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ABSTRACT

Agriculture is one of the main sources of income in developing countries and at the same time one of the major drivers causing environmental conflicts like loss of biodiversity. Agroforestry, which combines agricultural with forestry components at plot, community and landscape level, through a component-specific management can satisfy a series of multiple demands, among them, biodiversity conservation and in general the provision of environmental services.

Since environmental services are proposed as alternative compensation schemes to prevent and remediate negative environmental impacts, incentives that support ecologically sound agricultural management practices are therefore needed. These incentives (e.g., compensation payments) have to be based on an adequate understanding and evaluation of the services provided by the agricultural systems.

For this purpose, the concept of biodiversity in land-use systems has been revised. 'Functional biodiversity', in contrast to traditional approaches, emphasizes the system's dynamics at various levels and the implications of these on its functioning as a whole. To operationalize such a concept, an assessment protocol based on multicriteria analysis has been developed. The approach combines productive, ecological and operational indicators to describe functional biodiversity, and aims at the identification of those management decisions and interventions that support this.

The suitability of the evaluation protocol was tested with 70 farms in the Brazilian Amazon region divided in three groups, which had been defined based on the time of settlement, property size, technological know-how, organization and access to market, i.e., 'CAMTA partners' long-ago established farmers, 'immigrated' some time ago and recently immigrated farmers 'newcomers'.

The analyses reveal that the most relevant factors supporting functional biodiversity in agroforestry systems are: (1) the farmers' technical qualification, (2) their preference for low impact techniques, (3) their capacity to adapt to environmental, social and political changes, (4) the diversification of species composition at plot level, (5) the increase in the use of perennial species; and (6) the financial profitability of the system. Concerning the differences among groups, the 'CAMTA partners' farmers are significantly superior to the two other groups only in agricultural practices related to production.

As the functional biodiversity concept is based on an integrative approach, its outputs provide a supportive platform for the proposed assessment framework. In turn, the developed protocol can be used to optimize biodiversity roles on farms and support decisions regarding compensation payments. Nevertheless, its further validation, testing and adaptation as a monitoring tool are necessary.

KURZFASSUNG

Die Bewertung von Umweltserviceleistungen: funktionale Biodiversität in tropischen Agroforstsystemen (Das Beispiel Tomé-Açú, Nordbrasilien)

Landwirtschaft ist eine der Haupteinnahmequellen in den Entwicklungsländern und gleichzeitig einer der größten Verursacher von Umweltkonflikten wie z. B. Biodiversitätsverlust. Agroforstwirtschaft, die landwirtschaftliche und forstliche Komponenten auf Feld-, Gemeinde- und Landschaftsebene verbindet, kann durch flächenspezifisches Management vielfältige Anforderungen erfüllen, unter anderem den Erhalt von Biodiversität und ganz allgemein die Bereitstellung von Umweltdienstleistungen.

Da Umweltdienstleistungen dazu beitragen können, Umweltprobleme zu verhindern oder zu lösen, sind Anreize notwendig, die ein ökologisch sinnvolles Landmanagement unterstützen. Diese Anreize (z.B. Ausgleichszahlungen) müssen sich auf eine fundierte Kenntnis und auf die Bewertung der Umweltleistungen von Landnutzungssystemen stützen.

In der vorliegenden Arbeit wurde ein Konzept erarbeitet, das auf der funktionellen Rolle der Biodiversität in Landnutzungssystemen basiert. 'Funktionelle Biodiversität', im Gegensatz zu traditionellen Ansätzen, betrachtet auf verschiedenen Ebenen die Dynamik des Systems sowie deren Auswirkungen auf das Funktionieren des Systems als Ganzes. Als wesentlicher Bestandteil des Konzeptes wurde auf der Grundlage einer 'Multicriteria Analysis' ein Bewertungsprotokoll entwickelt. Dieser Ansatz verbindet produktive, ökologische und operationale Indikatoren mit dem Ziel, funktionelle Biodiversität zu beschreiben und Managemententscheidungen und -eingriffe zu ermitteln, die diese unterstützen.

Die Eignung des Bewertungsprotokolls wurde auf 70 Farmen in der brasilianischen Amazonasregion überprüft. Die Farmen wurden in folgende drei Gruppen eingeteilt: (1) Zeitpunkt der Niederlassung des Farmers, (2) Größe der Farm, und (3) technologisches Know-how, Organisation und Zugang zum Markt. Die untersuchten Farmen gehörten Farmern, die sich (1) vor Jahrzehnten ('CAMTA Partner'), (2) vor längerem ('immigrated'), und (3) vor kurzem niedergelassen hatten ('newcomers').

Die Analysen ergaben, dass (1) die technische Qualifikation der Farmer, (2) minimale Bodenbearbeitung, (3) die Fähigkeit der Farmer, sich an ökologische, gesellschaftliche und politische Veränderungen anzupassen, (4) die Artendiversifizierung auf der Fläche, (5) der verstärkte Einsatz von mehrjährigen Arten, und (6) die Wirtschaftlichkeit des Systems zur Aufrechterhaltung der funktionellen Biodiversität in agroforstlichen Systemen beitragen. Hinsichtlich der Unterschiede zwischen den Gruppen, heben sich die lang etablierten Farmer ('CAMTA Partner') signifikant von den anderen beiden Gruppen nur in den produktionsspezifischen landwirtschaftlichen Aktivitäten ab.

Da das Konzept der funktionellen Biodiversität auf einem integrativen Ansatz beruht, liefern die Ergebnisse eine Grundlage für den vorgeschlagenen Bewertungsrahmen. Das entwickelte Protokoll kann zur Optimierung der Rolle der Biodiversität auf der Farm und als Entscheidungshilfe hinsichtlich Ausgleichszahlungen eingesetzt werden. Weitere Validierungen und Anpassungen als Monitoringinstrument sind notwendig.

RESUMO

Uma abordagem para a avaliação de serviços ambientais: biodiversidade funcional em sistemas agroflorestais tropicais (o caso de Tomé-Açú, Norte do Brasil)

A agricultura é uma das fontes principais de renda em países em desenvolvimento e ao mesmo tempo uma das maiores causas de prejuízo ambiental, como no caso da perda da biodiversidade. A agrofloresteria ao combinar componentes agrícolas e florestais a níveis de parcela, comunidade e paisagem, pode a través dum manejo específico de cada componente pode satisfazer múltiplas demandas, tais como a conservação da biodiversidade e em geral a provisão de serviços ambientais.

Para se possibilitar os serviços ambientais, propostos como mecanismos pra prever e remediar os danos ambientais, precisam de incentivos que promovam praticas agrícolas ecologicamente amigáveis. Estes incentivos (por exemplo os pagos compensatórios) devem se basear na adequada compreensão e na avaliação dos serviços providos pelos sistemas agrícolas.

Com tal propósito, tem se revisado o conceito de biodiversidade em sistemas de uso da terra e o de "biodiversidade funcional" o que, ao contrario das abordagens tradicionais enfatiza na dinâmica do sistema em vários níveis e as implicações das partes no funcionamento do conjunto. Para operacionalizar tal conceito foi desenvolvido um protocolo de avaliação baseado em análise multicritério, que combina indicadores produtivos, ecológicos e operacionais objetivando descrever biodiversidade funcional, e identificar as decisões de manejo e intervenções que a promovam.

O protocolo de avaliação foi testado em 70 propriedades agrícolas da Amazônia brasileira, divididas em três grupos tendo como critérios o tempo de estabelecimento, tamanho da propriedade, capacidade técnica, nível de organização e acesso ao mercado. Assim foram definidos os grupos: ('CAMTA partners') primeiros colonizadores, ('immigrated') imigrados ha tempo e os recentemente imigrados ('newcomers').

As análises revelam que os fatores mais determinantes da biodiversidade funcional em sistemas agroflorestais são: (1) a capacidade técnica dos agricultores, (2) a sua preferência pelas técnicas de baixo impacto, (3) a sua capacidade para se adaptar as mudanças ambientais, sociais e políticas, (4) a diversidade de espécies ao nível de parcela, (5) o aumento no uso de espécies perenes; e (6) a rentabilidade do sistema. Com respeito às diferenças entre grupos, 'CAMTA partners' é significativamente superior aos outros dois grupos apenas no que tange às práticas agrícolas produtivas.

Ao ser conceituada a biodiversidade funcional numa abordagem integral, ela fornece uma base para o protocolo de avaliação sugerido. Por sua vez, o protocolo pode ser utilizado para otimizar as atividades e decisões de manejo concernentes aos pagamentos compensatórios. Apesar disso, a sua validação avaliação e adaptação como ferramenta de monitoramento são necessárias.

RESUMEN

Un enfoque para la evaluación de los servicios ambientales: biodiversidad funcional en sistemas agroforestales tropicales (el caso de Tomé-Açú, norte de Brasil)

La agricultura es una de las principales fuentes de ingreso en los países en vías de desarrollo y al mismo tiempo una de las mayores causas del daño ambiental, como, p.ej., la pérdida de biodiversidad. La agroforestería al combinar componentes agrícolas y forestales a niveles de parcela, comunidad y paisaje, puede, a través de un manejo específico de componentes, satisfacer múltiples demandas, entre ellas la conservación de la biodiversidad y en general la provisión de servicios ambientales.

Dado que los servicios ambientales son propuestos como esquemas para prevenir y remediar los perjuicios ambientales, se requieren incentivos que promuevan prácticas ecológicamente amigables. Tales incentivos (p.ej., pagos compensatorios) deben basarse en un adecuado entendimiento y evaluación de los servicios prestados por los sistemas agrícolas.

Con tal propósito, se ha revisado el concepto de biodiversidad en sistemas de uso de la tierra y sugerido el de "biodiversidad funcional" que, a diferencia de los enfoques tradicionales, enfatiza en la dinámica del sistema a varios niveles y en las implicaciones de las partes en el funcionamiento del conjunto. Para operativizar tal concepto se desarrolló un protocolo de evaluación basado en análisis multicriterio, que combina indicadores productivos, ecológicos y operativos para describir la biodiversidad funcional e identificar las decisiones de manejo e intervenciones que la promueven.

El protocolo de evaluación se probó en 70 propiedades agrícolas de la Amazonia brasileña, divididas en tres grupos definidos con base en el tiempo de establecimiento, tamaño de la propiedad, capacidad técnica, grado de organización y acceso al mercado. Los grupos son: ('CAMTA partners') primeros colonizadores, ('immigrated') inmigrados de algún tiempo atrás y ('newcomers') los recientemente inmigrados.

Los análisis revelan que los factores determinantes de la biodiversidad funcional en sistemas agroforestales son: (1) la capacidad técnica de los granjeros, (2) su preferencia para las técnicas de bajo impacto, (3) su capacidad para adaptarse a los cambios ambientales, sociales y políticos, (4) la diversidad de especies a nivel de la parcela, (5) el aumento en el uso de especies perennes, y (6) la rentabilidad del sistema. Con respecto a las diferencias entre grupos, 'CAMTA partners' es significativamente superior a los dos otros grupos sólo en lo relacionado a prácticas agrícolas productivas.

Como el concepto de biodiversidad funcional está basado en un enfoque integrador, éste provee una base para el protocolo de evaluación sugerido. A su vez, el protocolo desarrollado puede usarse para optimizar actividades y decisiones de manejo concernientes a pagos compensatorios. Sin embargo, su validación, evaluación y adaptación como herramienta de monitoreo son necesarias.

LIST OF ACRONYMS AND ABBREVIATIONS

AFS	Agroforestry System
AHP	Analytic Hierarchy Processes
ANOVA	Analysis of Variance
ASB	Alternatives to Slash and Burn
BI	Biogeographical Islands
BTI	Biodiversity Threat Index
C&I	Criteria and Indicators
CAMTA	*Cooperativa Agrícola Mista de Tomé-Açú* (Mixed Agricultural Cooperative of Tomé-Açú)
CBD	(United Nations) Convention on Biological Diversity
CDM	Clean Development Mechanism
CIFOR	Center for International Forestry Research
CIMAT	Criteria and Indicators Modification and Adaptation Tool
CONACIN	*Coordinadora Nacional Indianista* (Indianist National Committee)
COP	Conference of the Parties
CPATU	*Centro de Pesquisa Agropecuaria do Tropico Umido* (Agricultural and Cattle Research Centre of Humid Tropics)
CRI	Capacity Response Index
DBH	Diameter at Breast Height
DNA	Deoxyribonucleic Acid
ECO 92	Earth Summit, Rio de Janeiro 1992
EMBRAPA	*Empresa Brasileira de Pesquisa Agropecuária* (Brazilian Agricultural. and Cattle Research Company)
FMU	Forestry Management Unit
GEF	Global Environmental Facility
IBGE	*Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics)
ICRAF	International Center for Research in Agroforestry
ITTO	International Tropical Institute Organization

IUCN	International Union for Conservation of Nature
LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
LSD	(Fisher's) Least Significant Difference
LUI	Land Use Intensity
MCA	Multicriteria Analysis
MDA	Millennium Development Assessment
MVA	Multivariate Analysis
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
PLEC	People, Land Management and Environmental Change
PROAMBIENTE	*Programa de Desenvolvimento Socioambiental da Produção Familiar Rural* (Socio-environmental Development Program for Rural Household Production)
RAF	Relative Agricultural Functionality
REF	Relative Ecological Functionality
SCOPE	Scientific Committee on Problems of the Environment
SFM	Sustainable Forest Management
SMI	Sustainable Management Index
SPSS	Statistical Package for the Social Sciences
TEV	Total Economic Value
UN	United Nations
UNEP	United Nations Environment Programme
WAC (ICRAF)	World Agroforestry Centre
WCPA	World Commission on Protected Areas

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1 INTRODUCTION

1.1 Background

Environmental management, like most human activities, has been grounded progressively in market-based approaches with the aim of making judgments and decisions more efficient and rational against the background of the global environmental crisis, its degree and its scope. The concept of payment for environmental services, a sort of trade of by-products to a third party, has taken a leading role. Several environmental disturbances have been managed under this approach (Kleinn et al. 2000).

