees causes a decrease in diversity of birds.

Symbols denoting value

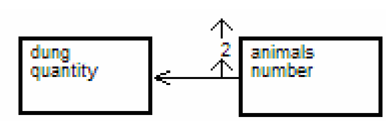
Increase and decrease are denoted by arrows ↑ or ↓
Other terms of value use the words that are used within the statement, e.g. 'high' or 'low', 'thick', 'soft'.

Order of symbols

If these is a value associated with the first statement, this appears followed by the causal symbol '1' or '2' followed by the value associated with the second statement if there is one.



Bird size is **small causes (1)** birds nesting coffee plant.



Number of animals **increases (↑) causes (2)** dung quantity **increases (↑)**. As this is a 2-way statement, it is also true for a decrease.

3.2 Biodiversity

3.2.1 Initial impressions

In general all informants, both farmers and workers, showed a depth of knowledge of the biodiversity present within their coffee farms, and were able to articulate reasons why that environment might be favourable. In order to initiate conversation around this subject area the word 'biodiversity' was not used; the assumption was made that most farmers and workers would not be aware of the term, or if they were may be put off by it, perhaps seeing it as a word used by scientists or by extension workers telling them what to do. Appendix 1 contains a list of questions that were used during interviews to encourage farmers and workers to talk about the wildlife (and water conservation) within their coffee farms.

The first part of this section seeks to briefly illustrate knowledge surrounding the species present within coffee farms and the interactions between them, and the main factors identified as affecting biodiversity, which were:

- Floristic diversity
- Structural complexity
- Habitat diversity

The merits of individual trees are also noted, and lastly perceptions of biodiversity are explored.

3.2.2 Flora and fauna

Fauna

Informants identified nearly 30 different bird species commonly observed within coffee farms throughout the year, and a lesser number of bird species that visited coffee farms at particular times of year. They also identified a number of animals that could commonly be found living within and visiting coffee farms, insects, and four different types of snake.

In many cases the common names used do not represent individual species but refer to recognisable taxa, e.g. bats and ants. Informants also spoke for example of 'palomas', a bird similar to a dove or a pigeon, acknowledging different types but referring to them all with the same name, whereas the birds 'chorchas' and 'gavilans' are definite species. As there does not always appear to be a distinction made then between species within a group, the general term used by informants has also been used within the knowledge base, since it also seems that any group exhibits similar characteristics and behaviour, and it can be spoken of in general terms to the level of detail given by informants.

Figure 4 shows the object hierarchies created within AKT to represent this classification, using local names. Scientific names, where known, can be found within the knowledge base under each relevant formal term. It was not always possible to be sure of species names without a detailed description or photograph; in these cases only the genus has been given, and in the case of large groups such as bats and ants, only the family name.

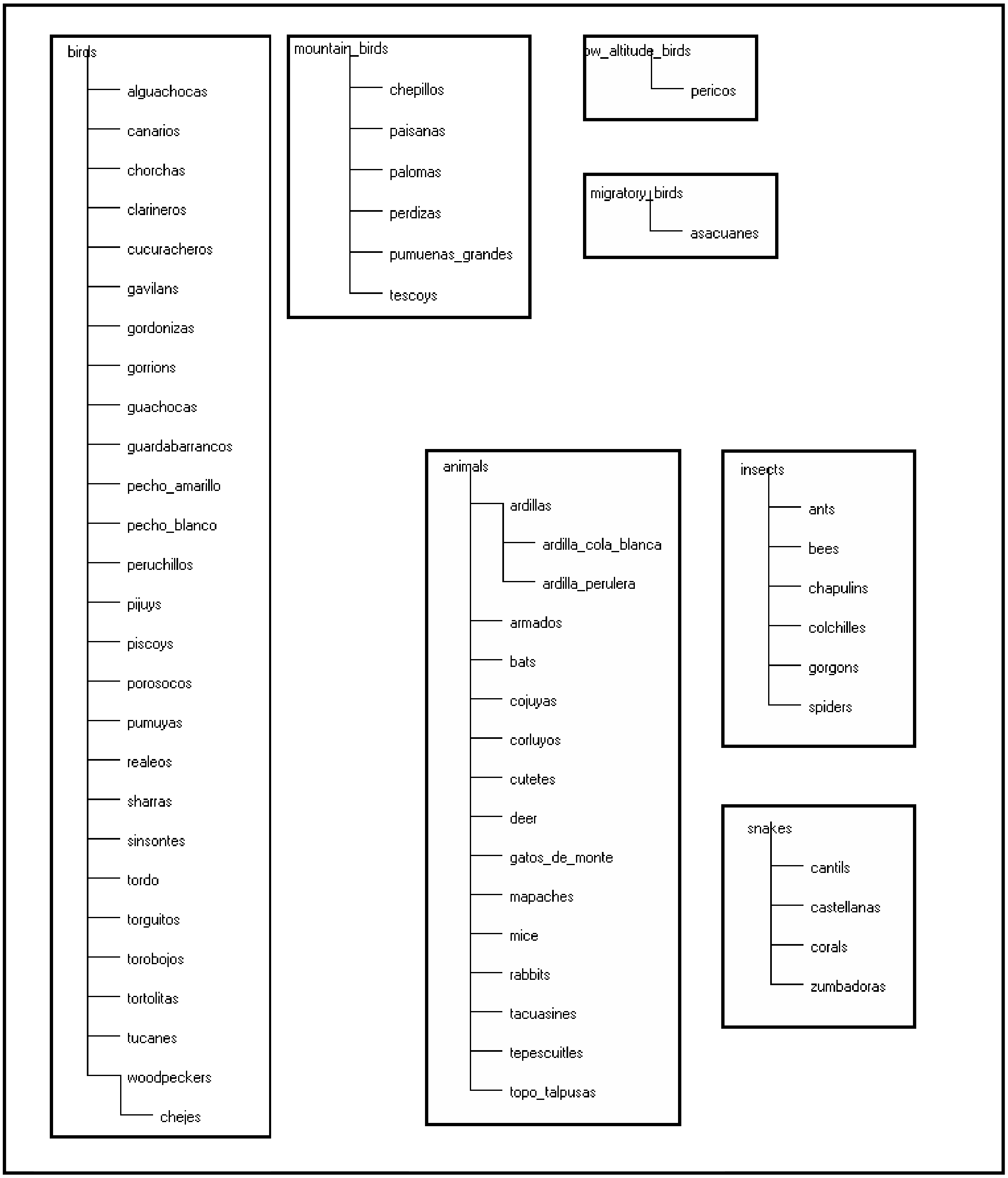


Figure 4: Object hierarchies for birds, animals, insects and snakes created within AKT

The 'birds' object hierarchy lists those birds found within coffee farms throughout the year. Birds that visit the coffee farm at different times of year were separated according to their different migratory patterns. 'Mountain birds' are so called because, as explained by informants, they usually live high up the watershed above the coffee zone in forest, and visit the coffee farm during the winter; at this time it is very cold at those high altitudes and food is scarce. 'Low altitude birds' usually live lower down the watershed where the climate is hotter and drier, and visit the coffee farms during the summer where it is cooler. 'Migratory birds' have been distinguished as those that come from outside the local area, their origin not necessarily known by informants. Of these latter two hierarchies, only one bird in each was mentioned during interviews.

Flora

Informants identified 61 different species of tree that could be found within their coffee farms, of greater and lesser frequency (the object hierarchy 'all_trees' can be viewed in the knowledge base). Individual tree species were also classified according to various characteristics that arose during the interviews as being important factors affecting biodiversity or water conservation; these will be explored in turn as appropriate. Trees were also classified according to their use by informants, so that the knowledge base includes object hierarchies for trees used for wood, firewood and medicine (see Figure 5). Again local names were used throughout the knowledge base, but scientific names can be found under the formal terms.

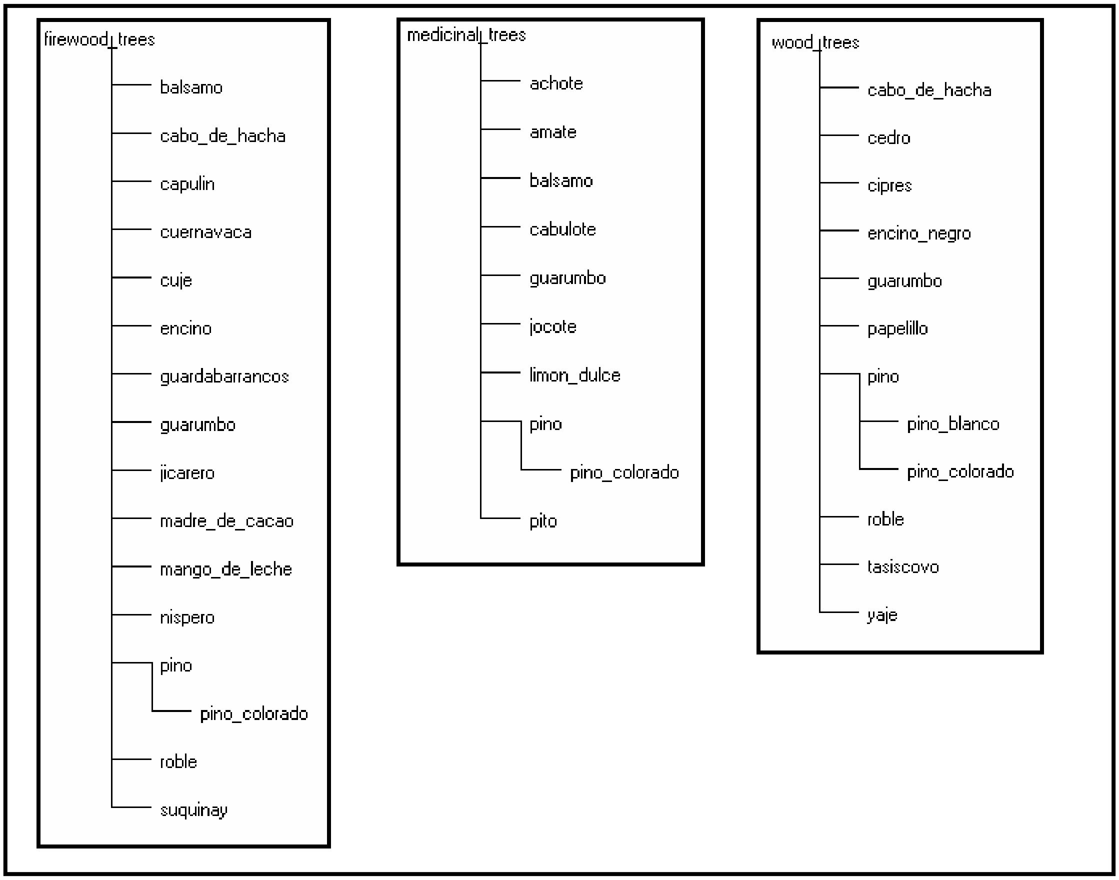


Figure 5: Object hierarchies for trees created within AKT, showing the different purposes for which trees are used by informants.

Interactions between and within flora and fauna

Informants exhibited knowledge concerning the behaviour of the majority of the birds and animals identified, such as feeding patterns and habitat preferences, which also reflect their interactions between each other and with various tree species. To give an example, Figure 6 shows the feeding patterns of mice and snakes, and the interrelationship between them and their prey. This is not a causal diagram but represents the feeding relationship as a link. Within the knowledge base there are 124 statements of this type.

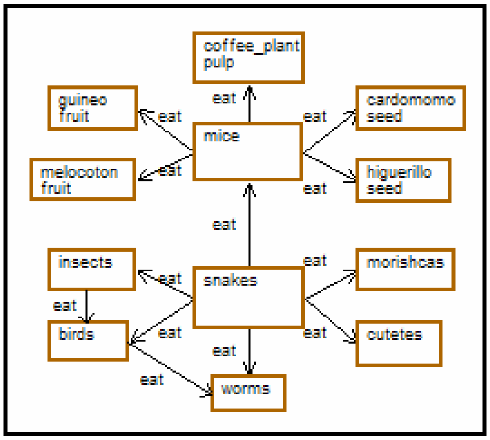


Figure 6: Link diagram showing principally the feeding behaviour of mice and snakes, and the interrelationships between them and their prey.

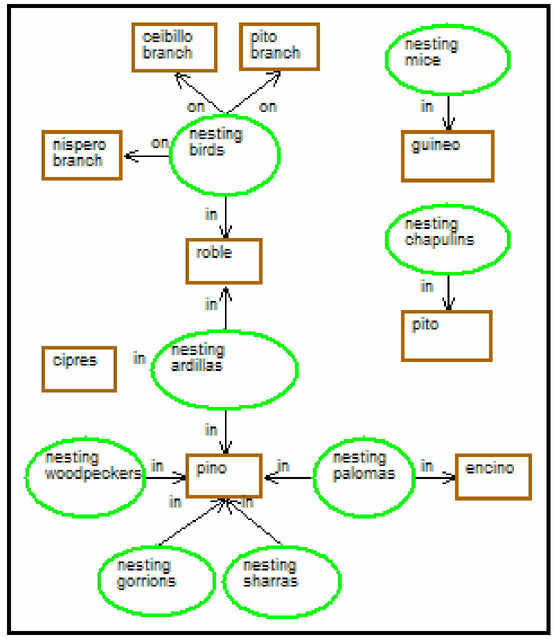


Figure 7: Link diagram showing the nesting habits of selected fauna in different species of tree.

Figure 7 illustrates knowledge surrounding the nesting behaviour of various animals and birds, specifically their relationship with particular trees found within the coffee farms. This shows that informants made general statements about birds, but they also had more detailed knowledge of where specific birds usually nest. Again, this is not a causal diagram. Within the knowledge base there are 81 statements of this type.