The two greatest challenges facing world agriculture are the production of sufficient food for the world's population and the conservation of biodiversity (Conway 1997). Countless alternatives have been suggested, such as agroforestry, which is a series of land-use management principles based on a high number and diversity of components, flexible technical management, and a multicriteria decision making, aimed at increasing land productivity while taking into consideration ecological and economic concerns (Schroth et al. 2004).

Previous investigations in agroforestry systems as environmental services providers, (in our case biodiversity conservation) have been wide but disperse. Neither, framework, criteria and boundaries, nor assessment, management and monitoring aspects have yet been defined (Nair 1997, Callo-Concha 2003).

The premise of functionality, i.e., the roles performed by systems, has not been adequately dealt with by the environmental services approach. The studies have usually focused on biophysical and/or economic status evaluation. This approach in fact shifts the focus from the main aim of land-use systems management, which is the continuous provision of goods and services (Altieri & Nicholls 1999).

The inclusion of this premise into agroforestry systems management is attempted through the functional biodiversity approach, which emphasizes the processes triggered by organisms and the subsequent benefits rather than their static condition. In the present study, agroforestry systems are seen as environmental services providers in addition to its most important goals, i.e., assurance of food provision and generation of income opportunities.

1.2 Hypotheses and objectives

1.2.1 Hypotheses

General hypothesis

Agroforestry systems maintain functional biodiversity at levels sufficient to keep the production sustainable and the environmental processes stable.

Premises

- The theoretical background suggests that the abundance and richness of species in a system should be highly related to the intensification of processes occurring in it.
- It is believed that the intensification of the ecosystem functionality implies the intensification of the production processes and consequently the increase in yields and by-product generation.
- There is no consensus on how biodiversity should be assessed in agro-ecosystems nor which biodiversity approach or approaches should be applied.
- There are many scientific references about the virtues of agroforestry systems to maintain biodiversity, generally enunciative but have been demonstrated conclusively yet.

Specific hypothesis 1

The degree of functional biodiversity in agroforestry systems depends on the level of technical management.

Specific hypothesis 2

A model derived from the criteria and indicators approach should provide a better understanding of agroforestry systems efficiency to maintain functional biodiversity.

1.2.2 Objectives

General objective

To assess the factors that influence the processes that determine the capabilities of agroforestry systems to maintain functional biodiversity (case study: municipality of Tomé-Açú, Pará state, northern Brazil), underlining management as a key factor to improve the systems towards making them more productive and sustainable.

Specific objective 1

To develop a protocol for evaluating functional biodiversity in agroforestry systems.

Specific objective 2

To define a management optimization model of agroforestry systems for enhancing and maintaining functional biodiversity.

1.3 Scope of the study

- It is a common understanding that environmental services are biodiversity preservation, carbon sequestration, water management and scenic beauty. However, for conceptual and methodological reasons, this study will cover only biodiversity, which, due to its complexity also involves directly or indirectly the other services.
- It is assumed that the benefits obtained from agroforestry systems+ should be assigned in the following order of priorities: assurance of food security, increment of system productivity, tradable surpluses to access the market, progressive capitalization based on the production of high market-value products, and eventually provision of environmental services.
- We assume that agroforestry generally develops progressively with the capabilities of those involved, so we consider it as a small farmers' option; however several considerations can be extrapolated to larger scales.

1.4 Expected outputs

This research discusses the theoretical topic 'functional biodiversity approach for agroforestry systems', and also provides pragmatic means for optimizing land-use system performance by stakeholders.Within this frame, the expected outputs are:

1.4.1 Protocol of evaluation

A protocol to characterize, evaluate, analyze, rate, weigh and interpret functional biodiversity in agroforestry systems, able to extrapolate to similar conditions elsewhere.

This protocol will be based on a small-scale study, so neither the agroforestry systems nor the conditions are really representative. Thus, we will focus on the extrapolation possibilities rather than on the accuracy of a particular case study.

1.4.2 Criteria and indicators set

A Criteria and Indicators (C&I) set for functional biodiversity assessment in tropical agroforestry systems, clustered, hierarchized, and interrelated; developed ad hoc but eventually able to extrapolate to similar conditions with some modifications.

1.4.3 Optimization model

The integration of a protocol of evaluation, a set of indicators and an *ad hoc* analysis procedure will provide a dynamic model of the systems functioning, defining topics of action, support and prediction, and could serve as a political negotiation argument in an environmental services payment framework. This optimization model will be highly location specific.

1.5 Structure of the study

This study is organized as follows:

- Chapter 1 summarizes the problem focus of this research, its conceptual premises, original idea and necessity of further validation, and details the hypotheses, objectives, scope of the study and, expected outputs.
- Chapters 2, 3 and 4 consist of the literature review of the three conceptual pillars on which this research lies: agroforestry, biodiversity and environmental services.
- Chapter 2 provides an overview of agroforestry as a production paradigm, analyzing its advantages against other land-use systems aiming at biodiversity conservation, the most important technological variations and their environmental advantages, and the trends of research on biodiversity.
- Chapter 3 deals with the evolution of the concept of biodiversity in relation to land-use systems, i.e., approaches, conservation strategies and assessment. The chapter ends with a revision of the emerging ecological concept of functional biodiversity, suggesting its adaptation to agro-ecosystems, which is the conceptual core of this study.
- Chapter 4 explores the concept of environmental services from four aspects: conceptual, operational, socioeconomic and biophysical, highlighting the characteristics most relevant for this study. The chapter concludes with a brief review of the Brazilian environmental services program.

- Chapter 5 presents the study area: biophysical and socio-economic conditions, the subjects of study and the unit of analysis, i.e. local agroforestry systems.
- Chapter 6 describes the methodological approach, applied analytical tools, further development and integration, concentrating on Multicriteria Analysis (MCA) definition and operationalization, the Criteria and Indicators (C&I) approach, principles and supporting software, as well as the Multivariate Analysis (MVA) methods (cluster analysis and factor analysis). It concludes with the exposition of the linkage between MCA and MVA.
- The results in Chapter 7 are divided into two subchapters: (1) the evaluation protocol: study scope, data collection and integration scheme, conceptual model with the relevant components, a hierarchization of the proposed C&I set, details of each C&I component and description of their application; and (2) the optimization model, i.e., the univariate statistical analysis of the Sustainable Management Index (SMI) per group and as a whole, the multivariate analysis (cluster analysis and factor analysis), results and interpretation.
- In the general discussion in Chapter 8, results are analyzed with respect to the established hypotheses. The main limitations regarding the feasibility of the proposed approach are discussed, and finally suggestions are made for further research for the improvement of the approach or its upgrading into an environmental services evaluation protocol.
- Chapter 9 provides conclusions and outputs.

2 AGROFORESTRY
A further alternative in the production-conservation bridge

2.1 Pre-existence and definition and paradigm

Agroforestry existed well before its scientific characterization. There are vestiges of agroforestry in most agro-centric cultures where various productive components were integrated and managed in a complex manner. What is new, is its naming and the systematization of its study (Young 1989, Nair 1993).

There was a great deal of discussion about the definition of agroforestry during the 1970's and 80's, and consequently many definitions exist. Nevertheless, it was generally agreed that a definition must include the following items (Table 2.1):

Table 2.1 Prerequisites for defining agroforestry

As a science	As a socioeconomic option	As a productive practice
- It is interdisciplinary and integrative. - Requires understanding of its biophysical and socioeconomic circumstances.	- Must be compatible with local habits. - It is not an alternative by itself, but becomes such circumstantially.	- Must include at least one wood component - Includes in the same plot: herbaceous crops and/or shrubs and/or trees and/or animals. - Attempts to optimize the use and recycling of available resources. - Affords various spatial and/or temporal arrangements. - Focuses on yield maximization in the long term.

Based on Nair (1985), Young (1989), Leakey (1996), Nair (1997) and Huxley (1999).

In addition, every agroforestry system must fulfill the following criteria: must be intentional, its components must interact, it must generate multiple outputs (products and/or services), and exceed a one-year management term.

The World Agroforestry Centre (former International Center for Research in Agroforestry ICRAF) defines agroforestry as: "*A dynamic, ecologically based, natural resource management practice that, through the integration of trees and other tall woody plants in the farm and within the agricultural landscape, diversifies production for increased social, economic and environmental benefits*" (ICRAF 2000).

Agroforestry demands a re-conceptualization of productive practices that, instead of maximizing a unique output giving priority to a homogeneous production style, underlines the environmental sustainability, strengthens economic profitability, promotes productive diversity, enforces social equity, and protects the cultural diversity of existing and introduced systems (Callo-Concha 2003).

Thus, agroforestry does not represent a uniform ensemble of systems and technologies. The global qualities commonly attributed to agroforestry practices are not always observed, like soil conservation on steep slopes or higher soil fertility, where complementary factors, such as climate or physiognomy can have a drastic influence on the systems' characteristics and performance (Michon & de Foresta 1995).

The resourcefulness usually attributed to agroforestry systems manifests itself through an inherent and a key component of every agroforestry system: the 'multipurpose tree' one that besides the products and services usually given as wood, climate influence, soil improvement and organic matter addition, provides of important products and services as nitrogen fixation, forage, gums, resins, fibers, medicines, human-eatable products, etc (Krishnamurthy & Avila 1999).

2.2 Biodiversity conservation and enhancement in land-use systems

Colonization and land-use change have been pointed out as being the major causes of species loss in the past centuries. Modern agriculture based on substitution of natural systems for human-managed ones first converted small plots and later, as technology developed, large areas into intensive land-use systems (Albuquerque et al. 2000).

These farming systems are generally mono-specific and even mono-varietal based on intensive use of capital and external inputs, have lead to the loss of associated flora and fauna, endangering the equilibrium not only in natural ecosystems, but paradoxically also in the land-use systems themselves (Leakey 1999, Schroth et al. 2004a, Ammann 2004).

Several management tools have been proposed as more environmentally friendly alternatives: agroecology, ecoagriculture, permaculture, etc. Agroforestry, far from being a panacea, has become a further option in this large spectrum of alternative land-use management paradigms.

2.2.1 Agroforestry paradigm

It has been assumed that agroforestry systems are more complex than monocultures but less complex than natural systems (Bates 1999), and by their biophysical structure are more in tune with primary forest, forest reserves and similar biotopes (von Maydell 1990).

Agroforestry focuses strongly on the increase in income through involving a diversity of components and conservation of natural resources (Williams et al. 1997). Moreover, a positive correlation has been found between the size of the system and the scale of management and the attention to environmental problems (Krishnamurthy & Avila 1999, Izac & Sánchez 2001). This is possible because in contrast to other land-use systems where the farmer focuses on a limited number of products or services, in agroforestry the farmer generates a number of products, by-products and services in the way to set a final profit (Arnold & Dewees 1999).

2.2.2 Sustainability in land-use systems

Sustainability in a land-use system implies that its by-products should not disrupt the functioning of the system to the extent that the system's capacity to absorb those disruptions is surpassed. In other words: "*(...) a cropping systems is sustainable if has an acceptable level of production of harvestable yield which shows a non-declining trend from cropping cycle to cropping cycle over the long term*" (Izac & Swift 1994).

Assuring sustainability of land-use systems is the major focus of this research; an increase in biodiversity should contribute to its ecological sustainability, attaining equilibrium with multiple uses of the involved species (Padoch & Peters 1993, Bates 1999, Scherr & McNeely 2003).

Scientific literature has stated that agroforestry systems (1) are more efficient in the cycling and use of nutrients in a system (Nair 1987, 1993), (2) have a higher structural complexity and greater diversity of biological components (Kidd & Pimentel 1992, Leakey 1999), (3) have structures, composition and interactions that imitate natural forests (Shoeneberger 1993, Williams et al. 1997, Krishnamurthy & Avila 1999, Newman & Gordon 1997), and (4) reduce the pressure on deforestation since their outputs have multiple uses (Krishnamurthy & Avila 1999, Wilkinson & Elevitch 2000).

These are all characteristics that lead to an increase in the agroecosystem diversification capacities and thus maintaining and even enhancing biodiversity.

2.3 Agroforestry practices for biodiversity conservation and enhancement

Agroforestry does not represent a uniform ensemble of systems and technologies, and biodiversity conservation is function of several factors, such as system type, ecological interactions, species composition and their spatial and temporal arrangements (Shoeneberger 1993, Pimentel & Wightman 1999). These qualities are not always present in agroforestry systems (Michon & de Foresta 1995). For clarification below are listed some agroforestry practices and their characteristics with respect biodiversity conservation.