Informants also drew attention to a particular relationship existing between birds and insects. It appears to be a directly proportional relationship whereby an increase in the number of insects leads to an increase in the number of birds and vie versa. Figure 6 indicates why, showing that insects are a food source for birds. Figure 8 illustrates this relationship with some examples.

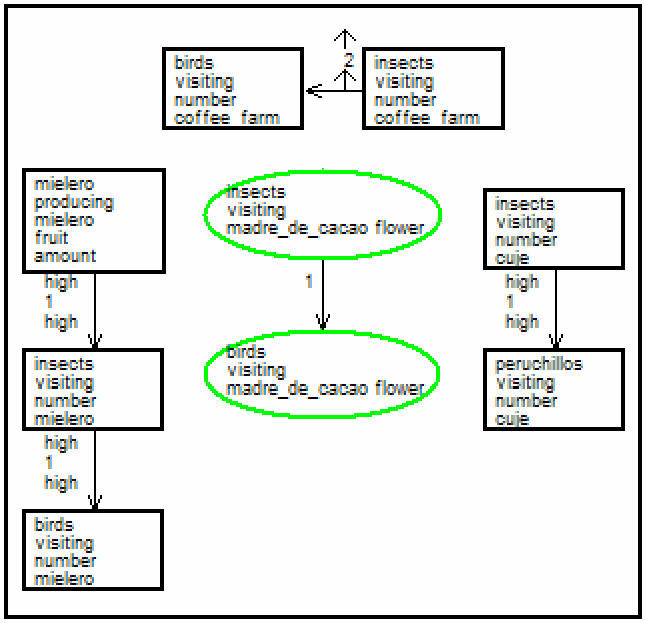


Figure 8: Causal diagram showing the relationship between birds and insects.

Informants noted that maize and beans also provided food sources for birds, but that the birds live within the coffee farm. They also only tend to feed on these crops when food is scarce elsewhere.

Changes in floral and faunal populations

Informants did not note any changes in populations that they thought had occurred naturally, but they did highlight a decrease in certain mammal populations due to hunting, namely tepescuitles, deer, tacuasines, mapaches, armados and rabbits. There was also recognition that excessive hunting of tepescuitles had caused them to be endangered.

3.2.3 Factors affecting biodiversity

Floristic and faunal diversity

Most informants recognised that a key factor influencing the level of biodiversity within coffee farms is the degree of floristic diversity, in this case primarily the diversity of tree species present. The link statements referred to above suggest that the majority of the trees identified by informants are used as a food source or for habitat. 15 tree species are specifically mentioned as providing habitat for various fauna, and 32 tree species as sources of food. Moreover, 25 of these are trees that bear fruit (the full list of these trees can be viewed in the knowledge base).

Informants emphasised then that the provision of habitat and the availability of a diverse range of food sources are important factors in attracting a range of fauna to coffee farms. Figure 9 illustrates these relationships, where an increase in the diversity of all tree species, but especially fruit trees, causes an increase in both the number and diversity of birds and animals. It also shows how, as trees produce fruit at different times of year, increasing the diversity of fruit trees will increase the likelihood of food being available throughout the year, again attracting a greater number and diversity of fauna.

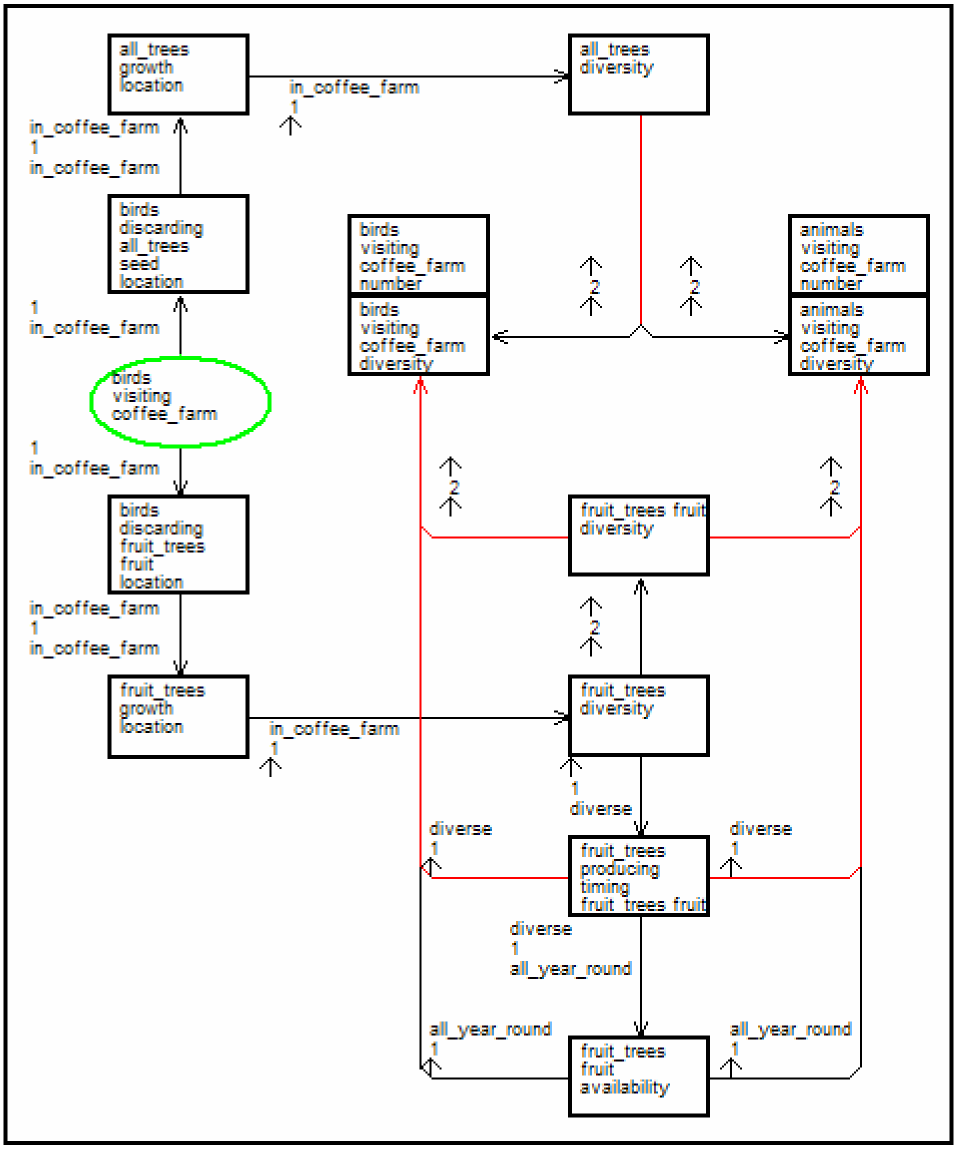


Figure 9: Causal diagram showing the influence of increasing diversity of trees on bird and animal populations, and illustrating how this is reinforced through natural regeneration.

Informants also pointed to the role that birds play themselves in increasing this diversity through bringing fruits and seeds from other coffee farms or from the forest, and contributing to natural regeneration and the establishment of new tree species. There is the potential then for a natural self-reinforcing process to occur, whereby tree diversity within coffee farms can be maintained and enhanced by the number and diversity of birds that the trees themselves attract. This is of course only possible if naturally regenerating trees, and new species, are not cut by coffee farmers, and this is discussed in more detail in Chapter 5.

Structural complexity

Informants also recognised the existence of a complex vertical structure within the coffee farms and the contribution this makes to providing habitat for fauna. Although not discussed in terms of its role in maintaining and increasing biodiversity, they identified the preferred habitat for a number of species as being at a specific level or strata. Table 4 and Figure 10 illustrate the preference of some birds and animals for a nesting site at or near ground level - at ground level utilising the soil, weeds, leaf litter, stones and caves, and Plate 1 shows a bird nest in the undergrowth of a coffee farm in Las Parcelas.

Table 4: List of statements showing recognition of the role of vertical strata at or near the ground for biodiversity

506: flying of palomas frequency is infrequent causes nesting of palomas location is on_ground
688: flying of palomas frequency is infrequent causes nesting of palomas location is near_ground
607: birds size is small causes nesting of birds location is near_ground
528: the quantity of leaf_litter is high causes snakes nesting leaf_litter
705: growth of weeds density is dense causes bats sleeping weeds
903: topo_talpusas nesting holes in soil if soil colour is black and the stone_content of soil is low

Plate 1: Birds on the ground in a coffee farm in Las Parcelas.

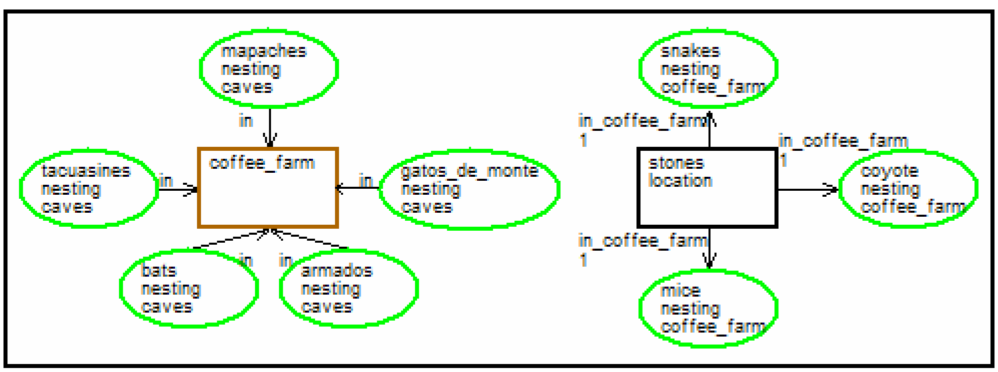


Figure 10: Causal diagram showing the importance of features at ground level in providing habitat.

Figure 11 shows the coffee bush itself, at the next vertical level, providing a habitat for snakes and small birds.

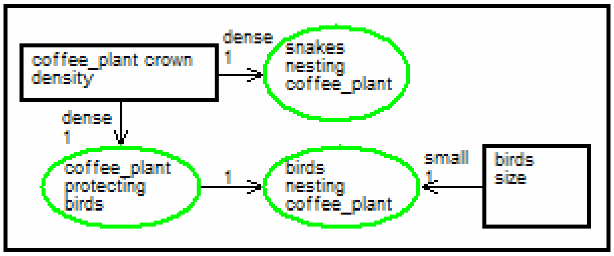


Figure 11: Causal diagram showing the properties of the coffee plant bush that attract different faunal elements

Lastly, Figure 12 shows specifically the importance of tall trees in providing habitat, particularly for large birds and ardillas (squirrels), as their height provides increased protection.

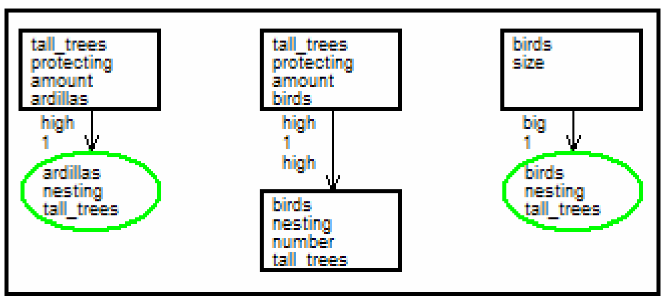


Figure 12: causal diagram showing the importance of the height of trees in providing habitat.

Habitat diversity

While different structural levels provide habitat for different fauna, informants recognised that other features that could be found within coffee farms were also important for particular species, each feature again providing a unique habitat. Figure 13 illustrates that trees with a dense crown are frequently sought out by birds due to their crowns providing increased protection against the elements and predators.

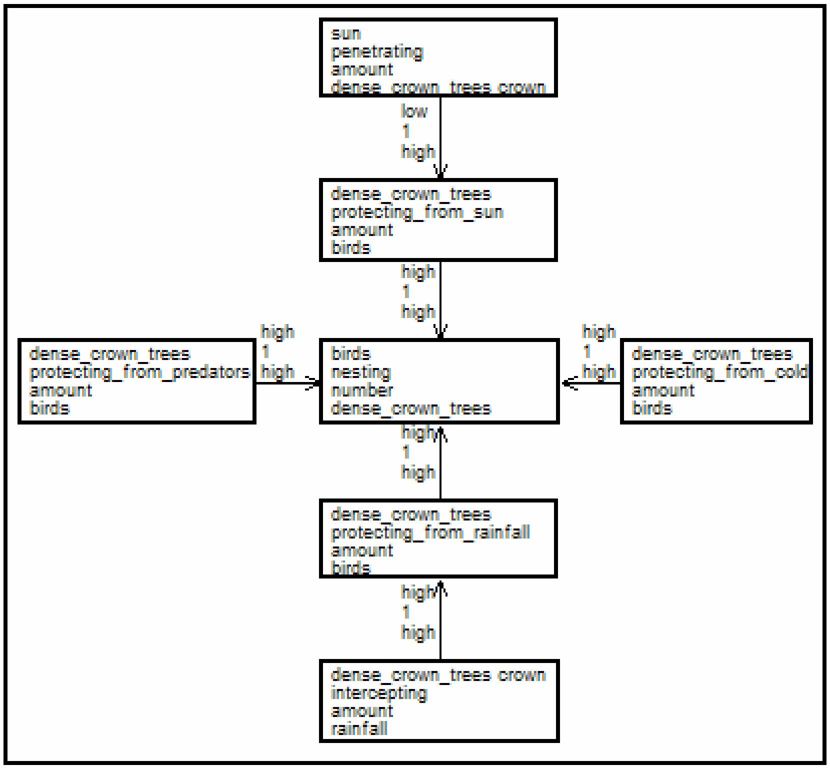


Figure 13: Causal diagram showing the preference of birds for trees with a dense crown and the reasons why.

Informants emphasised however that each bird or animal would have its own requirements and preferences, so dense crowned trees would not suit all. Table 5 illustrates this with the examples of tasiscovo, which has straight branches that attract squirrels, and mano de león, where it's more open crown is preferable to some birds. It also shows how the edge of coffee farms, where thickets are often growing naturally, can be an important habitat for a particular bird, the paisana.

Table 5: List of statements giving examples of the diverse preferences for particular types of habitat that can often be found within coffee farms.

923: paisanas nesting thickets in coffee_farm_edge
579: tasiscovo branch shape is horizontal causes ardillas nesting tasiscovo
1011: mano_de_leon crown density is not dense causes birds flying into_nest difficulty is easy

The maintenance of any dead trees as a habitat was not specifically mentioned, but informants showed an understanding of their utilisation, with reference to woodpeckers. They also had knowledge of the process whereby particularly species of pine remain standing after they have died, so providing a suitable nesting site (see Figure 14).

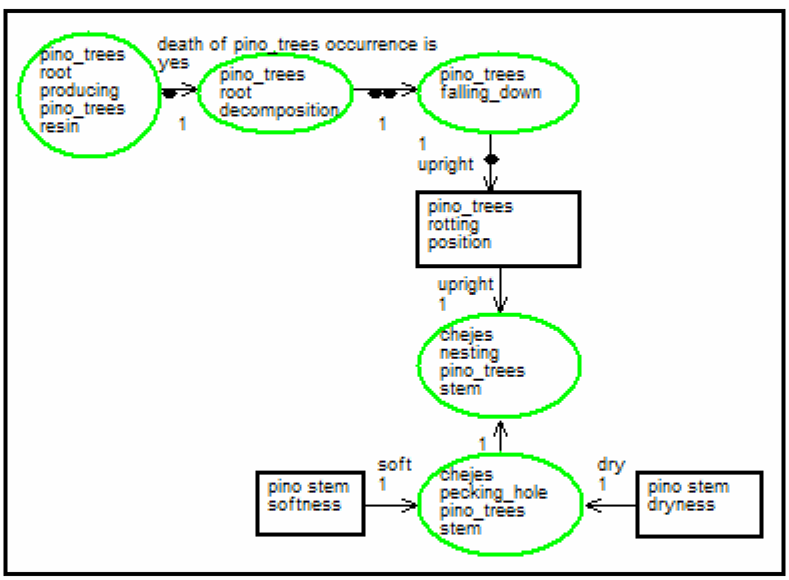


Figure 14: Causal diagram showing the process whereby pino remains upright after it has died, providing an important habitat for chejes (a type of woodpecker).

The utilisation of the soil itself, leaf litter, rocks and caves was outlined in section 3.2.2 in relation to structure, but each of these is also a separate feature that provides a distinct habitat for particular fauna that was recognised as such by informants.

3.2.4 Trees

As observed in section 3.2.3 a diversity of tree species was identified by informants as being an important factor in maintaining and increasing biodiversity, but emphasis was placed in particular on the role of fruit trees in providing a diverse and consistent supply of food. Informants also drew attention to specific trees that they considered attracted a greater variety of birds and animals than others. Figure 15 shows the different species of birds and animals that visit the amate and capulin trees primarily for their fruit, conspicuous by the number of different species actually named by informants. Table 6 shows general statements were also made about these trees attracting many different species of birds.

Table 6: List of statements showing a general recognition of trees that attract a great number and/or diversity of birds.

340: nispero fruit sweetness is sweet causes the number of birds eating nispero fruit is high
1012: birds eating amate fruit diversity is diverse
1013: birds eating capulin fruit diversity is diverse
686: the amount of capulin producing capulin seed is high causes the number of birds visiting capulin is high

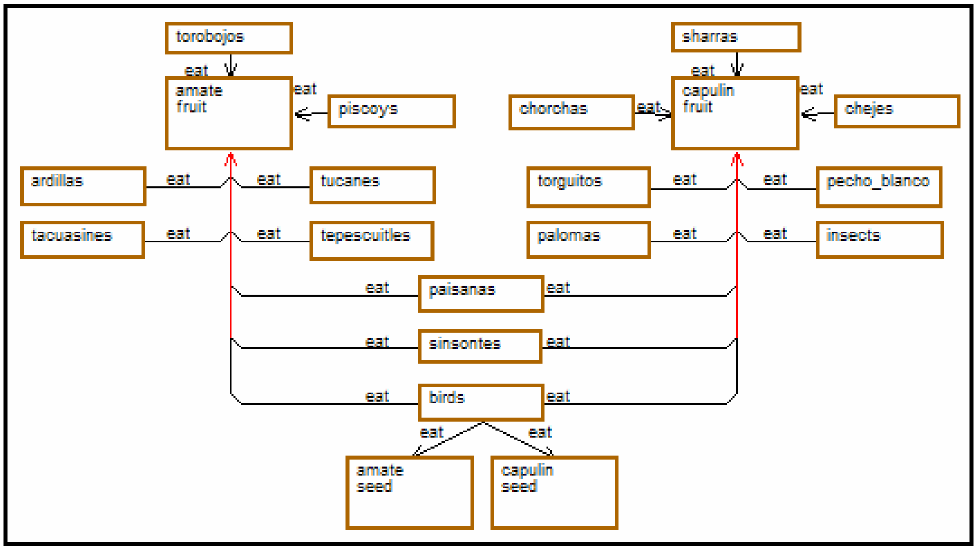


Figure 15: Link diagram illustrating the number of bird species attracted to amate and capulin due primarily to their fruit.

Other species of tree are also clearly important though; Table 6 also shows nispero attracting a great number of birds, and Figure 17 (see section 3.2.5) illustrates how many birds are attracted to cuje by virtue of the worms that eat its leaves. The important relationship between birds and insects was highlighted in section 3.2.2, so this is obviously a significant factor in attracting birds to particular trees. The statements listed in Figure 14 indicate that the quantity of fruit produced by a tree, and the sweetness of the fruit, are also factors.

3.2.5 Perception of biodiversity

In general, informants viewed the diversity of fauna that visit and inhabit their coffee farms positively, particularly the presence of birds; many referred to the pleasant environment created by the birds singing. To some extent then there was an intrinsic appreciation of biodiversity, not attached to any perceived benefit it incurred. There were also however various more concrete benefits and disadvantages identified, and these will be considered in turn.

Benefits

Informants observed that birds had a role in dispersing seeds and fruit that caused natural regeneration of tree species within the coffee farms (see, section 3.2.3, Figure 9) and many viewed this mostly as positive as it brought existing and new species that may be good with coffee. They acknowledged that species they did not consider to go very well with coffee may also naturally regenerate due to this, but did not state that it was a bad thing. Seed and fruit dispersal by birds was seen more as an advantageous natural process.

The relationship between birds and insects described in section 3.2.2 was identified by informants as being important in certain instances for the control of pests within coffee farms; the statement below illustrates this general effect.

607: birds eating insects causes a decrease in amount of insects damaging coffee_plant

Figures 16 and 17 give examples of how birds eating spiders and worms (names identifying more specific species or species groups were not given) decreases the damaging effect they can have on the coffee plant and cuje tree. This role that birds fulfil is particularly important for all informants as none apply pesticides or insecticides.

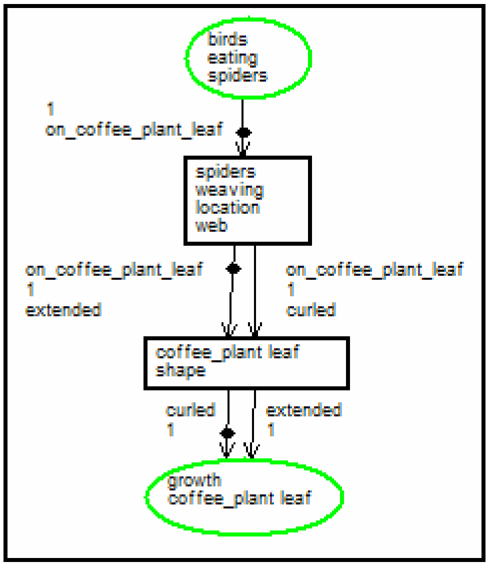


Figure 16: Causal diagram showing the beneficial effect that birds eating spiders has for the growth of the coffee plant.

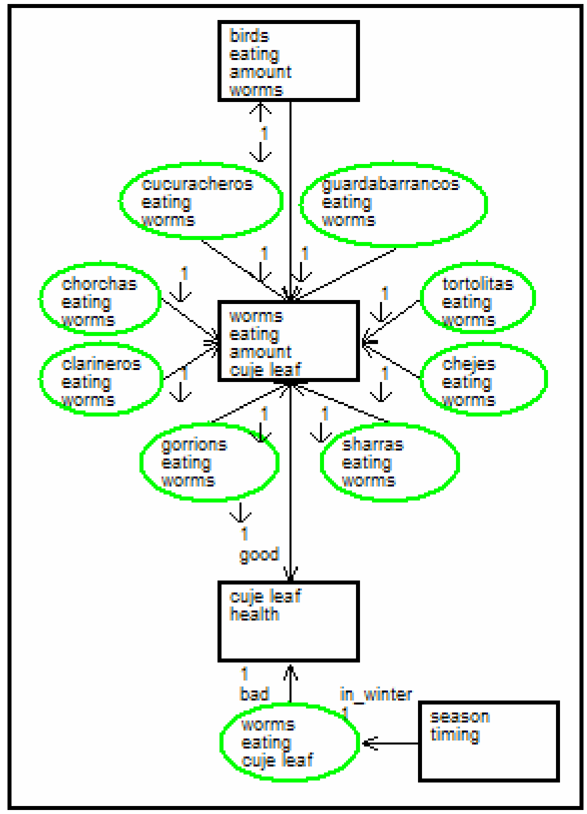


Figure 17: Causal diagram showing the beneficial effect that birds eating worms has for cuje.

Informants recognised however that insects could also have a positive role to play in the pollination of the coffee plant, as well as birds, in particular gorriones (humming birds), and bees (see Figure 18). While the majority recognised these vectors of pollination, those informants with coffee farms in communities higher up the watershed thought that their proximity to forest increased the effect.

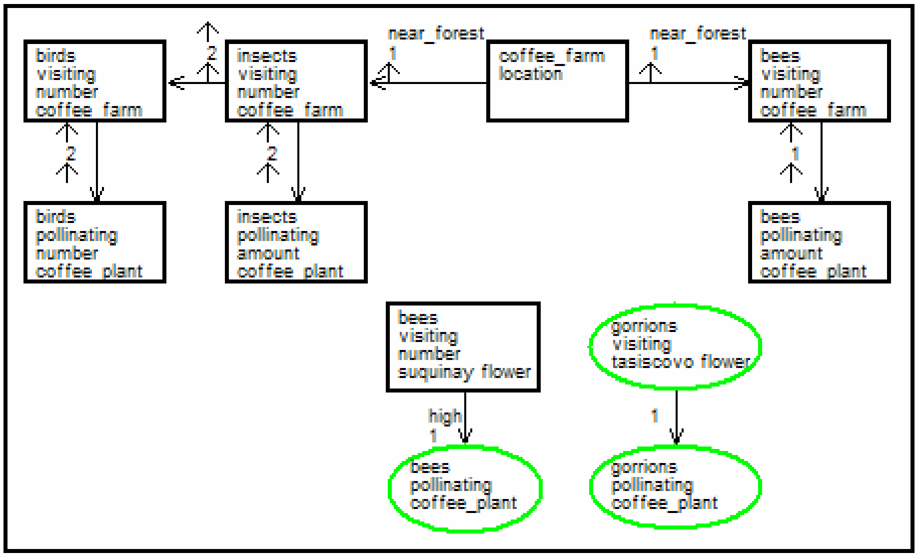


Figure 18: Causal diagram showing the beneficial effect of birds and insects in pollinating the coffee plant.

Informants also recognised the role of various elements of biodiversity in maintaining and improving soil fertility. Figure 19 illustrates the three main contributory elements outlined by informants as being a high number of birds and animals, a diversity of tree species and the presence of worms and microbes in the soil. Birds, animals and trees contribute their dung and leaves as nutrients, and worms and microbes are responsible for the decomposition of leaf litter that turns it into organic matter.

Most informants were aware of the role of worms in decomposition, but only a minority mentioned the action of microbes. Some informants were also able to identify the specific nutrient contained in the leaf of particular tree species, e.g. nitrogen in the leaf of cuje, potassium in the leaf of nispero, or calcium in the leaf of guayabo, but they were in the minority. The majority of informants however recognised that a variety of nutrients existed, and the leaves of different tree species would contribute something different to the soil, the combination of which was better than one alone. This provided a strong incentive to maintain a diversity of species within their coffee farms.