2.3.1 Linear technologies

Biodiversity corridors, living fences and windbreaks are categorized as linear technologies. They consist of one or more lines of a number of tree species partially or completely surrounding the production plot.

The two principal benefits of linear technologies for biodiversity preservation are providing habitats for wild and/or useful fauna, and supplying connectivity between areas with different diversity levels. However, several critical factors such as structure, composition, management and location in the landscape can also influence the level of biodiversity conservation (Harvey et al. 2004, Laurance 2004a).

Biodiversity corridors

Biodiversity corridors provide mobility to animal species (Harris & Eisemberg 1989), simulating to some extent the natural vegetation coverage that could have previously existed (Gascón et al. 2004). They facilitate wildlife movement locally and during migration and dispersion processes, provide habitats for resident species during nesting, and support ecosystem processes (Shoeneberger 1993, Laurance 2004a).

It is important to notice that as ‘preserver systems’, biodiversity corridors are not better than monoculture farms (van Noordwijk et al. 1997).

Living fences

Living fences control the movement of livestock and people between farm boundaries. In addition, they can perform other functions such as prevention of soil erosion, and delimitation and parceling of properties or grazing lands (Budowski & Russo 1993).

In Central America, it is estimated that 60 to 95% of the cattle farms are surrounded by living fences (Harvey et al. 2004). Despite their initial poor diversity, with time they become structurally more complex, due to the progressive enrichment of under-story species as a function of a number of ecological factors such as seed input, regeneration dynamics, biophysical conditions (weather and soil quality), and management (pollarding and herbicides application) (Budowski & Russo 1993, Harvey et al. 2004).

Windbreaks

Windbreaks are to linear plantings of trees and/or shrubs (usually several rows together) whose primary function is to protect crops, livestock and houses from wind damage. They are used regularly in temperate regions, but are less common in tropical areas. Windbreaks can facilitate natural regeneration in their under-stories, serving as perching and seed deposition sites for birds and other animals, and providing microclimates that help the tree growth (Harvey et al. 2004).

The conservation value of windbreaks increases when they connect intact forest or remnants of natural vegetation, and are wide enough to contain some interior habitat (Schoeneberger 1993, Harvey et al. 2004).

Case studies

There is an extensive documentation that supports the benefits of linear technologies. It has been demonstrated that bird populations increase up to five times compared to conventional systems, while they host newcomer species that control pests (Williams et al. 1997).

In Usambara Mountains Reservation, Northeast Tanzania, from the surrounding living fences the farmers gather in average 45.5% of their fuel wood and 31.5% of poles, thus alleviating the pressure on the reservation (Huang et al. 2002).

In León, Nicaragua, 20-year-old multi-species windbreaks under two levels of maintenance (regular and poor) were compared to a control (no windbreaks). The Shannon index value in well maintained windbreaks was (2.98) higher than the regularly maintained sites (2.62) and poorly-maintained sites (1.47), besides the benefits obtained from the windbreaks as food supplies and for resting, perching, and nesting areas for birds, windbreaks functioned as well as mobility corridors (Alvarado 2001).

2.3.2 Analog forestry or agroforests

The enrichment of natural forests with useful trees has been identified as the earliest form of agriculture, even preceding slash-and-burn systems, a model that still can be found in many peasant farms in humid tropics (Michon & de Foresta 1995). Agroforests are complex systems where a great diversity of species coexists in non-predefined spatial and temporal arrangements, following the physiognomy, structure and functions of natural forests. Normally they are composed of native vegetation and often exotic species that generate anthropogenic benefits (Torquebiau 1990, Michon & de Foresta 1995).

Agroforests are usually associated with annual cropping systems such as lowland rice, slash-and-burn plots, homegardens, pastures, perennial crop plantations and remnants of primary and secondary forests, appearing in a heterogeneous patchwork pattern (Schroth et al. 2004b).

Agroforests are nominally classified as: (1) cyclic agroforests, where the agroforestry phase alternates with a slash-and-burn phase in the same piece of land, and (2) permanent agroforests, where continuous small scale-processes occur simultaneously rather than modifying the whole plot (Schroth et al. 2004b).

In contrast to other agroforestry systems, where every component receives the same treatment outputting a small number of products in high amounts, in agroforests each component is managed individually or by groups, generating in consequence distinguishable goods in moderate amounts (Torquebiau 1990).

The relatively high biodiversity in agroforests compared with typical agricultural systems is judged differently by different researchers: some consider it the only form of agroforestry with the potential to restore, sustain and conserve the original forest biodiversity (Michon & de Foresta 1995), while others point out that there are limited substitutes for natural forests, due to the presence and under-representation of forest-dependant species (Schroth et al. 2004b).

Nevertheless, agroforests are useful as buffer zones in protected areas and deforested regions, where they can offer refugee habitats to forest-dependent flora and fauna, promoting biophysical interactions and enhancing landscape connectivity (Wilkinson & Elevitch 2000, Guiracocha et al. 2001).

The case of the Sumatra and Kalimantan lowlands in Indonesia is well known, where small farmers have modified the crop-fallow systems introducing rubber trees plus annual and perennial crops. These rubber-based agroforestry systems have been able to conserve 50% of the original pool of birds, 70% of the plant species and much of the native soil microfauna, while providing dependable income to at least 5 million people (Padoch & Peters 1993, Leakey 1999, Wilkinson & Elevitch 2000, Schroth et al. 2004b).

2.3.3 Homegardens

Defined by Kehlenbeck & Maass (2004) as "*a clearly bounded piece of land cultivated by a diverse mixture of annual and perennial crops and on which a house is built*", homegardens can be found in almost every socioeconomic and biophysical situation. They are characterized by high species diversity, including indigenous and exotic species, showing a varied and apparently haphazard horizontal and vertical stratification, and generating constant outputs (Krishnamurthy & Avila 1999). In addition to their main function, i.e., guaranteeing food security to their owners, homegardens can also provide cash crops, and be a source of extra income (Krishnamurthy & Avila 1999, Kehlenbeck & Maass 2004, Leakey 1999).

In Sulawesi, Indonesia, 30 homegardens in three localities near the Lore Lindu National Park were studied and 149 plant species, mainly fruit, vegetable, spices and medicinal plants were identified. The Shannon index as well as the Sørensen coefficient showed considerable differences among the sampled sites; the differences were attributed to the dissimilar socioeconomic characteristics, origin and economic activities of the owner groups (Kehlenbeck & Maass 2004). In Cuba, in a similar investigation assessing 31 homegardens in three villages 101 plant species were observed, with the number of species varying between 18 and 24 and a maximum of 49 per plot, each with a different composition (Wezel & Bender 2003).

2.3.4 Slash-and-burn agriculture

No other land-use system has been so controversially discussed than slash-and-burn agriculture also called shifting cultivation. On the one hand, it is considered the major agricultural system given the availability of resources and technology. On the other hand, because of its role in replacing natural vegetation, it is the major cause of habitat destruction and biodiversity loss in the tropics (Nye & Greenland 1960 cited by Myers 1980, Myers 1980).

Known as well as 'swidden agriculture', it was defined by Finegan & Nasi (2004) as: "*(...) any agricultural system in which the fields are cleared and cultivated for periods shorter than which they are fallowed*". It proposes a strategy of resource management in which fields are shifted in order to exploit the energy and nutrient capital of the vegetation-soil complex for future uses.

Widely practiced in tropical areas, slash-and-burn agriculture leads to the enlargement of the farming frontier to substitute the cultivated areas with depleted fertility after sequential cultivation seasons. Originally, this system was sustainable as the land availability was extensive, but currently, demographic, political and environmental pressures have curtailed its usefulness (Krishnamurthy & Avila 1999). The main consequences of shortening the fallow period are decline in crop yields, weed increase and consequent rising demand for labor (Finegan & Nasi 2004). Nonetheless, about 350 to 500 million people, mostly poor farmers in tropical areas, base their subsistence on slash-and-burn agriculture, making it the most widespread agricultural practice worldwide (Krishnamurthy & Avila 1999).

The contribution of slash-and-burn agriculture to biodiversity conservation must be considered in both cultivation and fallow stages, and in consequence their evaluation has to consider not just the diversity of species, but also the system structure and the diversity of niches (Finegan & Nasi 2004).

Crop biodiversity in slash-and-burn agriculture has received little attention, because most participant species are propagated vegetatively, making their conservation unfeasible through the *ex situ* conservation approach. This has changed with the introduction of the *in situ* conservation paradigm and participative methods (Finegan & Nasi 2004).

2.3.5 Tree-crop combination

Tree-crop combinations, installed in a regular (temporal and spatial) pattern are the agroforestry systems more analogous to extensive monocultures. They have defined design principles and management strategies, and pursue an economic rationality that normally is based on the woody component (Bates 1999, Krishnamurthy & Avila 1999). These systems have become extensive and economically important and have received increasing attention with respect to technological improvements, e.g. 'alley cropping' (Kang & Wilson 1987).

The most well known cases of tree-crop combinations are shade-coffee (*Coffea* spp.) and cocoa (*Theobroma cacao*) plantations, which dominate agricultural economic activities in more than 50 countries, covering 11 million ha and providing support to more than 25 million people (Somarriba et al. 2004).

The structural and spatial arrangements of coffee plantations can generally be extrapolated to other tree-crop combinations. The most representative coffee tree-crop plantation models are open coffee monocultures, coffee plantations with lateral shading from linear plantings in field borders, monolayered shade canopy (usually only one woody species), two-layered shade canopies (generally one tree component and some other intermediate species that perform short-term functions), multistory coffee policultures (with three or more species and three or more vertical strata), and rustic plantations (understory of natural forest cleared to host coffee plants) (Somarriba et al. 2004).

Research has shown that traditional coffee associations are only second in importance to primary forests in terms of their diversity of birds, insects, bats, microfauna and even mammals, who use shade species and related flora for nesting, mating, foraging and sheltering (Wilkinson & Elevitch 2000, Guiracocha 2001). In Mexico, 24 large mammal species, including three types of cats, have been reported in shaded coffee systems (Somarriba et al. 2004). In Salamanca Costa Rica, the mammal biodiversity in multi-strata agroforestry systems was 32 and 18 species for cacao-based and banana-based systems, respectively, numbers not greatly different from those of natural forests (Guiracocha 2001). In Colombia, 170 species of avifauna were found in three tree-crop systems, about 10% of the known species in the country. In the forests of central Guatemala, the bird populations ranged between 87 and 122 species, out of which 73 were found in coffee-shadow plantations (Somarriba et al. 2004). Similar results were found when comparing the diversity and abundance of coffee agroforestry systems with the semi-evergreen tropical forest in southern Mexico: up to 180 species of birds, more than 10 times the number of neighboring monocultures (Wilkinson & Elevitch 2000, Villavicencio-Enríquez & Valdez-Hernández 2003).

Another study in Costa Rica compared the diversity of Homoptera in three different coffee plantation arrangements: no shadow, shadow through *Erythrina poeppigiana* and shadow through *Erythrina poeppigiana* and *Cordia alliodora*. The greatest diversity and richness was found in *Coffea* + *Erythrina* + *Cordia* combination, followed by *Coffea* + *Erythrina* and then by *Coffea* monoculture (Rojas et al. 1999).

2.4 State of the art of the research on agroforestry and biodiversity conservation and enhancement

2.4.1 Conceptual propositions

The current research knowledge allows formulating the following three propositions over the contribution of agroforestry systems towards preserving biodiversity.

Agroforestry-deforestation

Agroforestry can help to reduce the pressure on natural forests resulting from the clearing of additional land for agriculture if adopted as an alternative to more extensive and less sustainable land-use practices. It can also help local populations to cope with a limited availability of forestland and resources. Nevertheless, its success depends on other socioeconomic issues, such as food security, profitability, and political factors, i.e., good governance, appropriate legislation and effective enforcement.

Agroforestry-habitat

Agroforestry systems can provide habitats and resources for forest-dependant native plant and animal species, which would not be able to survive in a purely agricultural landscape, thus directly helping threatened species, especially in regions where native forest areas have been reduced. However, agroforestry cannot become a substitute for natural habitats, but only a complementary activity near these.

Agroforestry-matrix

In landscapes that are mosaics of agricultural and natural vegetation plots, the conservation value of the remnant vegetation (which may or may not be protected) becomes greater if it is embedded in a landscape dominated by agroforestry elements and not by crop fields and/or pastures. This would facilitate connectivity between patches of natural habitats and buffer areas, and consequently the internal movement of species (Schroth et al. 2004c).

2.4.2 Suitable principles, systems and practices for biodiversity conservation and enhancement in agroforestry systems

In general, biodiversity tends to reach a maximum in fallows, secondary and primary forests, and diminishes progressively when the capacity to produce biomass reduces (Bates 1999). The level of management of agroforestry systems varies from intensely managed systems, as in alley cropping, to less demanding systems, as in agroforests. The higher management scale the more participant variables, and hence the weaker the selection pressure and hence a higher density of species (Michon & de Foresta 1995); in contrast the less intensively a system is managed, the more diffuse and localized is the species selection (Bates 1999).