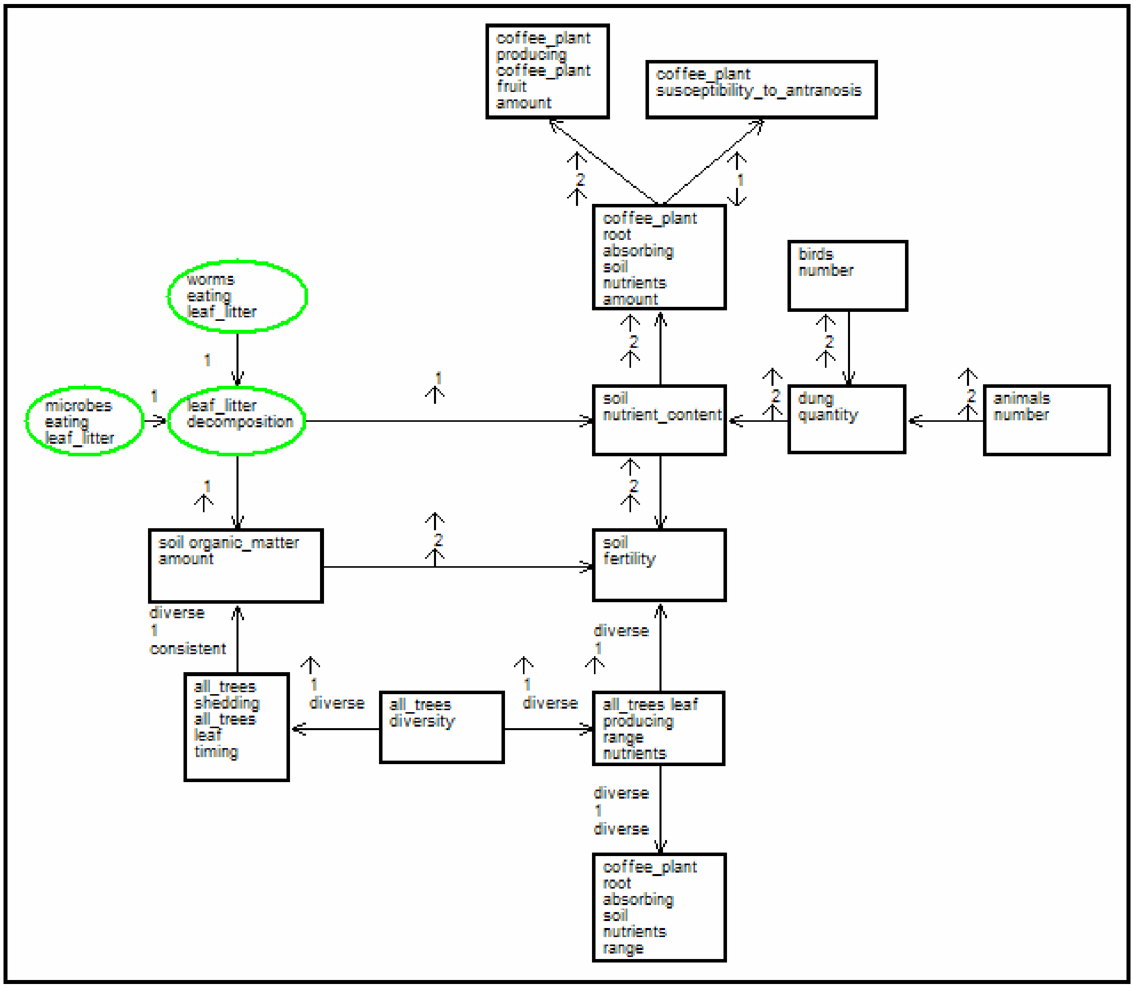


Figure 19: Causal diagram showing the beneficial effects of different elements of biodiversity for soil fertility and the growth of the coffee plant.

Informants also recognised the role of worms in increasing the permeability of soil, improving the growth of coffee (see Figure 20).

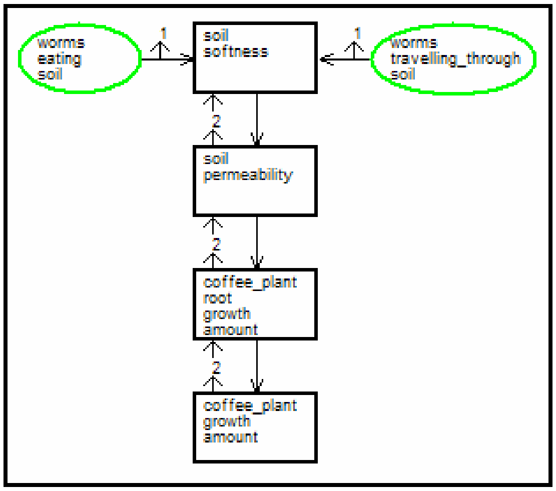


Figure 20: Causal diagram showing the beneficial effect of worms on the permeability of soil.

Besides the high number of tree species contributing to soil fertility as outlined above, informants also saw this as a benefit economically. The object hierarchies (see Figure 5, section 3.2.2) classify the various uses made of different trees, illustrating the importance of maintaining a greater diversity of species. Trees are used as firewood, to provide energy for cooking and heat, as medicine, and for their wood. This latter use provides material for constructing buildings and fences, but trees with good quality wood also provide income when needed. Fruit trees are also important for subsistence, and farmers sell the excess at the local market.

The hunting of birds and animals was not discussed by the majority of informants, whether in connection to the benefits and disadvantages of biodiversity or not. Some informants however, notably those with coffee farms at the lowest altitude visited, mentioned during interviews that a particular bird was good to eat, perhaps indicating that some informants viewed the number and diversity of birds and animals that visited their coffee farms, in close proximity to their households, as beneficial in providing a source of food.

Disadvantages

The main problems encountered by informants were of birds and animals eating the pulp surrounding the coffee bean, and animals eating their chickens. Figure 21 shows the main birds and animals that eat the coffee pulp, and a list can be found in the knowledge base under the object hierarchy 'animals_that_damage_coffee'. However, all informants indicated that they only turn to coffee when the availability of other food sources is low, and that they do not consider the amount of coffee lost to their predation to be significant enough to warrant any efforts to stop it. Many informants also expressed the view that all birds and animals are simply trying to survive so it would be wrong to hunt them on that basis alone. The statement below made by one informant summarises this viewpoint.

516: killing of animals_that_damage_coffee causes nature balance is imbalanced

However, as outlined earlier in this section, it is not true to say that informants stated that they did not hunt birds or animals at all. Table 7 lists statements showing which animals prey on chickens belonging to the households of informants, and Figure 22 shows that they have been and are hunted, but that there is also a willingness to find solutions to this problem, the constructing of chicken runs, to the benefit of both informants and the animals themselves. There is also an understanding that, as with the birds and animals that eat coffee pulp, that generally this only occurs when the availability of other food sources is low.

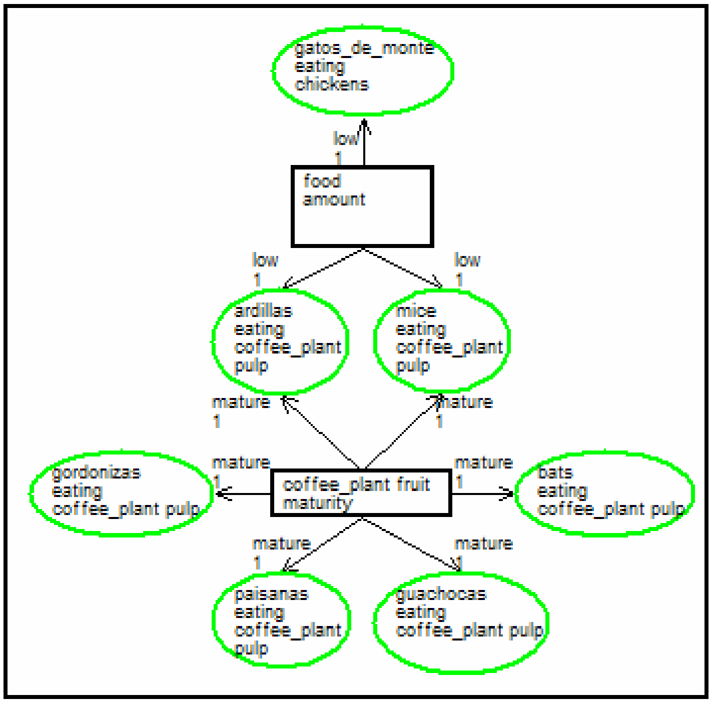


Figure 21: Causal diagram showing which birds and animals eat part of the fruit of the coffee plant.

Table 7: List of statements showing which animals eat chickens.

249: the amount of food is low causes gatos_de_monte eating chickens
829: coyote eat chickens
832: tacuasines eat chickens
843: corluyos eat chickens

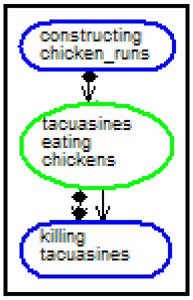


Figure 22: Causal diagram depicting the interaction between tacuasines and humans.

3.3 Water conservation

3.3.1 Initial impressions

In general all informants also had a depth of knowledge about the conservation of water within their coffee farms. Those characteristics identified as affecting the water balance, and the statements made about them, were consistent. This means it was possible to classify different tree species according to these various characteristics and make statements about different tree 'types' and their effect on water.

Much of the discussion during interviews around the issue of water conservation was centred around the growth of coffee to make the subject area relevant to informants. The maintenance of an appropriate level of humidity for the optimum growth of coffee is an important aspect of coffee management, and informants explained that at different times of year more or less humidity is needed according to the stage of growth of the coffee plant. The different conditions that prevail in each season and at different altitudes also impacted on humidity levels and the manner of management. Through the practice of attempting to control the level of humidity within their coffee farms then, the majority of informants had a good knowledge of the possible factors affecting the water balance. It is also interesting to note that most informants also had an awareness of the conservation of water beyond the immediate locality of their coffee farms.

In this section each feature identified by informants as affecting humidity, and its characteristics, is discussed in turn; these are:

- Tree canopy
- Leaf litter and understorey vegetation
- Soil
- Roots

The water balance at landscape level is also considered, and the merits of individual tree species.

3.3.2 Tree canopy

The tree canopy as a whole plays an important role in the conservation of water as it is the medium through which the effects of the sun and rainfall are filtered. Informants understood the basic protection that a canopy of trees in general provided by filtering sunlight and so reducing the evaporation of moisture from the soil, and also in reducing the erosivity of rainfall and thus runoff of water. They also recognised that the capture of rainfall by the tree canopy could decrease the amount of rainfall reaching the soil, so preventing the input of that moisture into the system.

Informants identified these two processes then as being key factors in influencing the water balance: the interception of rainfall, and the penetration of the sun. They also recognised differences in the crowns of different tree species that would mediate the effects of these processes to varying extents. As the differences and effects identified were consistent, tree species were classified within the knowledge base accordingly. In terms of these two processes, informants considered that crown density, leaf size, leaf texture and tree height were significant factors. Tree species were classified then as dense crowned, sparse crowned, having small or large leaves, having soft or stiff leaves, or as short or tall. The tree species included in each category can be found in the appropriately named object hierarchies in the knowledge base.

Figure 22 illustrates the different effects these attributes have on the two processes identified. Dense crowned trees and large leaved trees capture more rainfall so allowing less to reach the ground, but also filter the sun more effectively to decrease soil moisture evaporation, whereas sparse crowned trees and small leaved trees let both more rainfall and sunlight through. The point was also made however that rainfall does still penetrate dense crowned trees, and as it does so slowly, moisture in the soil can be maintained over a longer period of time. The general statement below

1016: all_trees crown intercepting rainfall causes rainfall flowing_down all_trees stem

also shows the way in which rainfall can penetrate the crown and reach the soil regardless of its density.

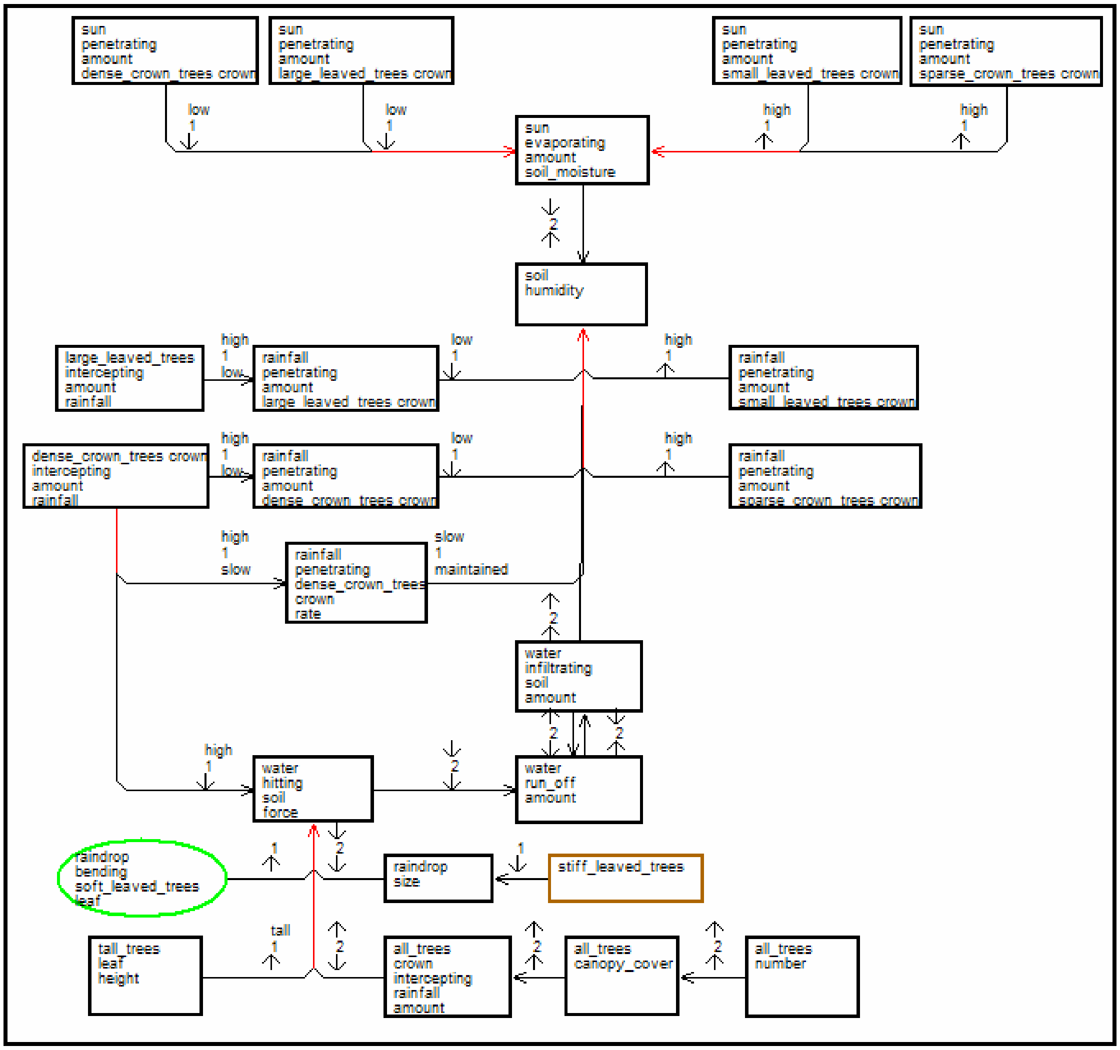


Figure 22: Causal diagram showing the influence of different types of tree crown on soil humidity and the water balance within coffee farms.