Based on the above review, some general guidelines are given for the mentioned land-use systems:

- When optimizing the management of linear technologies, it is recommended to conserve the remnants of primary and riparian forest, encourage the use of shadow in traditional plantations, include native species and large fruit trees, plant as wide windbreaks as possible, fill the gaps between plantation lines, confine domestic animals, and to control hunting (Laurance 2004b).
- In the case of tree-crop combinations, the diversity is strongly linked to the diversity of trees and layer-story, plantation management, and composition and structure of the surrounding landscape (Somarriba et al. 2004).

- To improve the biodiversity of slash-and-burn systems, the focus must be on the variation of their spatial characteristics over time, regeneration mechanisms, change in richness, diversity and composition per cycle, the systems' contribution to conserving original forests and the landscape, and on the role of management in increasing the conservation value of individual components (Finegan & Nasi 2004). Important are also the recently developed improved or planted fallows, which focus on enriching the plot with leguminous species under appropriate management, with the aim of restoring fertility, accelerating decomposition and inducing regeneration of beneficial (woody) species (Beer 1983 and Budowski 1987 cited by Krishnamurthy & Avila 1999).
- The species selection factor supports more than any other the socioeconomic concerns of biodiversity preservation, because of its importance as a source of valuable goods and a way of achieving economic profit (Bates 1999). Considerable advances have been made with the use of cinderella species, which are little known indigenous trees that are highly profitable both economically and environmentally (Leakey 1999). However, despite these advances, the demand for multipurpose tree species is still high. This shows that it is difficult to integrate sustainability criteria with local values in the species selection (Bates 1999).

Managing agroforestry systems

The conceptual observations relevant to managing land-use systems for biodiversity conservation are summarized by Bates (1999) in four ideas: (1) in almost every situation, fewer species are used than those available, (2) the selection of species depends on a combination of factors, (3) external factors tend to influence the decisions of farming communities regarding resources management, and (4) when the value and importance of certain species increases, the selection favors the cultivated ones against the wild ones.

Considering these we should focus on: (1) diversifying species composition, e.g., multistoried systems provide more benefits than the addition of subsystems, (2) creating a variety of niches for wildlife (over-story, under-story and ground layer), minimizing the management activities that could alter them, (3) creating wildlife corridors, preferably in natural undisturbed areas with limited human presence, (4) providing shade and augmenting niches for sun-demanding species through spatial arrangements, (5) also managing the non-crop species, (6) conserving and storing water on the land or nearby, and (7) encouraging the presence of particular species to satisfy specific demands (Shoeneberger 1993, Bates 1999, Leakey 1999).

Summarizing, in order to reach higher biodiversity standards, environmental research recommends that agroforestry should: in biophysical terms follow successional phases by developing productive and complex agroecosystems similar to natural ecosystems, and in socioeconomic terms identify commercially and functionally valuable species and develop an entrepreneurial mentality in system management (Leakey 1999).

2.4.3 Perspectives of agroforestry as a biodiversity-friendly production paradigm

Since the beginning of agroforestry as an academic discipline thirty years ago, the focus has changed constantly and meaningfully. Initially, the discipline aimed at developing a theoretical framework based on related fields, such as agronomy, forestry, ecology, economics and anthropology, producing as outputs databases, methodological guidelines, and empirical approaches. Once the theoretical basis had been established, its focus shifted to transboundary issues, such as biophysical interactions, system design, and integration of socioeconomic and animal components. Lately, responding to market and environmental forces, the attention have moved to issues such as product marketing, economic assessment, carbon sequestration, water quality and biodiversity conservation (Nair 1997).

It seems that the future research agenda will continue along such a trend, integrating paradigms and demands, taking into consideration the key concepts complexity, profitability and sustainability.

Integrating perspectives, aims and outputs

Keeping in mind that the greatest challenge for land-use systems is integrating production and conservation, the question whether combining a wide variety of species to perform a great number of functions is better than efficiently producing certain goods and services through a less diverse system comes into the fore. In the case of agroforestry systems, which are by definition more diversified than other land-use systems, the disjunctive remains (Leakey 1999).

Probably the best answer to the above question is given by Van Noordwijk et al. (1987), who stated that optimization processes of segregation vs. integration are system specific and their equilibrium point always needs to be searched for.

The question of the degree of correlation between management intensity and level of diversity can be easily extended to our research issue: which is the equilibrium point in the design of a productive, profitable and sustainable (environmental services provider) agroforestry system? One of the goals of this study is to contribute to the answering of this question.

3 BIODIVERSITY IN LAND-USE SYSTEMS
Beyond conservation: the maintenance of processes

3.1 Definitions and concepts

3.1.1 Definition

Like most controversial topics, there is no single definition for biodiversity (Noss 1990, Chadwick 1993). On the contrary, there are many approaches, which vary from static "*(...) the variety of life on Earth"* to more functional, like *"(...) the study of the processes that create and maintain variation*" (Takacs 1996).

However, seems that an integrative idea of biodiversity should consider variability of vegetation, fauna and micro-organisms, and the ecosystems occupied by such species. It also considers the genetic resources and the products of their manipulation, as well as nations, peoples, ethnics, and in general human groups who handle the resources and their inherent knowledge related to the resources management (Harte 1996, Goicochea 1998, Acharya 1999, Stocking 2002, Altieri & Nicholls 2004).

The most accepted definition of biodiversity is the one introduced during the United Nations Earth Summit in 1992: "*(...) the variability among living organisms from all sources, including, interalia, terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems.*", which later was adopted by The United Nations Convention on Biological Diversity (CBD 2007).

3.1.2 Biodiversity study organization, perspectives, importance and functions

The study of biodiversity is categorized in three levels, namely genetic, species, and ecosystem biodiversity. Genetic biodiversity considers genes as key structures, as the basis for species' evolution and adaptation in the long term. At the species level, the individual is treated as the unit of analysis, and its study is supported by classification, sampling, and derivation of statistical operators as assessment tools. Thus, the number and types of species and changes in their populations are assumed as comprehensive measurements of the health of an ecosystem. The ecosystem level refers to communities whose spatial and temporal boundaries are not well defined: they could be a fragment of a forest or the entire biosphere; the study of biodiversity at ecosystem level focuses on the distribution patterns of species and their roles (Ryan 1992, Srivastava et al. 1996, Harrison et al. 2004a).

Similarly, biodiversity can be studied from two perspectives: one considers biodiversity as a charismatic global-interest issue and encourages efforts to safeguard it, and the another deals with its performed roles (Tomich et al. 2004). This role-oriented perspective is addressed through the following approaches: compositional diversity, i.e., ecosystems, species and genetic diversity; structural diversity, given by spatial and temporal arrangements at different scales; and functional diversity, reflected by variations in ecological processes at all scales (Table 3.1).

Table 3.1 Disintegration of the concept of biodiversity into its operative components

	Biodiversity components		
	Compositional	**Structural**	**Functional**
Genetic	Number of genes, alleles	Genetic structure	Recombination, evolution
Species	Number and types of species	Species distribution and abundance	Trophic levels, life history
Ecosystems and community	Number and types of communities and ecosystems	Habitat structure and distribution	Ecosystem processes

Source: Adapted from Schoeneberger (1993)

The importance of biodiversity can be argued in two ways: intrinsic and extrinsic. The intrinsic factor is based on ethics, stressing on the idea and need of evolution, questioning the activities that risk and constrain biodiversity existence in future as stated by the Noah Principle: "*...the usefulness of a species is not considered when discussing its conservation, but rather its very presence in the long history of evolution is sufficient to warrant its preservation*" (Ehrenfeld 1972, 1998). Complementarily, the extrinsic argument is much more utilitarian and anthropocentrically-oriented, emphasizing on the benefits that biodiversity provides to the societies in maintaining human life and its activities (Harrison et al. 2004) (Table 3.2).

Table 3.2 Principal benefits provided by biodiversity

Level	Provided benefits
Genetic	- Regulation of global processes: (gas flow, climate stability, etc.) - Conservation of soil and water (invigoration of hydrological cycle, erosion control, flood avoidance, infiltration enhancement, etc.) - Cycling of nutrients and energy (photosynthesis, soil renewal, nitrogen fixation, organic matter decomposition, etc.) - Reserves of matter and energy
Species	- Provision of raw materials for sustaining human activities: agriculture, medicine, manufacturing, industry, etc. - Increasing populations resilience
Ecosystem	- Saving of genetic information - Saving of promising materials for coping present and/or future needs

Source: Adapted from Perrings et al. (1995), Swift et al.(2004), Vermeulen & Koziell (2002), Stocking (2002), Altieri & Nicholls (2004), Swift et al. (2004).

3.1.3 Biodiversity concentration in the tropics

Tropical rainforests comprise only 6 to 7% of the Earth's land surface, but they make up approximately 50 to 90% of the global biodiversity, more than 80% of all plant species and nearly 50% of all animal species (Mooney et al. 1995, Gascon et al. 2004). It has been estimated that Colombia, Ecuador and Peru alone shelter 60% of the worldwide biodiversity (Kloppenburg 1988); nonetheless a great number of species in the tropics are still little known and unclassified, e.g., in the case of Amazonia, it is believed that the non-classified species vary from 65% to 99% (Mooney et al. 1995).

The factors determining biodiversity concentration in tropics are (1) time, as tropics are older than most ecosystems, they have higher indices of complexity, and in consequence relatively longer processes of evolution, speciation and persistence, (2) climatic stability and other climate-derived factors that define the lack of inter-annual and intra-annual variations optimize species performing conditions, (3) co-evolution as function of interactions with countless individual mechanisms such as pollination, predation, speciation and competency, (4) spatial heterogeneity, which provokes a great diversity of niches for a large number of species, and (5) greater water availability, which enhances cycling processes and biomass production (Eisemberg & Harris 1987, Detweiler & Hall 1988, Vitousek & Hooper 1993, Mooney et al. 1995, Gascon et al. 2004).

Concerning cultivated plants, tropics are equally important, since they maintain a high number of varieties and races of main crops as well as of their wild and weedy relatives (Harlan 1975 cited by Altieri & Nicholls 2004). The pioneering work of Vavilov in the 1920's enumerated the centers of origin and centers of diversification, which are sites of higher ratios of inter and intra-specific variability of cultivated plants. Interestingly, most of them are located in the tropical area (Kloppenburg 1988). This finding became the basis for the development of the *in situ* conservation approach for maintaining and repositioning the diversity of native crops (Altieri & Nicholls 2004).

3.2 Biodiversity loss

Biodiversity loss has become a central topic in environmental science because of the massive species extinction in the past few decades and its anthropogenic, ethical, social and economic implications (Stocking 2003).

3.2.1 Factors causing the loss of biodiversity

It is widely accepted that human disturbance is the major threat natural ecosystems are facing (Vitousek et al. 1997, Huang et al. 2002), and paradoxically humans themselves are greatly affected by the provoked changes. Phenomena like the extinction of species and the subsequent loss of genetic resources, or migration of species to marginal areas due to land pressure and its collateral effects, have reached levels that could endanger human survival (Stocking 2003). The triggering factors for this depletion chain are the industrialization, technological expansion and by-products generation; the rapid population increase and consequent rising demand for goods and services; and the growth of environmentally-noxious consumption habits (Takacs 1996).

Between 1991 and 2000, an area twice the size of Portugal (around 500 000 km^2) in the Brazilian Amazon was converted from natural areas to human land-use purposes (CIFOR 2004). In Central America, about 95% of dry forest areas have been converted into agricultural fields (Mooney et al. 1995). It is calculated that approximately 2 billion ha of forested areas have disappeared since the beginning of the agricultural revolution (Gascon et al. 2004). If these rates of deforestation were to continue, the world's rain forests would vanish within 100 years, provoking innumerable harmful effects (Urquhart et al. 2007).

The most relevant factors of biodiversity loss in natural ecosystems are listed and discussed below.

Habitat fragmentation

Landscape fragmentation leads to changes in the landscape performance as a whole, increasing the vulnerability of component species, and causing inbreeding and genetic drift, low heterozygosis, fecundity reduction and diminishing of offspring viability. The case of meta-populations is quite illustrative: small numbers of newcomer species shape subpopulations in places that have lost their original populations, thus immigration becomes the only way of restoring species composition in these areas (Laurance & Vasconcelos 2004, Gascon et al. 2004).

The factors affecting biodiversity in a fragmented landscape are fragment size (large areas are less affected than small ones), distance among patches (the longer the distances the slower the movement and propagation of related organisms), and the matrix effect, which combines interactions of the two above factors at landscape level. In general, it can be said that the more patchy a landscape, the more diverse (Laurance & Vasconcelos 2004).

Introduction of species

Closely linked to landscape fragmentation is the fact that prevalent species are replaced by newer wide-ranging species, which are tolerant to disturbed habitats and harsh conditions. Subsequently, native species are displaced and new predator species begin to appear, provoking a cascade effect, while the damaging phenomena are masked by the increase in biodiversity richness (Gascon et al. 2004).

Pollution

Economic growth reaches a detrimental point when the human population cannot be maintained or increased without damaging the natural ecosystems and the processes occurring in them (Gascon et al. 2004), as in the case of the biogeochemical cycles affected by human drivers, such as emissions by industries, mining and agricultural by-products to air, water and soil (Tilman 1999).

3.2.2 Agriculture as a driver of biodiversity loss

Agriculture is commonly seen as an enemy of biodiversity rather than an ally, because raising crops and livestock have changed vast areas of the available land, which is estimated to be around 25 to 30% of the total land surface on the Earth (Srivastava et al. 1996, Altieri & Nicholls 2004).