In terms of the erosivity of rainfall, dense crowned trees and trees with stiff leaves were identified as having a positive effect. As dense crowns capture more rainfall they decrease the height and so the force with which raindrops fall to the soil; as outlined above, rain is also more likely to reach the soil more slowly via the stem. In contrast, as the branches of tall trees are higher above the ground, rain captured by the crown would fall from a greater height and hence with greater force. Stiff leaved trees break up raindrops into smaller droplets, which also decreases their force and hence impact on the soil, whereas raindrops just bend a soft leaf and roll off it, so the leaf does not reduce the size and hence impact of the raindrop as effectively.

Informants also explained the interaction between the eight different characteristics identified for those tree species that exhibited more than one. To give an example, species of pino (pine) have both dense crowns and small leaves; in this case although the leaves are small, as they grow together densely the crown would intercept a high amount of rainfall, and not allow much penetration of the sun. Canopy density therefore has a greater influence than size of leaf. It was also emphasised that, in the case of a tall tree with stiff leaves, e.g. balsamo, while raindrops would have a greater force due to the height, their smaller size due to the stiff leaves would decrease the force of impact from that which it would have been had the tree had soft leaves.

3.3.3 Leaf litter and understorey vegetation

Informants recognised the leaf litter layer and understorey vegetation as also having a role in mediating the impact of the two processes described above: the penetration of the sun and the interception of rainfall.

There was a general understanding of the protection leaf litter affords the soil against the evaporation of moisture by the sun, but again informants highlighted factors that affect this protective capacity; these were the quantity of leaf litter and the extent of its coverage.

Again, informants noted differences in the leaves and the leaf fall of different tree species that contributed to the level of these factors, allowing the further classification of tree species into those that shed a high amount of leaves and those that didn't. These object hierarchies appear in the knowledge base as high_leaf_shedding_trees and low_leaf_shedding_trees. The size of the tree leaf also had an effect, allowing further statements to be made about small leaved and large leaved trees.

Informants explained that the majority of the trees within their coffee farms are evergreen and shed leaves throughout the year, although more in the summer months. High leaf shedding trees literally shed a larger quantity over any period than low leaf shedding trees.

Figure 23 illustrates the effects these characteristics have on the quantity and coverage of leaf litter. High leaf shedding trees create a greater quantity of leaf litter, and large leaves cover a greater area of soil than small leaves, so these are considered as providing more effective protection against evaporation. Informants also noted the protection that weeds provide against this.

Informants recognised the general protection the leaf litter layer provides against the erosive force of the rain, which decreases the runoff of water. They also pointed to a self-reinforcing effect whereby a decrease in the runoff of water also means that less leaf litter is washed away, so remains on the top of the soil to continue to provide protection.

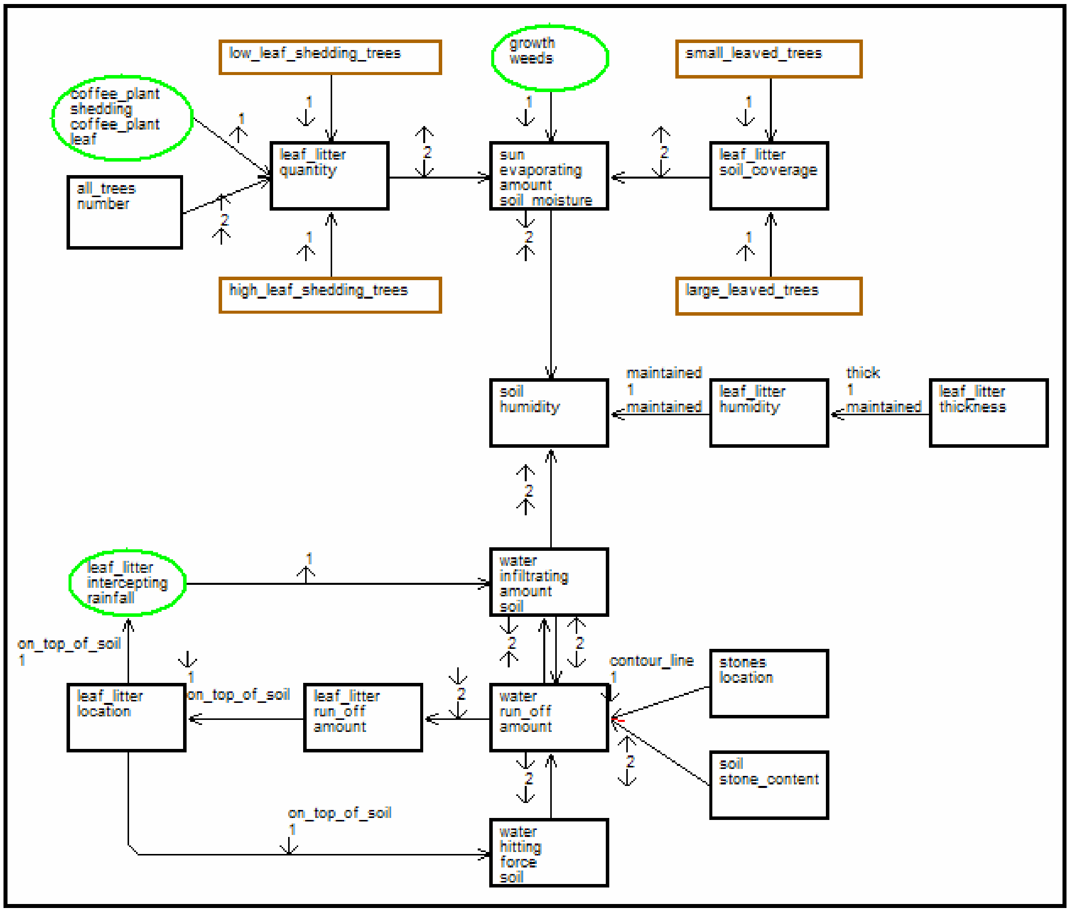


Figure 23: Causal diagram showing the influence of ground vegetation on soil humidity and the water balance within coffee farms.

The way in which water remains within the coffee farm and does not flow away even when its force has been diminished by the canopy and leaf litter layer was also described. A number of informants spoke of the leaves 'consuming' water, meaning that they intercept rainfall in a similar manner to the way in which the canopy does, allowing it seep gradually through to the soil. In this way leaf litter actually aids the infiltration of water into the soil.

Informants also recognised that the presence of stones helped to decrease runoff, both naturally present in a high quantity in the soil, and also purposefully placed on contour lines.

3.3.4 Soil

Soil type was also considered to have an effect, notably on the infiltration of water into the soil. Three main soil types were recognised, named according to their colour: black soil, yellow soil and red soil. Table 8 summarises their main properties.

Table 8: Soil types and descriptions

<table>
<tr><th>Soil</th><th>Content</th><th>Fertility</th><th>Permeability</th><th>Humidity</th></tr>
<tr><td>Black soil</td><td>High organic matter and sand content</td><td>High</td><td>High</td><td>Maintains humidity well</td></tr>
<tr><td>Yellow soil</td><td rowspan="2">High clay content</td><td rowspan="2">Low</td><td rowspan="2">Low</td><td rowspan="2">Tends to become waterlogged in winter and dries out in the summer</td></tr>
<tr><td>Red soil</td></tr>
</table>

Informants made clear that some soils may be also be a mix of these types, e.g. 50% black soil and 50% yellow soil, but they did not have distinct names for them. Figure 24 shows the effect of the different properties of the soils on their permeability and hence water infiltration. A high organic matter and sand content are seen as improving permeability, therefore black soil is the ideal and allows the greatest infiltration of water. There is also an understanding of the role that trees can play in improving soil by adding organic matter through the decomposition of leaf litter, although informants appreciated that structural change of a soil by this process would take a long time. One informant had had direct experience of this, having planted coffee on soil with a high clay content that had been compacted by livestock grazing. After 16 years he observed that the organically rich topsoil had grown to 10 cm in depth.

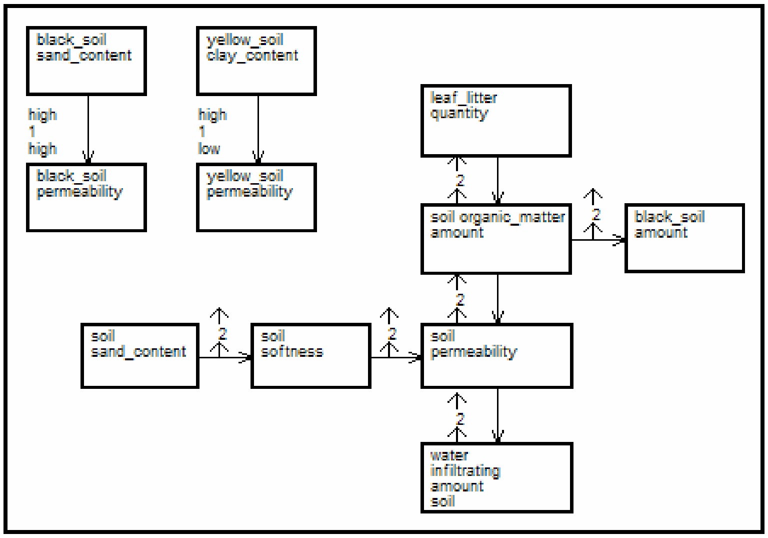


Figure 24: Causal diagram showing the influence of soil type on soil infiltration.

3.3.4 Roots

The roots of trees were understood to have a complex role in the conservation of water. There was an understanding of the ways in which roots aided in the conservation of water, but also of how they removed water from the system. The main processes involved are the absorption of water from the soil through the root, and roots enabling infiltration of water into the soil.

Again informants distinguished amongst tree species according to differences in their roots. Whilst all roots were understood to grow extensively in length in the topsoil due to the higher concentration of nutrients there, the important difference recognised as affecting the uptake of water and nutrients was the amount of roots. Tree species classified as having many or few roots can be found in the knowledge base under the object hierarchies low_root_trees and high_root_trees. Figure 25 illustrates how trees with few, more sparsely spread out roots absorb less water, while trees with many, dense roots absorb more water and affect the humidity of the soil adversely.

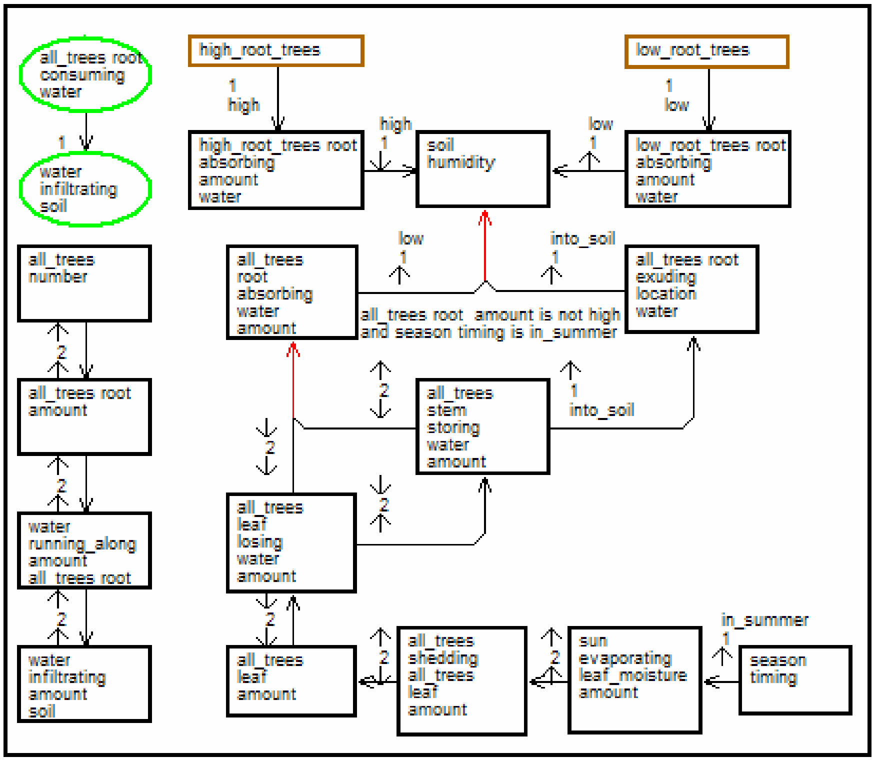


Figure 25: Causal diagram showing the influence of tree roots on soil humidity and the water balance within coffee farms.

It is important to note here however that informants still maintained these tree species within their coffee farms. Part of the reason for this is outlined in section 3.2.5, as many tree species are useful over and above their use as a shade tree with coffee. However, informants also stated that trees with high roots (and other trees with qualities considered negative for coffee) did not cause many problems if they were well spaced apart and kept at a minimum within the coffee farm. This is reflected in the general practice of not cutting every tree that may not go so well with coffee. Cutting is generally only carried out when the cover of shade is considered to be enough and more shade would be damaging, or when there are already many of that particular tree in the coffee farm.