The extinction of species associated and not associated with farming is a concomitant phenomenon alongside the development of agriculture and human colonization. A total of 34 mammal genera have become extinct as a consequence of the first colonization of North America. The collapse of the Mayan Empire around 800 AD is closely related, as the archeologists argue, to the modification of the Yucatan rain forest conditions resulting from the unsustainable agricultural practices of the Mayan. The heavy erosion periods in pre-Columbian Mexico coincide chronologically with the widespread cultivation of maize (*Zea mays*) in sloped areas and the precedent demographic explosion. Similarly, about 90% of the European Mediterranean mammals became extinct after the agricultural expansion in the middle ages (McNeely 2004).

Today, monoculture farming is recognized as the main driving factor for the extinction of species due to the expansion of agricultural land, which leads to the loss of natural habitats, to the conversion of forested areas into homogeneous agricultural landscapes with low habitat value for wildlife, to the loss of wild and beneficial species as a direct consequence of agrochemical inputs and noxious practices, and finally to the erosion of genetic resources due to the expansion of improved varieties and more recently genetically modified organisms (Altieri & Nicholls 2004). In addition, continuous overriding of ecological principles in the form of salinization, soil erosion, pests and pathogens attacks, and a greater dependence on external inputs destabilize the ecosystems and make them vulnerable to constant breakdowns (Altieri & Nicholls 1999, 2004).

Contemporary agricultural practices, i.e., expansion of farming frontiers, hegemony of monoculture faming, over-application of agrochemicals, excessive water consumption and heavy mechanization, have enhanced significantly the above negative impacts (Altieri & Nicholls 1999, Brookfield et al. 2002). In the last millennia, from about 20,000 edible species around 3000 were selected and only a few hundred of those were cultivated in fields and gardens. In the twentieth century, less than 100 food species were considered significant enough to be included in the global list of agricultural crops, and nowadays barely three species supply nearly 60% of the calories derived from plants (Vietmeyer 1996). It is estimated that in the twentieth century, 75% of the genetic diversity of agricultural crops has disappeared (Brookfield et al. 2002). A similar phenomenon occurred in forestry, where nearly 2 billion ha of forests have disappeared, and conifers dominate forest plantations, comprising roughly 80% of the total area (Gascon et al. 2004). The situation with regard to livestock is worse, where 90% of the cattle raised belongs to only 14 species (Brookfield et al. 2002). The series of these phenomena is currently known as the sixth major extinction events in the history of life (Chapin et al. 2000).

3.3 Biodiversity conservation strategies

3.3.1 Conventional approaches for biodiversity conservation

The conservation approach aims at protecting ecosystems, populations or even individuals from harmful impacts. Here, human activities in endangered ecosystems are forbidden to allow these to recover to previous equilibrium stages, while a precautionary action is taken to prevent later damage. Such an approach is applied in all types of different cultures evolution (CONACIN 1998).

In the development of a conservation strategy, the following phases are normally experienced. The development of a technology that implies the degradation of an ecosystem in the medium-long term is followed by the detriment of the society by the over-exploitation of the resources supplied by the system. Then comes the reduction of human pressure on the resource and consequent return to high levels of productivity and diversification (sometimes permanently), and finally the determination of the best way of protecting the ecosystem, which generally oscillates between two extremes, i.e., strict protection and intensive use (McNeely 2004).

There is a consensus that conservation strategies must be formulated based on a comprehensive set of both the biophysical and socioeconomic data of an area (Gascon et al. 2004). Recently, was suggested the idea of controlled intervention rather than the intangibility of protected areas, which is promoted by mass media and supported by global and local policies (Gomez Pompa & Kaus 1999, McNeely 2004).

Conservation strategies present some variations according to the scale of their application:

At the global level, conservation strategies are focused on areas where the biota is threatened, protecting them via different kinds of seclusion schemes, such as the creation of protected areas or the use of a controlled resource exploitation regime as in the case of national forests (WCPA 2007). Such strategies are criticized for their siege mentality where certain ecosystems are confined and their integration into a global system denied (Stocking 2003).

At the landscape level, there are countless principles and techniques, such as landscape fragmentation, which intends to make heterogeneous areas interact dynamically through the mobility of individual species and exchange of nutrients, water and energy (Gascon et al. 2004).

At the species level, the key factor lies on the linkage between species and habitat conservation. Therefore, conservationist measures should attempt to safeguard natural habitats for wild species and populations, and improve the management of human-modified habitats, such as farmlands (Srivastava et al. 1996).

In the conservation of agricultural species, two approaches have been widely used: *ex situ* and *in situ*. The *ex situ* approach removes the endangered species from their original but threatened habitats and places them in a new location to be monitored by humans, frequently using laboratory techniques to maintain reproductive germs. The *in situ* approach refers to the protection given to the species in their natural habitats, maintaining the populations in the environment where they have developed their characteristics, which are essential factor in safeguarding their evolution (Brookfield et al. 2002).

3.3.2 Biodiversity conservation in land-use systems

The most productive agricultural areas in the world coincide with the most biodiverse ones, (Stocking et al. 2003) and these areas are expanding resulting in extensive monocultures.

On the other hand, not all forms of agriculture lead unavoidably to the simplification of biodiversity. Some farming systems, especially in developing countries, manage to maintain higher degrees of plant diversity in forms of polycultures and/or agroforestry patterns (Altieri & Nicholls 2004). Then it is possible to extend the principles of natural systems to land-use systems. Some theoretical arguments like the niche complementary hypothesis states that species-mixed rather than mono-specific communities are more stable and efficient in the use of resources and in coping with environmental disturbances, pests, diseases, and even seed predators (Tilman 1997, Ashton 2000, Naeem et al. 2003, Samu 2003, Atta-Krah et al. 2004).

In land-use systems, the users arrange the component species in groups according to their needs: the first group provides the target product or service, a second group complementary to the first, provides functions and/or services, and a third group is able to substitute the other two in their production of goods and services. Eventually a fourth group can exist, benefiting not the people but the environment (Bates 1999).

That is why the sustainability of a system can only be fulfilled with the utilization of multiple benefit species, or with the integration of various species performing various roles involving the three main dimensions: economic, social and environmental (Bates 1999), and furthermore the application and promotion of practices, technologies and policies that enhance the productivity and provide multiple goods and services (Gollin & Smale 1999, CDB V 2000 cited by Stocking et al. 2003).

Local land-use systems as a conservation strategy

Local farmers use their indigenous knowledge to develop strategies to manage the resources appropriately: preventing oscillating markets and environmental constraints, diversifying the use of the landscape and mixing their agricultural practices with off-farm activities (Srivastava et al. 1996, Brookfield et al. 2002, Altieri & Nicholls 2004).

However, there are factors that support the inclusion of small farmers in a conservation framework, such as their considerable participation in global food production: around 15 to 20% of world's supplies are provided by traditional multiple-cropping systems (Altieri & Nicholls 2004). It is possible to extrapolate these farming practices, despite the great diversity of environments and factors: evidence suggests that farmers under similar agro-ecological situations take similar functional-aspect decisions (Tomich et al. 2004).

Complementarily, alternative land-use systems like agroforestry have gained attention as integrated approaches to biodiversity conservation of natural reserves

(Sánchez 1995, Dobson et al. 1997, Leakey 1999) because of their ability to maintain a high proportion of species compared to natural forests (about 50 to 80%) and because they prevent the conversion into mono-specific crop lands or grasslands (Huang et al. 2002).

Research and management

Biophysical research concerning biodiversity in different land-use systems has arrived at two main conclusions. First, the increase in biodiversity in landscapes through biodiversity islands which strengthens the resilience of the surrounding areas depending on their size and connectivity (McNeely 2004). Second, biodiversity is increased at parcel/system level by promoting biophysical interactions. Research in interactions is covered by the study of invasive species management, and interactions among established species (Richardson 1999, McNeely 2004).

Biodiversity management is possible only through an integrative framework, which needs various levels and groups of interest (local, regional and national), different stakeholders (small farmers, indigenous groups, civil society, research institutions, public agencies and private investors), a multi-output platform that includes a diversity of outputs and beneficiaries in terms of food security, income generation, environmental services, and a financial support mechanism, such as a taxing system or payment for environmental services (Altieri & Nicholls 1999, Callo-Concha 2003, McNeely 2004).

Nevertheless, there are important aspects to consider. First, from the farmers' point of view, the principal interest lies in the improvement of their lives rather than in conservation, therefore, no agroecosystem could be maintained as a museum, neither for a crop plant or a field method (Brookfield 2002). Second, the assumption that agricultural practices that promote biodiversity are not yet generalized nor well integrated with local ecosystems, livelihoods and households means that the promotion of these practices cannot be done through the conventional extension model of technology transfer (Stocking et al. 2003).

3.3.3 From agrobiodiversity to agrodiversity

The term agrodiversity entered the literature only in the 1990's in the PLEC (People, Land Management and Environmental Change) Project, which attempted to develop biodiversity management models in agricultural ecosystems based on locally developed management systems that embrace ecosystem functions and processes (see section 3.4.4) (PLEC 2007).

It is important to distinguish between biodiversity and agrobiodiversity, which are linked but not synonymous concepts. Agricultural diversity, or agrodiversity in short, means "*the many ways in which farmers use the natural diversity for production*", which includes not only their choice of crops but also their management of land, water, environment and biota as a whole; in this concept agrobiodiversity or agricultural biodiversity is considered a subset (Brookfield et al. 2002).

The components of agrodiversity are: agrobiodiversity; management diversity of water, biota and other physical resources; biophysical diversity related to the physical environment; and organizational diversity, i.e., the manner of organization of resources and workforces.

Although we intend to differentiate agrobiodiversity from the larger array of biodiversity in general, we have to say that the boundaries between them are not very clear-cut. Agroecosystems, especially at small-farmers' scale, are highly dynamic, changing continuously in time and space according to biological, cultural, socioeconomic and environmental factors (Altieri & Nicholls 1999, Stocking 2003), as well as other less conventional factors, such as changes in technology, consumer preferences, rising fuel prices, alternation of pricing policies and, more recently, global warming and genetic manipulation (Vietmeyer 1996, Callo-Concha 2002).

However, we should keep in mind that the premise of agroecosystems is the production of specific goods and values for human consumption, although it may lead to a reduction in species diversity due to the high level of disturbance, i.e., agricultural practices (Swift et al. 2004).

Components and roles of agrobiodiversity

With respect to logistical aspects, agrobiodiversity has two important components: (1) planned biodiversity, included purposely by the farmer (mainly crops and animals), which depends on management inputs and spatial and temporal arrangements on the farm, and (2) associated biodiversity, which includes all remnant flora, fauna, and microorganisms that depend heavily on the system's management and its structure

(Vandermeer & Perfecto 1995 cited by Altieri & Nicholls 2004, Swift et al. 2004) (Figure 3.1).

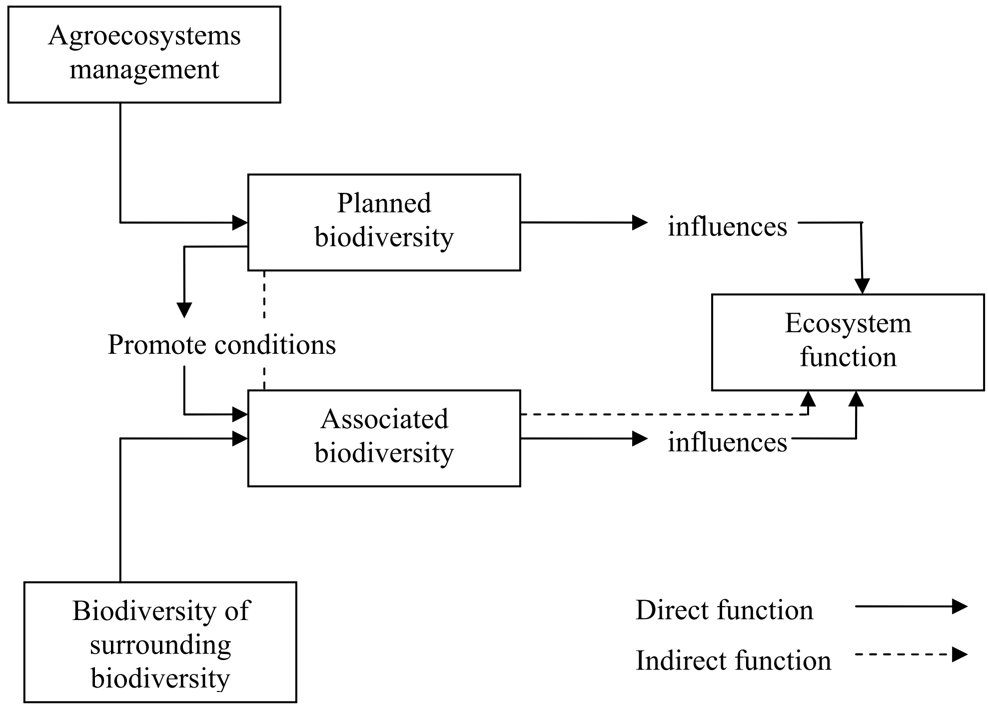


Figure 3.1 Relationship between planned biodiversity and associated biodiversity and how both influence ecosystem functions.
Source: Modified from Vandemeer & Perfecto (1995) cited by Altieri & Nicholls (2004)

The roles that biodiversity components play in the operation of an agroecosystem have been classified in three groups: (1) productive biota, trees and animals determined by farmers to perform specific roles in the system, (2) resource biota, i.e., organisms that contribute to productivity through pollination, biological control and decomposition, and (3) destructive biota, i.e., weeds, insects, pests and microbial pathogens (Swift & Anderson 1993 cited by Altieri & Nicholls 2004).

In natural ecosystems, the internal regulation of functions is substantially a product of plant biodiversity through biological synergisms and antagonisms; this form of control is progressively lost under agricultural intensification and simplification. Monocultures require external inputs, such as petrochemical energy and manpower to perform such functions (Altieri & Nicholls 1999, Swift et al. 2004). That is why biodiversity functions in agroecosystems are still poorly understood, even though is known that agriculture normally results in less rich and lower planned diversity, genetic variation, and presence of functional groups (Swift et al. 2004).

However, there are some indicators of the agroecosystem's capacity to enhance agrobiodiversity, such as the permanence of various crops, the diversity of vegetation within and surrounding the system, the intensity of management, or the extent of the isolation from natural vegetation (Altieri & Nicholls 1999).

Biodiversity diversification factors

The degree of determinism of the vegetation structure in a community is influenced by the canopy disturbance, the resources availability and a combination of both. Thus, the combination of this 'threshold opportunity' factor plus stochastic processes makes the community structure virtually unpredictable (Ashton 2000).

In all cases, coexistence occurs when resource demand differs among species and these are replenished to levels that allow competitors to survive. Sometimes homogeneous plantations may contribute through the modification of original vegetation to the regeneration of non-frequent species or the penetration of pioneers (Ashton 2000). Therefore, mixtures can be more efficient ecologically in the resource exploitation over time through their succession or by maximizing the yield of harvested products. Such mechanisms are applied empirically by smallholders, spreading the risk and perhaps increasing productivity (Izac & Sánchez 2001).

Nonetheless, there are still some knowledge gaps regarding species' co-habitation, such as the differential response to light of tropical evergreen woody species, distances between individuals, population densities, or correlations between specific predation and pathogenicity (Ashton 2000).

However, there is a little evidence that farmers may choose not to plant mixtures or to selectively thin or lop their plantations for ecological reasons. It can be assumed that the reasons are more pragmatic.

3.4 Biodiversity assessment

3.4.1 Approaches to valuing biodiversity

For the reasons given above, assigning a value to biodiversity is a complex and demanding task. There are several considerations to be taken into account. First there is the intrinsic value, which assumes that the essential value of biodiversity is based on its mere existence and its cultural, social, aesthetic and ethical significance (Suzuki Foundation 2007, Shiva 1993), second the utilitarian value, that refers to the direct utility that biodiversity provides for commercial sectors of society, such as agricultural, pharmaceutical and infrastructural, then follows the 'serependic', potential or bequest value, based on the belief that biodiversity should be conserved for the benefit of future generations, founded on the theory that any species may have a potential value that we have not yet discovered (Harrison et al. 2004). Finally, the supportive value refers to ecological functions in form of goods and services and ecosystem stability and resilience (Weesie & van Andel 2003, Harrison et al. 2004, Swift et al. 2004).

3.4.2 Evaluating biodiversity

Levels of evaluation

As stated previously, biological diversity has been analyzed at three levels: genetic, species and ecosystems; thus, the ecological valuation analysis, conceptualization and measurements are done at the same levels.

At genetic level, the differences among species are established in terms of allelic frequencies, phenotypic traits and DNA sequences. In general, these perspectives and methodologies focus on other aspects (rooting species origins or identifying relationships), and therefore do not coincide with the objectives of this study.

At species level, diversity is understood as a complete catalogue of the distribution and abundance of species in a particular site, but since it is not easy to carry out a full inventory, the catalogue is generally based on samples of populations. There are three main terms for measuring biodiversity over spatial scales: (1) alpha diversity, within a particular area or ecosystem, usually expressed by the number of species (richness), (2) beta diversity, a comparison of diversity between ecosystems, where the species that are unique to each ecosystem are compared to each other, and (3) gamma or geographic-scale diversity, which is a measure of the overall species diversity for different ecosystems within a region (Harrison et al. 2004).

At ecosystem level, biodiversity evaluation covers multiple relationships at various stages, and involves a series of factors, making the process very complex and less clear.

Other methods combine several factors into one specific function, such as the ecosystem health index, which is an overall indicator of integrity between ecological and human systems and their functioning (Nunes et al. 2001).

In addition, mapping methods can be used to carry out measurements at a larger scale, identifying types of vegetation using geographical information systems and remote sensing tools (Podolsky 1995).

Diversity indices

Species level has become central in biodiversity assessment procedures and the definition of indices. According their ability to perform different measurements, biodiversity indices are grouped in richness, abundance or both. (1) Indices of species richness, which estimate the number of species for a sample unit, and are optimally applied when the target species is enumerated and identified for a defined space and time. Among the most commonly used are Margalef's index and Menhinick's index, (2) Indices of abundance, which focus on the evenness and unevenness of the species' distribution. There are four main models: log-normal, geometric, logarithmic and the Mac Arthur's broken-stick distribution, and (3) Indices based on the proportional abundance of species, which through a single measurement give both the abundance and evenness at the same time. The most commonly used are the Shannon index and the Simpson index.

There are other complex indices that integrate several components at the same time, which were developed for different management purposes, such as the SDI (species diversity index) that ranks political units of administration according to their infrastructure and supervision capacities. In addition, we have the BTI (biodiversity threat index) based on population density, area of disturbance, change in areas of croplands, and percentage of annual loss of forest, which gives projections of biodiversity loss in land-use change scenarios, and finally the CRI (capacity response index) that calculates the capacity of an administrative unit to respond to biodiversity threats (OECD 2002).

The advantages using indices for biodiversity assessment are that they provide a transparent and repeatable evaluation framework criterion, allowing a direct comparison of management and conservation strategies, and permit an evaluation even when some of the data are missing (Nunes et al. 2001). A disadvantage is that there are too many indices differing only slightly from one another (Lek 2005), and since "*(...) it is a single statistic that only summarizes characteristics and it is not very informative by itself*" bear the risk of becoming a non-concept (Hulbert 1971 and Pielou 1975 cited by Noss 1990).

3.4.3 Alternative assessment frameworks

In the evaluation framework established above, the functions performed by ecosystems are underestimated or simply not considered, therefore de Groot (1994) indicated that at least some functions should be included in the assessment, such as life support, carrier of processes, production, and information flow, to make the assessment framework more utilitarian (Nunes 2001).

Hierarchical characterization approach

Noss (1990) suggested that biodiversity should be treated at various levels of organization and at multiple temporal scales, and proposed the 'hierarchical characterization' approach, based on the attributes recognized initially by Franklin (1988), such as composition, structure and function. This approach nests these attributes into a hierarchy that incorporates elements of each attribute at four levels of organization: regional-landscape, community-ecosystem, population-species and genetic.

Hierarchical characterization is based on the definition of indicators that perform as measurable surrogates of the influential factors. Ideally, an indicator should be sensitive enough to provide an early warning of change, it should be distributed over a broad geographical area or otherwise widely applicable, and it should be capable of providing a continuous assessment over a wide range of stress. Furthermore, it should be independent of sample size, easy and cost-effective to measure, collect, test and calculate, be able to provide information to distinguish its origin whether from natural cycles or induced by anthropogenic stress, and finally be able to represent significantly the targeted phenomenon (Franklin 1988). Since no single indicator possesses all these desirable properties, a set of complementary indicators is required.

In general terms, the indicators are in the following four main crossing scales:

- Genetic: produces very specific and reliable information concerning traces of evolution trends and taxonomic proximities, but is restricted to specific demands and the availability of technological resources.
- Population-species: applies single-species indicators due to its relative simplicity and tangibility. The most well known indicator group species considers ecological indicators, keystone species, umbrella species, and vulnerable species (IUCN 2007).
- Community-ecosystem: combines interacting populations of relevant species and abiotic components of the ecosystem, and generates variable indicators well known in community ecology, such as species richness, diversity dominance, diversity curves, life forms, guild proportions and other compositional measures.
- Regional-landscape: combines functionally the habitats in a landscape mosaic related to animal movement. Its major determinants are ecotone differences, biogeochemical, hydrologic and energy flow disturbances, while the major controllers are heterogeneity, patch size, perimeter-area ratio, and connectivity. At this scale, the inventory and monitoring are done through aerial photographs and satellite imagery.

In implementing this evaluation framework, Noss (1990) suggests the following steps. First, the final objectives and the mid-term goals of the evaluation should be defined. Second, data gathering and integration should be at the beginning establish the baseline conditions and later identify hot spots, e.g., ecosystems at risk. Third, specific questions to be answered by monitoring and, based on these questions, indicators of structure, function and composition are defined. Finally, control areas and treatments should be established, sampling schemes design and implemented, and relationships between indicators validated.

3.4.4 Agrobiodiversity assessment

Typical biodiversity assessment methods are not capable of depicting the full picture of biodiversity in small farmers' land-use systems, mainly because they cannot cope with their inherent complexity (Stocking et al. 2003).

Alternatively, several methods have been proposed, e.g., method developed by PLEC Biodiversity Advisory Group, which besides trying to widen the evaluation scope, focuses on ensuring the method's repeatability and quality to meet international standards. PLEC's methodology is based on the following principles: each sample area is stratified based on a particular field type; the samples selected have to show a great variety of species; multiple sample plots of mixed dimensions are surveyed; and, to capture temporal variations, the plots are re-assessed at appropriate intervals.

The data analysis can include classic biodiversity indices, i.e., species richness and utility within each plot, within field type and within land-use stage; similarity analysis, such as Sørenson's index calculation under three situations (temporal variations of species composition in the same plot, replication sample area variations of species composition in the same field type, and field type variations of species composition within the same land-use stage), and species-area curves and abundance-diversity curves (Zarin et al. 2002).

3.5 Functional biodiversity

3.5.1 Antecedents and conceptualization

Functional biodiversity was first mentioned in a specialists meeting held in Mitwitz, Germany, organized by E.D. Schulz and H.A. Mooney in 1991, while launching a research program by SCOPE (Scientific Committee on Problems of the Environment) whose aim was to assess the state of the knowledge and the role of biodiversity in all dimensions and at ecosystem and landscape levels (Mooney 2002).

An intense debate soon followed about the role of biodiversity in the functioning of ecosystems, and the type of relationships among the factors involved. This spotlighted this topic as one of the main issues of contemporary ecology (Naeem et al. 2003, Swift et al. 2004).

Functional biodiversity is an alternative perspective in the study of biodiversity in ecosystems, and is based on the heterogeneity and dynamism of community components, and on the feedback of biophysical and socioeconomic variations.

Functional biodiversity assigns more weight to biodiversity components' roles in ecosystems than to the number of species per unit of area, or similar quantitative approaches. This finally provides sustainability to the system through the enhancement and intensification of the processes (Altieri & Nicholls 1999).

As functional biodiversity derives from the accurateness of plant species number and agroecosystem stability, the optimal functionality depends not on finding a high number of species *per se*, but on determining their correct assemblage (Vandermeer 1995).

Based on the above, the attention shifted to the study of species' cohorts, categorized according to their ability to carry out certain types of activities (Huang et al. 2002). This categorization led to the identification of types of desirable biodiversity, i.e., functional groups, which should be capable of supporting, maintaining and enhancing specific ecological services (Altieri & Nicholls 1999).

Nevertheless, functional biodiversity is an integrative concept, and several branches need to be addressed from one direction. Franklin (1988) developed a frame that can operationalize the functional biodiversity concept, defining the three operational groups: (1) compositional, based on the identity and variety of elements in a collection, including species lists and measures of species and genetic diversity, (2) structural, based on the physical organization, patterns within communities and at various scales, and (3) functional, involving ecological and evolutionary processes, including gene flow, disturbances and nutrient cycling (Figure 3.2).