Informants understood then that all trees, even those without a great density of roots, absorb some water from the soil in order to survive. By some water was described as the life blood of the tree, being absorbed by the roots and passing up the tree stem. Informants also thought however that all trees to some extent have the capacity to maintain water within their stems during the summer months. This is thought to be related to the fact that they shed more leaves thus absorbing less water through their roots. Some informants thought that also due to this some trees, although not those with lots of roots, could exude water from their roots into the soil. In this way, while trees take away moisture from the soil, it is thought that they can help to maintain its humidity at a time when there is little rain. This process is shown in Figure 25. The enhanced ability of particular tree species to do this is discussed in section 3.3.6.

Many informants also recognised that the roots of trees aided the infiltration of water into the soil. While many were unable to articulate how this process worked, but had an understanding that it took place, some explained how water travelled along the length of the root below ground, one informant likening the root to a vein.

3.3.5 Landscape level

The previous sections have described the understanding and explanations of informants of the main factors influencing the water balance and humidity within their coffee farms, which has arisen from their observations of the growth of the coffee plant and the condition of the soil, and the experience of managing the level of humidity. However, many informants also showed an understanding of the effect of their coffee farms at landscape level. They saw them as helping to maintain and feed streams and water sources for themselves, and also believed that the humidity travelled downwards to help feed streams lower down the watershed.

Many informants were unable to articulate precisely the processes by which this occurred, but all attributed it to the tree cover within coffee farmers, and the ways in which humidity is maintained throughout the year, particularly throughout the summer. One informant compared coffee farms favourably to the production of sugar cane, drawing from her own experience of seeing a neighbour replace his coffee farm with it. All the trees had been cut down and she said it was very dry there now. Others were able to explain more explicitly that some of the water infiltrating into the soil, that was not used by the plants within the coffee farm or evaporated from the soil, would flow underground as groundwater, which would feed water sources. As it flows underground from higher altitudes to lower altitudes, it would also help to maintain water sources further down the watershed.

Figure 26 draws together the knowledge of informants of those factors that affect the water balance, as described in the previous sections, to present a picture of the way in which trees in general help maintain humidity, particularly enabling the greater infiltration of water into the soil.

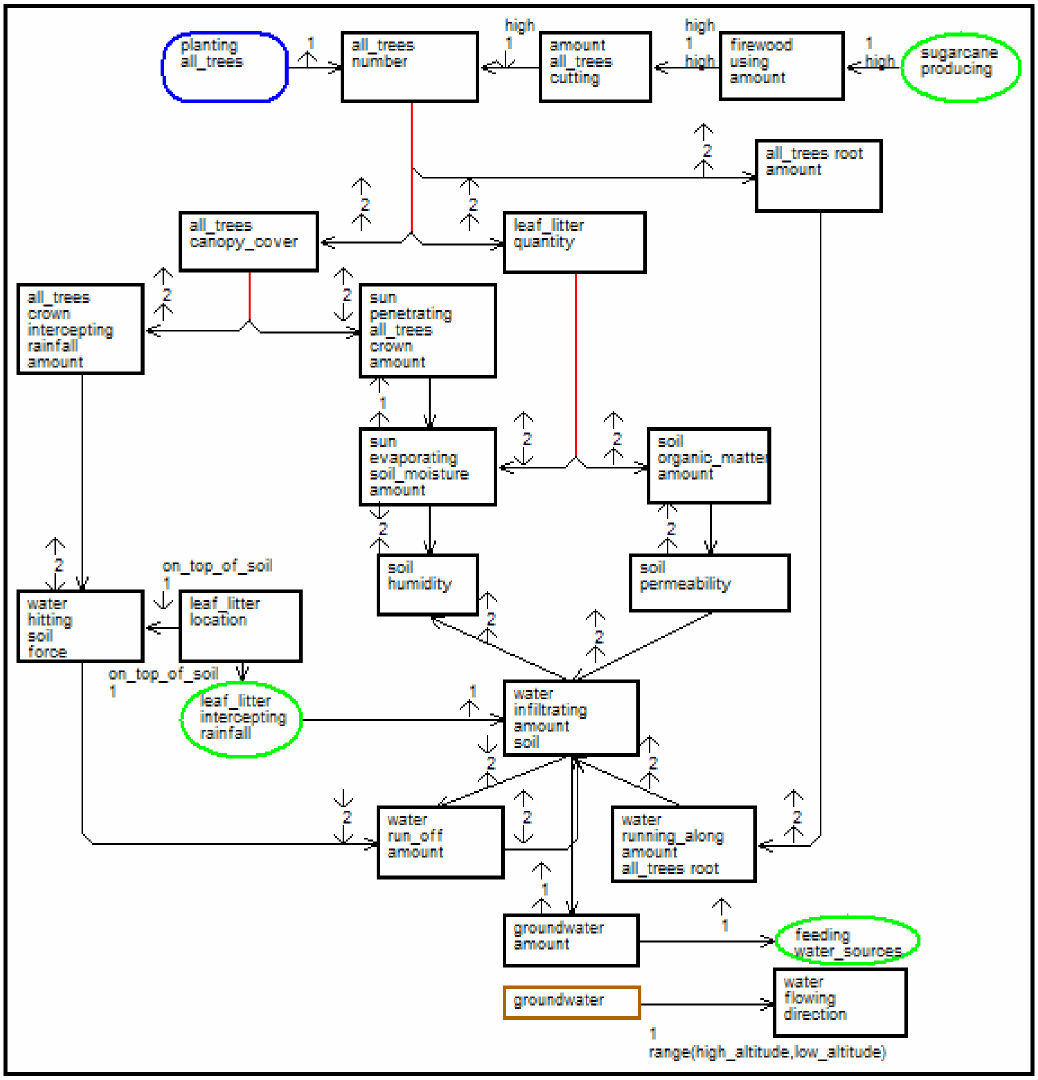


Figure 26: Causal diagram showing the overall influence of trees on the water balance at landscape level.

3.3.6 Trees

Many informants singled out particular tree species as being especially able to conserve water within their stems, and therefore maintain the humidity of the soil through reducing the absorption of water through their roots. The scientific term for this is succulency. In addition, informants said that these trees could improve the humidity of the soil by exuding water back into the soil through their roots. The six tree species identified by informants are shown in Figure 27.

In addition, some informants spoke of the roots of two of these tree species, amate and cedro, as actually 'attracting' water. Although they could not explicitly explain how, there was agreement that both species have long, deep roots. There also seemed to be a consensus that if amate was growing by a water source, it would attract more water, but nobody was sure if the water or the amate tree appeared there first.

It is also interesting to note that four of these species, amate, cedro, guarumbo and madre de cacao are deciduous and lose their leaves during the summer.

Plate 2: Inside of guarumbo bark cut off by an informants to demonstrate the moisture in the stem in Los Albores.

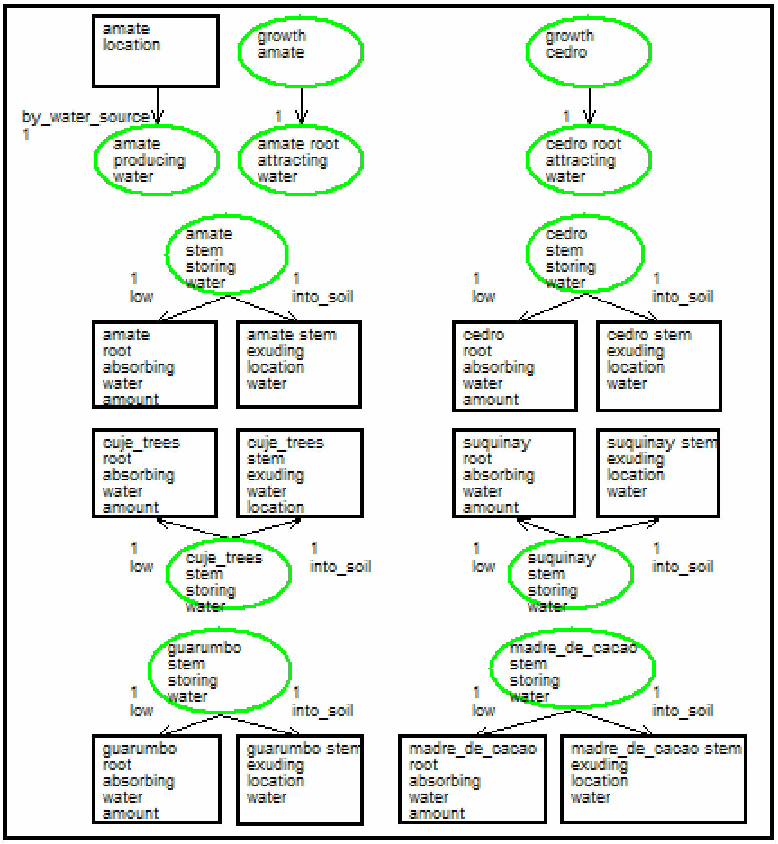


Figure 27: Causal diagram showing the beneficial effect of specific tree species on the water balance within coffee farms.

Many informants also drew attention to pino species, which, from their observations, appeared to intercept the water droplets in clouds such that, in one informant's words, it rained without there being rain (see Figure 28). While viewing pino species as good for humidity, informants also recognised that, with a high amount of roots, it also absorbed a lot of moisture from the soil around it.

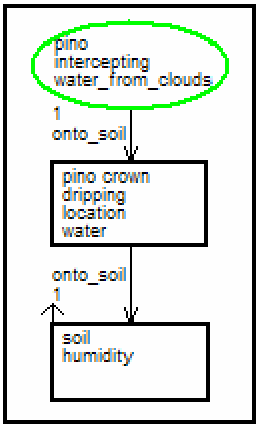


Figure 28: Causal diagram showing the effect of pino on the humidity of the soil

3.4 Differences in knowledge amongst informants

There were no real inconstancies in the statements made by informants, but there was a different in the amount that some informants knew or were able to articulate. The bulk of the useful, explanatory knowledge has been described in this section, but it is important to note that not all informants were able to explain processes or observations to the same depth.

This is most notable in some informants referring to trees as 'caliente' (hot) for coffee, i.e. it was observed that coffee did not growth well under that tree. There were informants who used this term and were able to give explanations, e.g. a dense crowned tree does not let enough light through (unless it is pruned), or a tree with many roots competes with coffee too successfully for water and nutrients. But others, as they observed the leaves of the coffee plant turning yellow, thought that somehow the tree was burning the plant or that there was a physical transfer of the colour yellow from the tree to the plant.

4: Comparing Scientific and Local Knowledge

4.1 Introduction

This chapter seeks to compare systematically local knowledge described in the previous chapter and scientific knowledge obtained from the literature. Such comparison looks at what knowledge is complementary and what is contradictory, to identify knowledge gaps and enable appropriate direction of further research and training. A synthesis of both knowledges can also enhance our understanding of the subject area.

4.2 Comparison of knowledge

4.2.1 Biodiversity

Fauna

There have been a number of studies conducted on the level of biodiversity within multistrata coffee agroforestry systems, focused particularly on Central America and covering different taxa. In general local knowledge agrees with scientific findings that these systems support a high diversity of many different taxa.

For example studies have typically documented over 100 different bird species and a diversity of mammals of typically between 20 and 30 different species (Faminow and Rodriguez 2001). While informants did not name quite as many, the results showed that they recognise differences between species but often use the same name to refer to them if they appear to belong to a group that exhibit similar characteristics. It is therefore likely that they recognise a greater number of species than they actually give distinct names to. Local knowledge also supports the findings of studies that a wide variety of mammalian taxa are present including bats, marsupials, rodents, rabbits and carnivores.

The amount of research carried out on reptiles, amphibians, arthropods, macrofauna and microbes is limited. However, the studies that exist indicate that multistrata coffee ecosystems are likely to support a great diversity of these species. Studies have noted in particular that the high incidence of trees that bear flowers and fruit attract a great diversity and number of insects (Faminow and Rodriguez 2001; Calvo 2001), agreeing with local knowledge. Scientific knowledge and local knowledge also both recognise the 'symbiotic' relationship between insect and bird populations, whereby an increase/decrease in one leads to an increase/decrease in the other (ibid.). Calvo 2001) noted that the use of chemical insecticides lower insect numbers and hence bird numbers.

Informants described all the various taxa and species they identified as being from the coffee zone, i.e. they had not originated from the forest. Many also explained that forest species did not visit the coffee farms both because they were adapted to a colder climate at higher altitudes, and also due to the greater inhabitation by people. Scientific studies support these explanations, finding a lesser number of specialist forest species within multi-strata coffee systems due to reduced habitat complexity, increased disturbance and affects of fragmentation, (Donald 2004). However, many studies do suggest that coffee systems can provide an important refuge for forest species in the event of deforestation.

Studies have also emphasised the importance of multi-strata coffee systems for migratory birds, although their number and species richness has been found to be less than resident birds; of the total number of birds recorded, Calvo (1997) found that 80% were residents and 20% were migrants. They are also only present at particular times of year; increased tree flowering and fruiting during winter has been found to be important for attracting them. Informants however only mentioned one migratory bird that they thought came from a long distance, and even then thought it had got lost. They were more aware of local migration, and recognised that mountain birds visited the coffee farms in the winter for food sources and a more favourable climate. It may be that as resident birds usually live in or visit the coffee farms throughout the year, and the same mountain bird species visit every winter, informants are naturally more familiar with them. However, as no studies of resident and migratory bird diversity have specifically been carried out in the River Hato or nearby watersheds for comparison, it should not be concluded that this necessarily indicates a gap in the knowledge of informants. One study has suggested that migratory birds are more commonly found in coffee plantations at a greater distance from forest (Donald 2004). It may then actually be the case that not many migratory birds visit the coffee farms in this area.

Flora

The number of tree species identified by informants is very much on a par with the number found in studies on coffee agroforestry systems commonly described as traditional rustic or polyculture systems. They identified 61 different species, which is at least equal to or higher than numbers scientifically documented (Faminow and Rodriguez 2001).