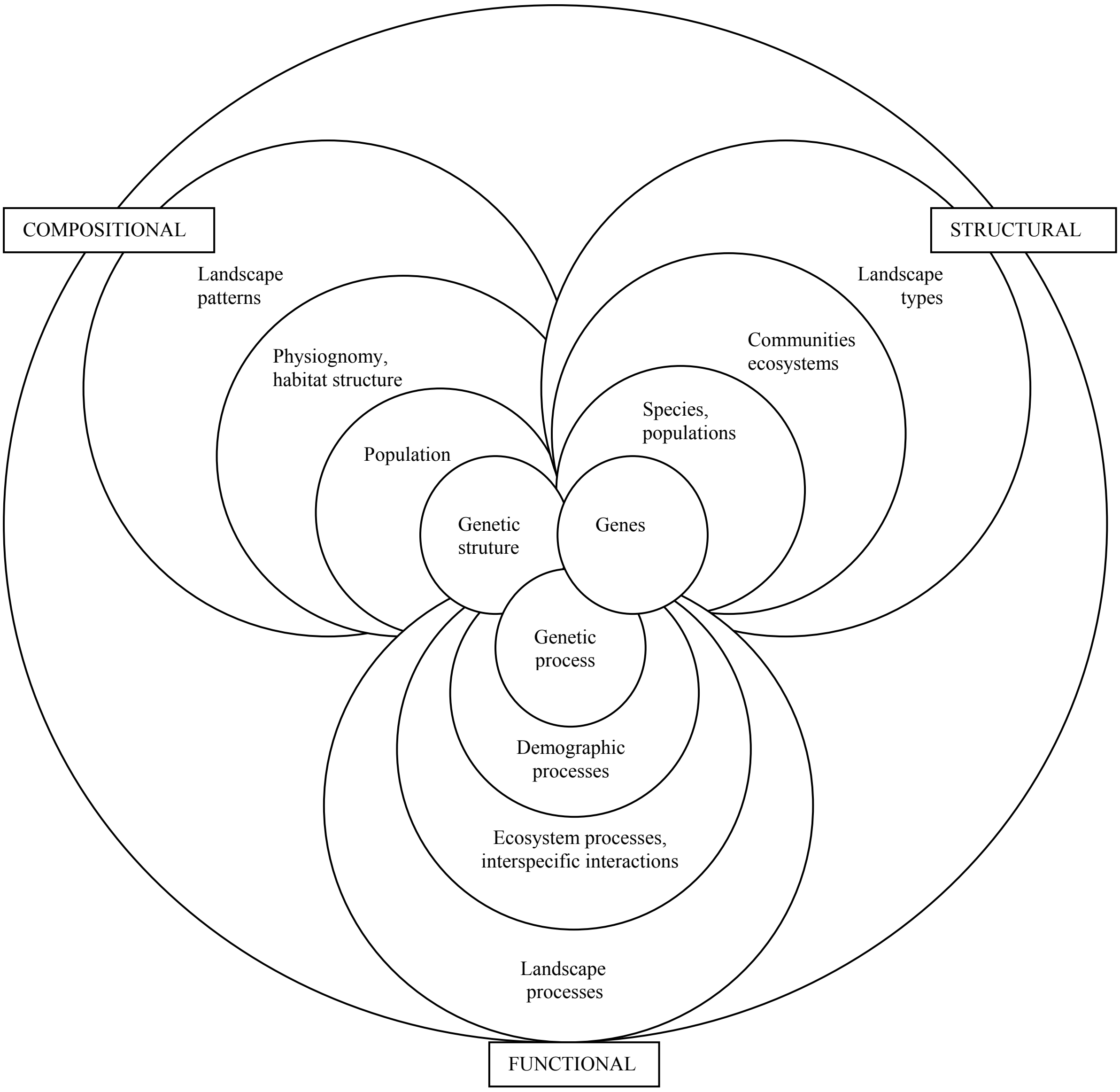


Figure 3.2 Operationalization of the functional biodiversity study through the fragmentation/integration on compositional, structural and functional issues. Source: Adapted from Franklin (1988)

3.5.2 Theoretical background

The Vitousek-Hooper relationship shows that the essential functions of an ecosystem require a minimum level of biodiversity to optimize its performance, and that effect is accomplished with a relatively low number of individuals, which normally consist of a selection of representative functional groups (Vitousek & Hooper 1993).

There are three types possible interactions between a given ecosystem function and the number of species involved in: in type 1, the ecosystem function is performed optimally by a small number of species; in type 2, the supply of the ecosystem function remains constant after having reached a specific number of species; and in type 3, a very low number of species can satisfactorily perform the function in question (Figure 3.3) (Vitousek & Hooper 1993).

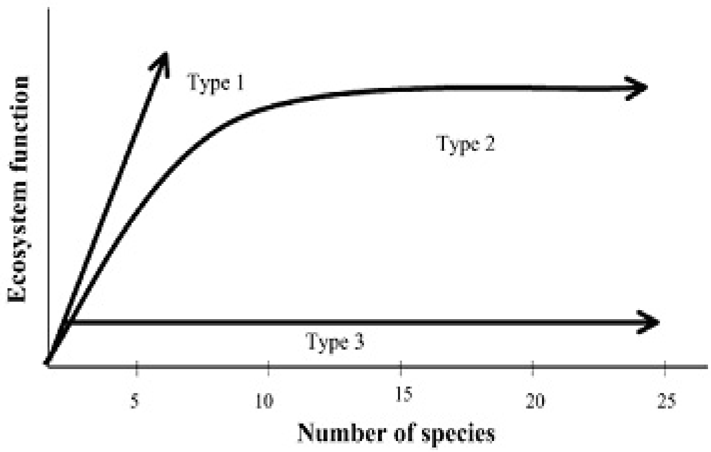


Figure 3.3 Possible relationships between biological diversity and provision of ecosystem functions: Type 1: few species provide the function optimally; Type 2: a number of species maintain the function constant; and Type 3: the ecosystem function provision is indifferent to the number of species. Source: Vitousek and Hooper (1993)

A functional group is defined then as a set of species (taxa) with common biological attributes, which determine their behavior and effects on specific biogeochemical processes (Huang et al. 2002, Swift et al. 2004).

Schematically, functional groups are divided according to their scope of influence in three main domains: (1) ecologically-functional, which is a set of species with similar impacts on ecosystem processes, e.g., a group of individuals not necessarily made up of the same species that can perform functions of soil erosion control or nitrogen fixation; (2) conservationally-functional, which is a set of species with similar impacts on human-environment interface processes: fuel, timber, fodder, fruit, medicine, edible plants, honey and hunting; and (3) livelihood-functional, which are species with similar impacts on the life-security processes of local people, such as crop species providing nutritional security, poverty alleviation and income. Of course, these three groups commonly overlap (Figure 3.4) (Huang et al. 2002).

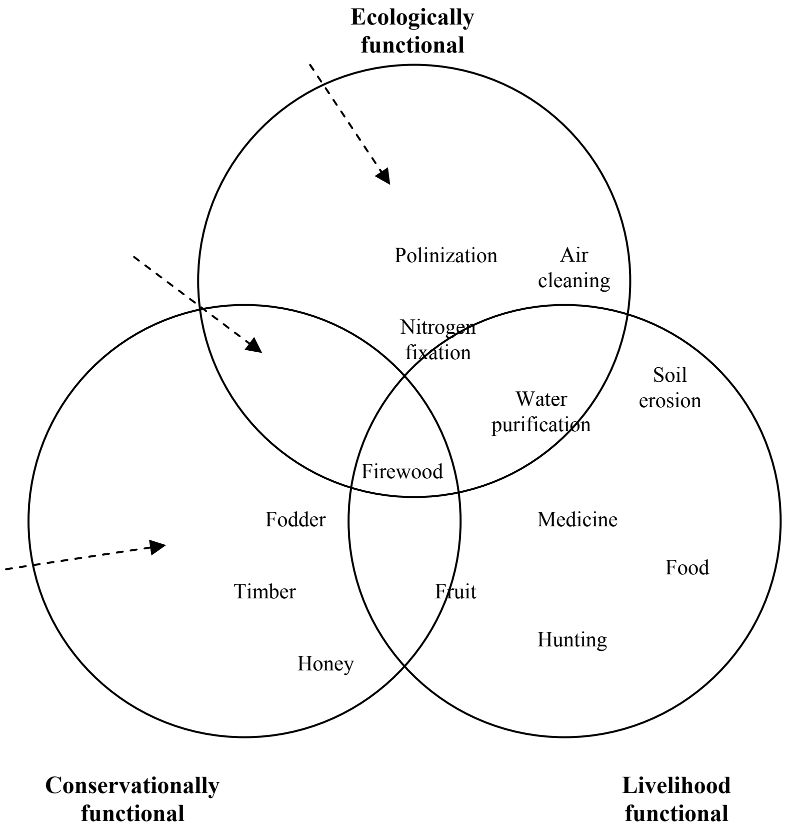


Figure 3.4 Three main functional biodiversity groups, the most frequent activities within each, overlapping and trends in human-oriented land-use systems.
Source: Modified from Huang et al. (2002)

Taxonomically, the main functional groups are: (1) primary producers, mainly vegetation of different strata as the major source of raw materials; (2) service providers, a large community of invertebrates, such as protists, bacteria and fungi that carry out functions of decomposition and mineralization of organic matter; and (3) primary and secondary regulators, organisms in charge of regulating biological influences on water flow, soil cover, organic matter content and soil activity, etc. (Swift et al. 2004) (Figure 3.5).

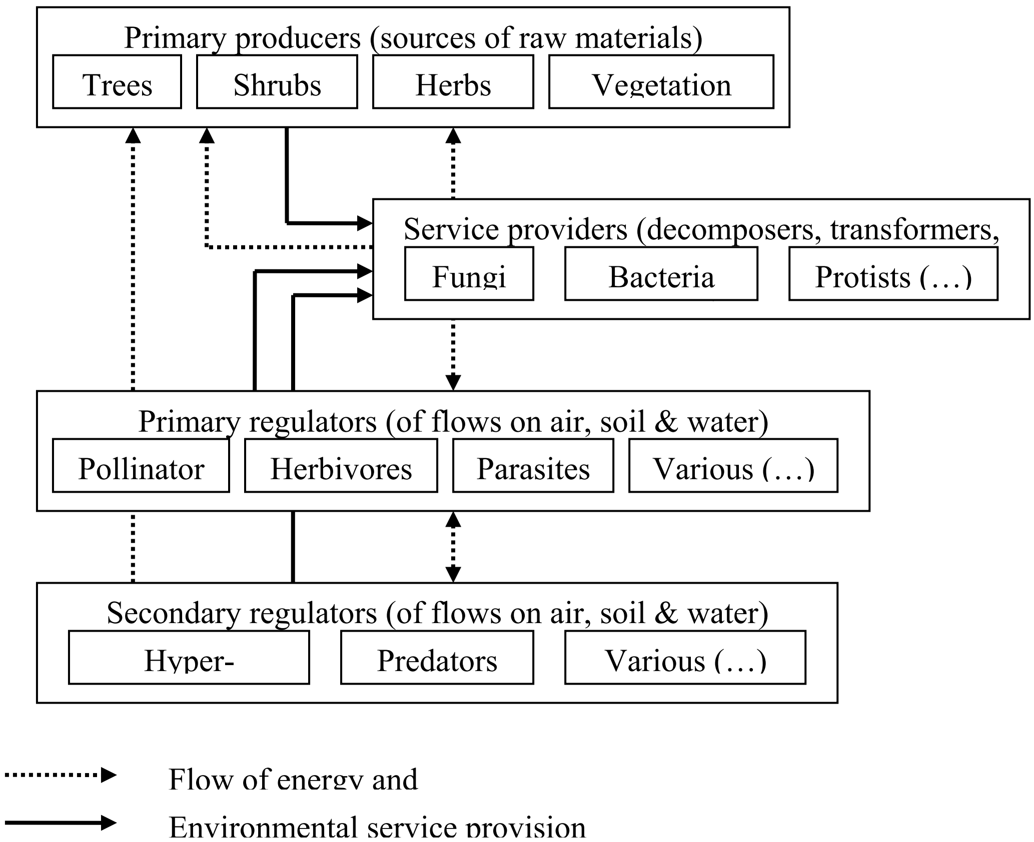


Figure 3.5 Hierarchical relationships between categories of functional groups.
Source: Modified from Swift et al. (2004)

Certain functional groups seem strongly influence certain manifestations of biodiversity, e.g., pine trees storing carbon, while others, like microorganisms, because of their high degree of redundancy may be functionally neutral, but at the same time very resilient. For that reason, no principles of biodiversity maintenance can be applied across all functional groups and environmental circumstances (Swift et al. 2004).

As the total (agro)ecosystem diversity and services are determined by the nature of the plant community in interaction with human influence, it is possible to reduce the biodiversity substantially down to a scale which maintains the productivity and resilience of the system. Then, certain ecosystem functions can be provided by a minimum essential diversity, represented by a few functionally distinct species, or a few representatives of functional groups. The total diversity will then depend on the number of recognized functions and on the degree of overlapping of functional groups (Swift et al. 2004, Tomich et al. 2004). However, in multifunctional ecosystems, a higher number of species is necessary to promote each individual process and the overall functioning of the system (Hector & Bagchi 2007).

The study of functional biodiversity has been made operative through approaches such as the analytic hierarchy processes (AHP), which generate a distinctness index of functional groups of various land-use systems and their impact on biodiversity conservation through the arrangement and comparison of criteria at various levels (Huang et al. 2002).

3.5.3 Functional biodiversity in land-use systems

Crop plants and animals, like all other organisms, need systems in place for uptake and metabolization of nutrients and water, protection against pests, diseases and competition. These services are provided fundamentally by the genetic make-up of each organism, and are supplemented by the interactions of adjacent organisms (Altieri n/d).

In human-managed ecosystems, the species are not introduced randomly but in oriented patterns. Yet the species used are not always the same, i.e., similar demands could be supplied by different providers, e.g., in post slash-and-burn systems, carbohydrates are supplied by cassava in Latin America, banana in southeast Asia, and yam in Africa (Bates 1999).

As a consequence, the utility of biodiversity in land-use systems depends on the way the systems cope with the impacts that disturb them, and how they strengthen their stability and resilience (Altieri n/d, Wolfe 2001), and at the same time generate useful outputs (Bates 1999).