Informants did not mention many other shrubs or plants by name, but in relation to understorey vegetation apart from coffee spoke generally of weeds. Studies have concentrated mainly on the faunal element of biodiversity, but some have documented a high diversity of plant species other than trees, including species found in natural forest (Bandeira et al 2005). Epiphytes were not mentioned but studies have demonstrated their importance in increasing the availability of suitable habitat, particularly for insects; Calvo (2001) found complex communities of arthropods in epiphytes that were in addition an important food source for birds.

Factors affecting biodiversity

There are a wealth of studies within coffee agroforestry systems demonstrating that bird and mammal populations increase in numbers and diversity of species with greater structural diversity, giving examples of the different habitats that are created being utilised by particular species or groups of species with similar characteristics (Gallina et al 1996; Calvo 1997; Greenberg et al 1997; Faminow and Rodriguez 2001). Informants did not explicitly refer to structural diversity, but recognised the importance of different vertical levels, giving examples of their utilisation, often with an explanation of why. Studies have drawn attention to the additional habitat that tall trees provide for some birds (Calvo 1997; Greenberg et al 1997; Faminow and Rodriguez 2001), and informants also recognised their importance for larger birds and squirrels.

Studies highlight the equal importance of floristic diversity (Gallina et al 1996; Calvo 1997; Greenberg et al 1997; Faminow and Rodriguez 2001), a factor that was also emphasised by informants for the diversity both of habitat and food. In addition, studies agree with local knowledge that increasing floristic diversity increases the likelihood that tree species will fruit and flower out of synchrony with each other, so providing food resources more consistently throughout the year (Faminow and Rodriguez 2001)

Studies also note the importance of weeds in augmenting habitat diversity; Valle and Calvo (1999), in comparing differently managed and structured coffee agroforestry systems, found that more intensive management using herbicides that killed weeds very efficiently led to a decrease in diversity of all taxa. Again this was not mentioned explicitly by informants, but they recognised that they provide nesting sites for a variety of taxa and are a source of food for mammals.

Informants drew attention to the preference of some birds for trees with dense crowns. This was not something mentioned within studies in relation to birds, but Valle and Calvo (1999) noted that low light levels are important for bats as they reduce predation, and Calvo (2001) demonstrated the importance of shade for the survival and growth of epiphyte populations. These studies also highlighted how the maintenance of habitat is important for these species, and therefore that evergreen trees are preferable to deciduous trees.

Studies have generally viewed tree species as more important for biodiversity than the coffee plant, which has been shown to be poor for foraging and is not utilised as much by birds. Informants drew attention however to the fact that some small birds and snakes can often be found nesting in the coffee plant, highlighting its importance as an additional habitat.

Science shows that dead trees can increase habitat diversity for a number of taxa (McComb and Lindenmayer 1999. While local knowledge did not specifically refer to this role, informants did recognise the role of dead trees as providing habitat for woodpeckers.

The influence of forest patches has been noted by studies as having an impact on levels of biodiversity, but this was not noted by informants apart from proximity to forest increasing the pollination of coffee, which has also been recognised in the literature (Calvo 2001; Ricketts 2004). Ricketts (2004) also highlighted the potential for bees to find nesting sites and access to floral resources within multi-strata coffee systems to perpetuate their populations, and indeed informants did note the presence of bees nesting in the hollows of trees within their coffee farms.

Cuje was mentioned by science as being beneficial for biodiversity through the provision of fruit and seeds (Calvo 2001), but there is little scientific information on the other tree species mentioned by informants and their role in increasing biodiversity.

Advantages of biodiversity

Studies have shown that birds and animals, including bats, aid in natural regeneration by dispersing seeds, and that they can also help to control pests (Calvo 1997; Valle an Calvo 1999). Informants recognised the role of birds, but that of animals and bats was not mentioned.

There is also agreement between scientific and local knowledge that soil fauna are crucial for soil fertility, and also that increased diversity of tree species can improve these services through probable differences in the timing of litter fall (Swift et al. 2004). Local knowledge also highlighted the role of birds and animals in providing dung.

4.2.3 Water Conservation

The hydrological cycle as it relates to tree cover and as it is understood by science consists of 7 main processes at work that both introduce water into and remove water from the system (see Figure 29). Scientific knowledge recognises four ways in which water reaches and enters the soil in systems with tree cover: precipitation that falls directly through or around the tree crown (throughfall), precipitation that is intercepted by the canopy and falls from the leaves, water flowing down the stem, and the infiltration of water in the soil. Conversely water is removed from the system by the evaporation of water from the stomata of the leaves (evapotranspiration), evaporation of rainfall intercepted by the tree crown, and runoff of water on the soil surface (INAB 2005, Huxley 1999, Imbach et al 1999, Rao 1998). The results show that informants had a basic understanding of nearly all of these processes. While they recognised that the tree canopy intercepts rainfall and prevents it from reaching the soil, they did not state that this is due to evaporation.

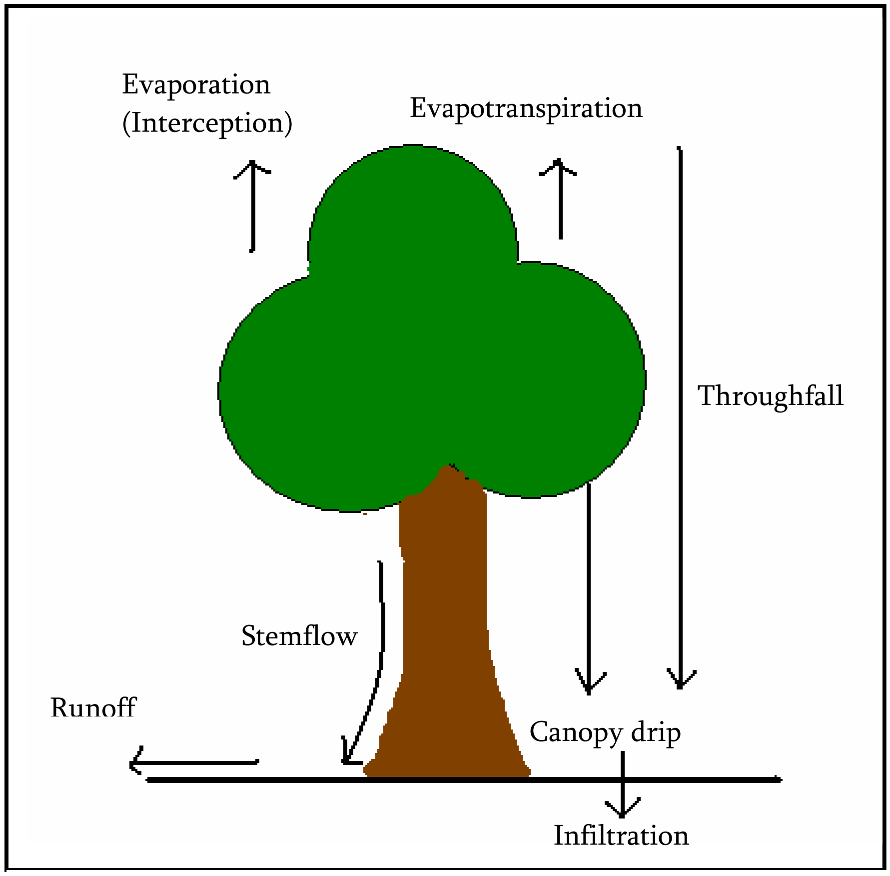


Figure 29: Simple diagram depicting the hydrological cycle of tree cover (adapted from a similar diagram in INAB 2005)

Tree Canopy

While local knowledge agrees with scientific knowledge that tree crowns intercept rainfall, informants thought that principally the density of the canopy had an affect on the quantity of rainfall intercepted, as would size of leaf, but that would be secondary to density. There was also a suggestion that this would allow some water to be filtered through to the ground by stemflow or canopy drip at a slower rate so contributing moisture to the system over a longer period, albeit in smaller quantities. Although stemflow and canopy drip are recognised in science as processes that redistribute intercepted rainfall (Rao 1998), there is no mention of canopy architecture affecting their rates.

There is agreement that the tree canopy reduces evaporation from the soil by reducing irradiance. Again, informants related the level of evaporation to canopy density and leaf size. Scientific literature also recognises reduced air temperature and windspeed as additional conditions that the canopy creates to reduce evaporation (Huxley 1999, ANACAFE 2006).

In relation to canopy drip, there is agreement that crown characteristics can affect the erosivity of the water droplet. Local knowledge from Nepal indicates that size of leaf has an affect, with large leaved trees causing the rain to coalesce and run off in a larger droplet, so having a greater impact on the soil (Thapa 1995). In contrast, small leaves minimise this (Beer 1987). Informants did not identify leaf size as a factor but leaf texture and height.

Leaf litter and understorey vegetation

Local knowledge and scientific knowledge agree that leaf litter plays a role in reducing evaporation of moisture from the soil and increasing the infiltration of water into the soil (INAB 2005; ANACAFE 2006). There is also a consensus that quantity of leaf litter is important (Beer 1987). In addition, informants identified size of leaf as a factor in soil coverage.

Soil Type

Scientific literature agrees with local knowledge in the recognition that soils containing more organic matter and sandy soils maintain humidity better than clay soils (Rao et al 1998), and there is also a common understanding that high quantities of leaf litter contribute to improving soil organic matter and hence infiltration (ibid., Pérez-Nieto et al. 2005, Huxley 1999). Rao et al (1998) also found that a large quantity of leaf litter increases soil faunal activity, reinforcing the process of organic matter production. While not exactly recognising this relationship, informants did note that leaf litter with a higher nutrient content attracts more worms than leaf litter with a low nutrient content.

Roots

There was agreement that roots enabled increasing infiltration of water into the soil by allowing water to pass through old root channels and increasing macropores, but also that the process of transpiration occurs with tree roots absorbing water from the soil (Huxley 1999, Rao et al 1998). Science suggests that the rate of transpiration is related to the extent of the root system and leaf biomass, with dense 'active' roots and higher leaf biomass leading to greater rates of water uptake and loss (Imbach et al 1989, Huxley 1999). Local knowledge echoes these findings, as informants distinguished between trees with a low amount of roots or a high amount of roots, and there was recognition that a decrease in leaf biomass would reduce leaf moisture evaporation and decrease root activity.

There was also agreement that tree root growth does occur laterally at the soil surface where the most nutrients are found (Huxley 1999, Schroth and Sinclair 2003).

There is some division within the scientific literature over the ability of some trees to maintain water in their stems to reduce uptake during the dry season, and even exude it into the soil. Bruijnzeel (2004) summarises the main viewpoints, but emphasises that increasingly scientific opinion is moving away from that idea.

Landscape level

The landscape level effects of tree cover are a complex subject area that is still not fully understood by science. There has been disagreement over whether tree cover improves or decreases water yield through either the aiding of water infiltration or water loss through interception. Bruijnzeel (2004) summarises the main studies undertaken since earlier this century and finds that there are many factors at work, including rainfall variation and geology, which can complicate results. However studies appear to show that while tree cover may reduce annual yield it is likely to be important for regulating seasonal flows, particularly in areas that experience a wet and dry season. This is primarily due to the capacity of tree cover to increase the infiltration of water into the soil, contributing to groundwater and helping to maintain base flows. The key process of water infiltration and the feeding of groundwater is in agreement with local knowledge.

Specific trees

There was little scientific information available on the specific tree species mentioned by informants, apart from profiles of cedro and madre de cacao. However these did not mention any ability of either of these trees to maintain water in their stems or to be succulent, discussing mainly silviculture and wood properties (CATIE 2003).

However, if these trees are succulent informants had a good knowledge of the process, as science agrees that succulent trees absorb less water through their roots (Nilsen at al 1990), although it was not stated that they exude water through their roots back into the soil. Some succulent trees can maintain their leaves throughout the year, but Borchert and Rivera (2001) state that tropical stem-succulent trees lose their leaves during the dry season.

There did not seem to be references to pine species directly, but McJannett and Wallace (2006) describe cloud interception as cloud or fog droplets collecting on vegetation surfaces, implying that tree species is not a defining factor. The ability of a tree to intercept clouds appears to be related to altitude (Cavelier et al. 1996). The fact that many of the coffee farms visited are at such high altitudes suggests that cloud may be low enough for pine trees to intercept clouds, and from personal observation this does appear to be the case (see Plate 3). Informants associated the ability of pine trees to do this rather than all trees by virtue of their height.

Plate 3: Photo of low cloud in El Carmen, demonstrating the possibility of cloud interception occurring with coffee farms.

Knowledge Complementarity and Knowledge Gaps

In general scientific knowledge and local knowledge are complementary with little disagreement. Science does not support local knowledge of canopy architecture and effects but there appeared to be no contradictory information either, so this might represent a gap in knowledge and may warrant further study. There was a knowledge gap in the local knowledge of interception and evaporation, where they recognised that tree crowns intercept rain but did state that it was evaporated.

Both types of knowledge were also able to add specificities, e.g. science highlighting the role of bats and animals in seed dispersal and pollination, and informants drawing attention to the nesting of small birds and snakes in coffee plants.

There are other differences that may not be necessarily complementary, e.g. science highlighted the size of the leaf as important in reducing erosivity. This was not mentioned by informants, although they drew attention to the height and texture of the leaf. All of these observation could be correct, and if so it illustrates how the amalgamation of knowledge can enhance our understanding.

5 Discussion

5.1 Introduction

This chapter discusses the findings of the research in relation to the specificities of the River Hato watershed and within the context of the Sierra de Las Minas Biosphere Reserve. It also draws conclusions surrounding the contribution that coffee farms can make to biodiversity and water conservation in this area.

5.2 Biodiversity value of coffee farms in the River Hato watershed.

5.2.1 Biodiversity as and for themselves

The research indicates that a high level of biodiversity across a range of taxa can be found within coffee farms in the watershed of the River Hato. On their own then they appear to have an important role to play in maintaining levels of biodiversity within the watershed and even increasing them. As outlined in Chapter 1, this may be highly important for the maintenance of ecosystem services and optimum ecosystem function.

5.2.2 Conservation of cloud forest

It is also important to place coffee farms in the context of the River Hato watershed, which is dominated at its higher altitudes by the protected area of the Sierra de Las Minas Biosphere Reserve, established in 1990 under the administration of FDN to conserve large tracts of upper montane cloud forest and lower montane moist forests (Dix, date unknown).

Informants stated that forest species do not visit coffee farms as they are adapted to the colder temperatures of the cloud forest. Indeed species native to cloud forest have been found to be very susceptible to changes in habitat and habitat loss (Bruijnzeel 2004), and within the department of El Progreso forest cover decreased by 24.81% from 1991 – 2001, an annual change of 1.29% (IARNA et al. 2006).

At first glance then it may appear that the coffee farms have no role to play in helping to conserve these vulnerable cloud forest species, particularly since land near the southern border, which is the River Montagua side, has been more heavily deforested than the northern border, and encroachment from coffee production has been partly to blame (Holder 2003). Much of this has been due to depressed prices for coffee after the crisis in 2000.

However, coffee farms also have the potential to provide a buffer against extraction from and encroachment into the cloud forest, indeed nearly all coffee producing communities are located in the buffer zone or sustainable use zone. Extraction usually takes place for firewood or timber to sell (pers. comm. Byron Medina), but this research indicated that within coffee farms a number of different tree species can provide this service. If appropriate markets can be found for the coffee within the River Hato watershed, with premium prices attached to the biodiversity or ecosystem service value of coffee farms as the CAFNET project seeks, this could also take the pressure off farmers to increase their area of production.

The need to find ways to improve the buffer zone service of coffee farms is illustrated by the fact that, although protected areas cover 31% of national territory in Guatemala, there are serious management and enforcement issues threatening their efficacy (IARNA et al. 2006), with over 60% of annual deforestation occurring in safeguarded parks and reserves (Ellis and Taylor 2007). In light of the water conservation value of cloud forests, detailed below in section 5.3.1, it becomes even more pertinent for this watershed.

5.2.3 Conservation of coniferous forest

Coniferous forest can also be found in Sierra de Las Minas to the north and south east. It is recognised as a major centre of *Pinus* species, and harbours 13 different conifer species (Dix, date unknown). This is particularly significant because within Guatemala species of conifers are the most under pressure and coniferous forests are experiencing the greatest fragmentation. These research findings indicated that *Pinus* species can frequently be found within coffee farms in the River Hato watershed, which suggests they may have an important role to play in conserving remnants of this type of forest and individual species.

5.3 Water conservation value of coffee farms in the River Hato watershed

5.3.1 Regulation of seasonal flows

The findings of this research demonstrate the ways in which coffee farms, through their tree cover, can increases the infiltration of water into the soil, which in turn increases groundwater levels. The feeding and maintenance of these levels help regulate seasonal flows, such that storm flows related to high rain events are reduced, decreasing the damage that they can cause, and low flows during the summer are increased. This function is particularly important in the River Hato watershed and for the whole of the River Montagua valley due the pronounced dry season that is experienced lower down the watershed and the problem of water availability.

5.3.1 Regulation of water yield

The general understanding is that tree cover reduces total water yield but regulates flows, as described above. However, cloud forest is an exception as its canopy often sits in cloud so there are low levels of evapotranspiration together with water inputs through cloud water interception. Cloud forests can therefore improve the water budget, particularly in the dry season, and ensure the continued supply of water for further down the watershed (Bruijnzeel 2004).

Studies show that forest cover below cloud forest may be important in the maintenance of this function. Bruijnzeel (2004) cited a study whereby deforestation lower down cloud forest on mountains in Costa Rica resulted in the lifting of clouds so they were no longer in contact with the cloud forest. It was due to an increase in air temperatures as evaporation had decreased with the decline in canopy cover. There is an implication then that while tree cover such as that found within coffee farms may not contribute to water yield, they may have a role in increasing or maintaining the ability of the forest to do so.

Informants recognised the ability of 'pino' species, to use their term, to intercept water from clouds, a phenomenon they had observed from the species within their coffee farms. In the case of the River Hato watershed, due to cooler temperatures at higher elevations (Holder 2003) where coffee is located, pines within the coffee farms themselves may also aid in improving the water budget.

Holder (2003) states however that as water demand has increased from irrigation and industries operating in the River Montagua valley and as deforestation has occurred, water flow has been reduced by over 40% in the last ten years and he water table has dropped. He relates this specifically to loss of vegetation. Figure 30 illustrates how the department of El Progreso and the communities lower down the River Hato water experience water shortages throughout the year, in the wet and dry seasons. It is therefore even more important to protect the cloud forest resource.

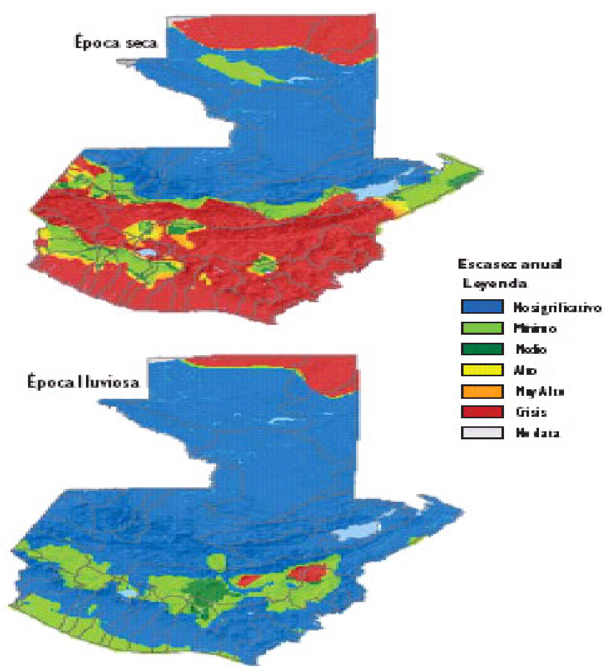


Figure 30: Map depicting scarcity of water in Guatemala during the dry and wet seasons. It shows that El Progreso department experiences critical scarcity throughout the year.

6 Recommendations

6.1 Introduction

This chapter seeks to suggest measures that can be implemented to increase biodiversity and water conservation within coffee agroforestry systems in general, particularly less complex systems with a monospecific canopy or systems grown under direct sunlight. The recommendations draw on an amalgamation of local and scientific knowledge.

6.1 Improving biodiversity

Local knowledge and scientific knowledge were strongly in agreement on the factors that affected biodiversity. The main ways in which biodiversity can be improved are:

- Increasing diversity of tree species
- Increasing structural diversity through the use of tree species of varying heights
- Increasing habitat diversity through the use of tree species that exhibit varying characteristics, e.g. dense and sparse crowned trees, variations in form of branches.
- Increasing the diversity and availability of food through an increase in the number and diversity of fruit tree species.
- Increasing the number and diversity of flowering and fruiting tree species to attract insects and pollinators.
- Maintaining habitat through minimal pruning of tree crowns and use of evergreen tree species.

- Stopping the use of chemical inputs for increased production and weed control.
- Increasing habitat diversity and foraging areas by decreasing the frequency and level of weeding.
- Allowing some trees to become old growth.
- Leave dead trees standing and fallen.

Local knowledge also suggests that certain trees may attract a greater number and variety of bird species, by virtue of their fruit or association with insects, e.g. amate, capulin and cuje.

6.2 Improving water conservation

Local and scientific knowledge agreed on the basic processes involved in water conservation, but there were some differences in the more specific characteristics of trees said to improve water conservation. However, through amalgamating the various suggestions water conservation can be enhanced by:

- Maintaining a fairly even mix of dense crowned and sparse crowned trees to attempt to achieve a balance of rainfall interception and sun irradiation.
- Increase the number of short and medium height species to reduce the erosivity of raindrops falling from tall trees.
- Increase the number of trees with small leaves and stiff leaves to reduce the erosivity of raindrops, and reduce those with large leaves and soft leaves.

- Increase the number of trees with a low amount of roots to decrease the absorption of water from the soil.
- Increase the number of trees that shed a large quantity of leaves to increase leaf litter for protection of the soil against evaporation, increased infiltration of water into the soil, and improvement in soil organic matter content.
- Increase the diversity of trees that shed many leaves to ensure that the leaf litter layer remains consistent throughout the year.

Again, local knowledge identified particular tree species as maintaining water in their stems so helping to increase soil humidity, amate, cedro, guarumbo, madre de cacao, suquinay and cuje. The latter two are evergreen trees so may be considered more advantageous as they would not expose the soil the drying effect of the sun. However, informants noticed that use of any tree with qualities considered negative had less effect when scattered at a distance from each other with other trees inbetween.

6.3 Meeting the twin objectives of increased biodiversity and water conservation

The two lists of suggestions above may be appropriate for meeting one or the other objective, but favouring some tree species over others due to their common characteristics as is recommended to improve water conservation is not conducive to enhancing biodiversity and will exclude certain tree species. In order to meet both objectives a certain percentage of the trees seen as preferable for water conservation could be included, with the proviso that the remainder are chosen in order to increase biodiversity.

It should also be remembered that a great diversity of trees provide goods such as firewood, good quality wood, medicine and food resources, which may help reduce the pressures on nearby forest. In choosing which tree species to include with coffee, the merits of each should be examined and the appropriate mix chosen according to the needs of the household, and the need to improve biodiversity and water conservation.

6.4 Utilisation of local knowledge

One of the most important contributions that can be made by local knowledge is to add to the body of knowledge on individual species, their characteristics and the effect these have on biodiversity and water conservation, in order that choices can be made by others of the most appropriate species to include within a coffee farm. Currently there is a lack of information in the literature about individual tree species but is has been recognised as a research priority.

6.5 Further Research

Although there is a general understanding by both science and informants of the processes involved in the water cycle and water conservation, different statements have been made about the attributes of particular trees in mediating these processes. Further research could be carried out on the effect canopy architecture has on rainfall interception.

The suggestion by informants that some trees retain water in their stems and improve soil is potentially significant as they could be important species for increasing the conservation of water. These particular tree species should be investigated further to discover if they are succulent.

It was interesting to note that informants had not observed many migratory birds visiting their coffee farms. It may be useful to carry out a study to actually quantify the number of migratory birds. If the number is low it could raise questions over why and increase our knowledge of the behaviour and habitat requirements of migratory birds.

7 Conclusions

Local knowledge has the potential to significantly increase our understanding of the merits of different tree species for biodiversity and conservation. In addition many interesting observations about the general attributes of groups of tree species could aid our understanding of the mediating effect of tree cover on the water cycle.

The role of the multi-strata coffee agroforestry systems in the River Hato watershed are highly important for the conservation of biodiversity as they were observed to have associations with a great number and diversity of species. Informants also had a real appreciation of the positive effects their coffee farms had on the water balance of the watershed.

The coffee farms have the potential to aid in the conservation of biodiversity within the Sierra de Las Minas Biosphere Reserve if appropriate measures are taken as it is hoped will be developed through the CAFNET project: increasing co-operation and organisation between small farmers to decrease the number of links in the supply chain that separates them from the buyer, and improved prices for their coffee drawing on its proven advantages for biodiversity and water conservation.

There is some worry around the shortage of water in El Progreso and the other watersheds surrounding the River Montagua. The role of the cloud forest has been recognised as being vital to sustaining water flow, and it is likely the coffee farms contribute to this also. If improved markets for coffee can draw those producers currently cultivating less favourable crops, e.g.

sugarcane to the production of coffee both biodiversity and water would benefit from the increased tree cover.

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Appendix 1: Checklist questions used for semi-structured interviews

1. ¿Qué árboles tiene en su cafetal?
2. ¿Colocan los árboles a propósito? ¿O crecen naturalmente?
3. ¿Porqué eligió estas especies? ¿O porqué guarda los especies que esten aquí naturalmente?
4. ¿Tienen los árboles algún uso? (Madera, leña, medicinal, cerca viva, rompevientos, alimento, otros)
5. ¿Qué beneficios proveen los árboles?
6. ¿Quita cualesquier especies de árbol? ¿Porqué?
7. ¿Tienen los árboles calidades negativos?
8. ¿Son de la área los árboles? ¿O el pais o on otro país?
9. ¿Cuál son los árboles principales?
10. ¿Porqué tiene más de estás especies que otras?
11. ¿Le afectan los árboles al suelo? ¿Cómo?
12. ¿Cómo le ayudan los árboles al suelo?
13. ¿Le afectan los árboles al agua? ¿Cómo?
14. ¿Cómo le ayudan los árboles al agua?
15. ¿Ha visto en el cafetal animales o aves?
16. ¿Qué arboles sirven como un lugar para vivir o alimento a pájaros u otros animales? ¿Cuándo ocurre esto? ¿Porqué cree que eligen estes árboles los animales?
17. ¿Cuáles árboles no son visitados por animales y a qué cree que se deba?

18. ¿Cree que haya árboles que tengan o atraigan más animales que otros? ¿Porqué?

19. ¿Cuáles animales son un problema para creciendo café?

20. ¿Cuáles animales cree proveen benefios? ¿Porqué?

21. ¿Realiza actividades que alientan los animales?

22. ¿Le gustaría a usted que en la finca hubiera más animales o aves? ¿Qué haría para esto?

23. ¿Cree que ha sido cambios en la poblaciónes o números de cualesquier animales? Porqué?

24. ¿Ve alguna diferencia entre la cantidad y calidad del suelo o del agua debajo de diferentes arboles o donde crecen otros cultivos sin árboles? ¿Porqué?

25. ¿Qué características afectan a la cantidad de animales? ¿y agua?

26. ¿Considera usted que la forma en que cultiva es amigable con el ambiente? ¿Porqué?