Some agricultural practices are known to be better than others in their potential to enhance functional biodiversity (Altieri & Nicholls 2004), and farmers participate actively in their selection (Swift et al. 2004). Tropical polycultures are good examples of such systems, characterized by a higher number of intercropped perennial and annual species, more intense interactions, lower costs, greater energy efficiency, greater natural biodiversity, more efficient internal fertilization processes, stronger pest and weed restrictions, and a wider range of products in different seasons (Wolfe 2000, 2001).

Expectations, perspectives

The functional biodiversity approach is new, and the lack of consensus has led to divergent products. Here lie the challenges for future research. Among these challenges are full understanding of biodiversity and ecosystem functioning, quantification of ecosystem services, increasing in the scale of study from small and single functional groups to landscape scale and different trophic levels, and finally the key challenge: how important is biodiversity in system processes over short- and long-term periods (Mooney 2002).

The first integrative approach for evaluating biodiversity was applied by Franklin (1988), who suggested defining indicators for depicting the main compositional, structural and operational functions. Later in 1990 Noss applied a hierarchical characterization to these indicators. Recently Huang et al. (2002) extended this approach trough the analytic hierarchy process.

This study evaluates biodiversity within this frame, coping the inherent comple and variability of functional biodiversity-related phenomena through the application of integrative methods.

4 ENVIRONMENTAL SERVICES
From the worldwide demand to the Brazilian Amazon case

4.1 A conceptual framework of environmental services

4.1.1 Background and conceptualization

Once environmental services were taken for granted or, if perceived at all, they were viewed as gifts of nature. Such a vision has changed since the end of the twentieth century, due to political, socio-economic and ecological forces, which warned us about the degradation of the environment and the goods and services supply (Tomich et al. 2004, van Noordwijk et al. 2004).

Ecosystem or environmental services refer to a wide range of conditions, processes and goods through which natural ecosystems help to sustain and fulfill human needs (Daily et al. 1997). Among these benefits are products that already have a value and are commercialized in several ways (Viana et al. 2006).

In addition, the concept includes goods that refer to tangible, materials and services that refer to processes themselves (Costanza et al. 1997). There is also the distinction between environmental services and environmental functions, the latter performed by nature and oriented to its own maintenance and non-human use; and environmental processes, performed by the nature without being part of any established framework (Brown et al. 2006). There is also the distinction between ecosystemic services when they are provided by nature but are not used and environmental services when their use is addressed by humans (Boyd & Banzhaf 2006).

The operationalization of the concept of environmental services is based on the relationship between beneficiaries and providers (Tomich et al. 2004). The extrapolation of this discussion on diplomatic level involving different interest groups with the aim of obtaining subventions for preservation activities has become very politically relevant. Furthermore, due to the increasing number of degraded ecosystems and affected parties, the focus has shifted to safeguarding the vulnerability of individuals, communities and nations (Daily et al. 1997, Pérez 2004).

Research on environmental services deals mainly with the following issues: understanding the pathways of resources generation, use and damage, recognition of the resources' spatial extent and distribution patterns as potential providers, development of indicators for recognition and monitoring environmental services, and simplification and making more accurate the measurements and validation of environmental services to facilitate negotiations among stakeholders (Tomich et al. 2004).

The determinant factors in any scheme of environmental services provision are natural capital, i.e., inherent richness of flora and fauna, soil and water, guardianship for preventing the destruction of the natural capital, and human capital, active management or stewardship (Tomich et al. 2004). The type and extent of interaction among these components will determine the degree of generation or degradation of the environmental services in a given system.

4.1.2 Classification of environmental services

The most pragmatic attempts to classify environmental services group them into four main groups: greenhouse gases fixation, biodiversity conservation, water management, and scenic beauty (Chaves & Lobo 2000); the Alternatives to Slash and Burning (ASB) consortium modified and extended this classification (Table 4.1).

Table 4.1 Ecosystem services classification

Group of service	Cases
Watershed functions (W)	W1 Water transmission (total water yield per unit of rainfall) W2 Buffering (above average river discharge per unit above average rainfall) W3 Gradual release of stored water supporting dry-season flows W4 Maintaining water quality (relative to that of rainfall) W5 Stability of slopes, absence of landslides W6 Tolerable intensities of net soil loss from slopes by erosion W7 Microclimate effects on air humidity and temperature
Biodiversity functions (B)	B1 Protecting the integrity of conservation areas by preventing loss of habitat and threats at population level in the areas directly around core protection areas B2 Providing habitat for a sub-set of the original fauna and flora inside agriculturally used landscapes B3 Maintaining connectivity between protected areas via corridors B4 Creating opportunities for local-level restoration, in landscapes where connectivity is still maintained B5 Various forms of *ex situ* conservation.
Carbon stocks (C)	C1 Protecting natural forest areas, peat soils and other carbon storage areas C2 Protecting above- and/or belowground carbon stocks in areas used for (agro)forestry and/or agriculture C3 Restoration, increase in tree cover (in a 'sustainable harvest' regime) C Stock of a land use system does not depend on the growth rate, but on maximum stock at time of harvest) C4 Accumulating wood and other products derived from recent plant production in, e.g., the form of houses, furniture, paper, organic waste dumps
Human health & landscape beauty (H)	H1 Regulation of human pests and diseases H2 Detoxification of air, water, food H3 Spiritual, religious and aesthetic values H4 Opportunity for active recreation (ecotourism) H5 Ecological knowledge
Productivity and direct profitability (P)	P1 Allowing extraction of potentially renewable resources P2 Non-renewable resource mining P3 Nutrient and water supply for agriculture P4 Biotic relationships: pollination, plant and animal pests diseases and their control

Source: Alternative to Slash and Burn ASB (n/d.)

4.1.3 Assessment of environmental services

Environmental services have been greatly under-valued because they are not traded in formal markets but treated as public goods and consequently private owners have had no way of obtaining benefits from them. This is an issue that has to be solved in order to define an assessment platform, which should permit both the conservation of natural resources and a socially rewarding mechanism.

But what should be assessed and how should it be assessed? There are several answers to these two questions. One could assess the contribution to the maintenance of a system's status, where every structure and function has a specific purpose and therefore a value (Costanza 2000). Or the qualities of each service referring to different demand-scales, e.g., including the recreational and aesthetic services of a forest, beyond the explicit goods and services provided, such as sustainability, stability and resilience (Costanza & Farber 2002). One could also assess the relative ability of certain systems to perform certain services, like forests compared to other land-use systems with respect to carbon sequestration. Studies could also be based on the time frame, where the needs of coming generations are taken into account, as in the case of biological resources, whose use has not been yet discovered but which are already in danger of extinction (Viana et al. 2006).

In practical terms, political decisions about what to assess, depend on how natural systems function and how societies alter them, as well as on the strategies developed to protect and preserve those resources (Costanza & Farber 2002). This involves determining the value of environmental services at different levels, i.e., ecological, sociocultural and economic (de Groot et al. 2002, Viana et al. 2006).

Ecological value focuses on ensuring the continued availability of ecosystem functions. The use of goods and services should be limited to sustainable levels, which are determined by ecological criteria, such as integrity, resilience and resistance. Since most functions and related ecosystem processes are interlinked, sustainable use should be determined under complex system conditions, taking into account the dynamic interactions between functions, values and processes (Boumans et al. 2002, Limburg et al. 2002).

Socio-cultural value is based on the perception of the society who determines the importance of natural ecosystems and their functions in human development.

Physical and mental health, education, identity and cultural diversity are some examples where natural systems are important to non-material wellbeing, and become indispensable for a sustainable society (Norton 1987 cited by de Groot et al. 2002).

Economic value is only one type of measuring environmental services, but is particularly useful when societies share an intuitive notion of it. Basically, it tries to assign a monetary value to goods or services, which are not normally valued within the market. Due to this paradox, its usefulness lies more in providing arguments to decision makers for regulating human activities (Costanza & Farber 2002, Farber et al. 2002).

Since economic assessment is the closest to decision makers, it has developed an extensive background. Its procedures are based on indirect measures, such as travel cost, reposition cost or hedonic prizing, that ask the possible beneficiaries about their willingness to pay for maintaining certain services or for certain goods provision. It is based on direct assessments, like the opportunity cost, which means the maximum compensation one can get by substituting harmful activities for others like preservation or restoration (Viana et al. 2006). In both cases, the marginal value, i.e., "*...how much the flow of ecosystem services are augmented or diminished with the preservation of the next unit of land or time*" has to be internalized (Daily 1997).

However, the evaluation of ecosystem services must integrate its various components and dimensions, although the economic and ecologic values tend to be more influential in policy decisions (Costanza & Farber 2002) (Figure 4.1).

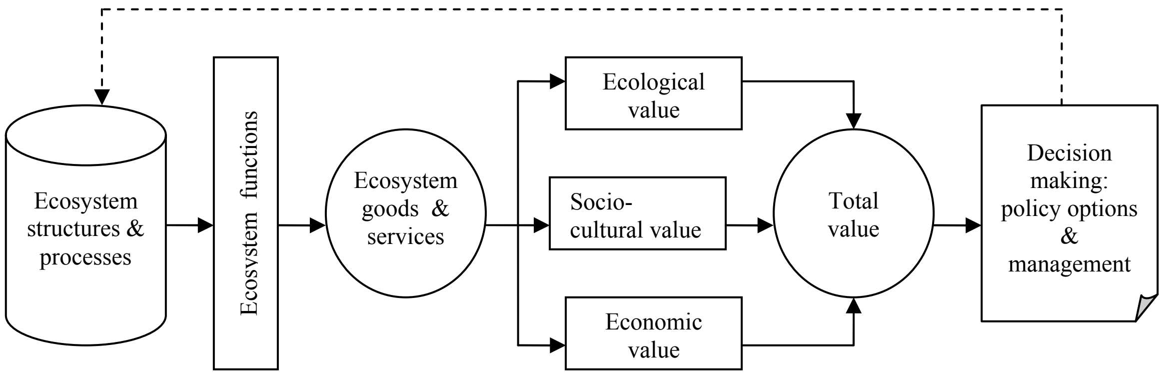


Figure 4.1 Framework for integrated assessment and valuation of ecosystem functions, goods and services.
Source: de Groot et al. (2002)

4.1.4 Payment for environmental services

The payment for environmental services refers to a contractual transaction between a buyer and a seller for a series of practices capable of assuring environmental benefits. This transaction is facilitated by the market, which is understood as "*a series of regulations that settle the principles on which a buyer, who so far made use of the same service as a common good, recognizes it as valuable for himself and society, and accepts to pay for it henceforth*" (van Noordwijk et al. 2004).

The natural capital through the providers' intermediation reaches the beneficiaries, while the process is addressed by compensation mechanisms and is triggered by the cost of opportunity (Figure 4.2).

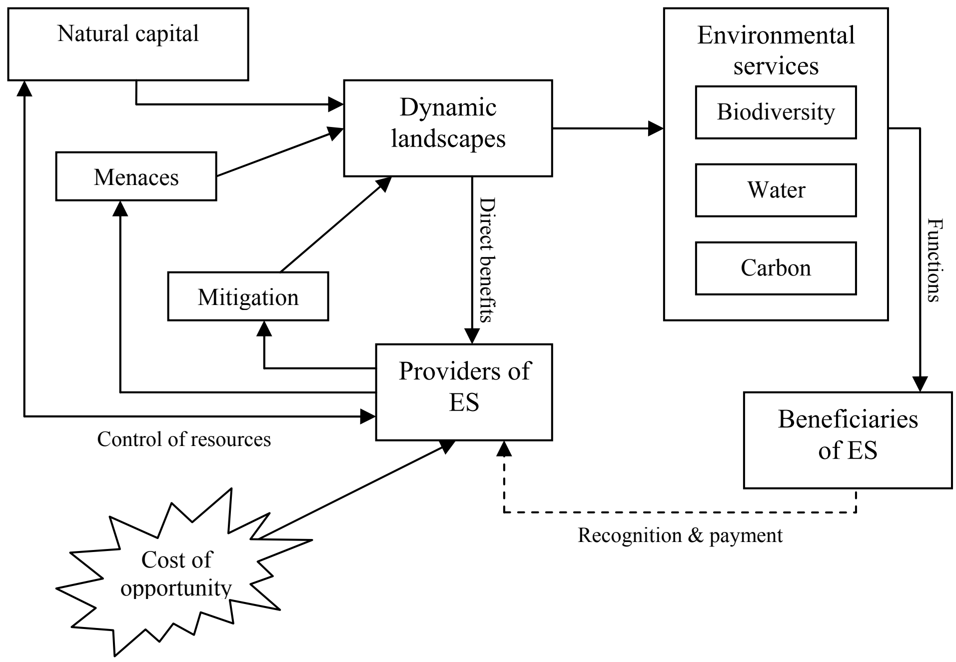


Figure 4.2 Scheme of recognition and payment for environmental services.
Source: Modified from van Noordwijk et al. (2004)

This framework can be affected by complementary considerations, such as the scale of the benefit, global in the case of climate regulation through carbon sequestration, or more restricted as in watersheds treatment; or the nature of the service, generated in the form of goods, such as food, fibers, or finished products; or of services, such as clean water, clear air, or fire risk reduction (Viana et al. 2006).

The operationalization of the payment requires establishing a proper political and economic framework for regulating the prices of environmental goods and services, through the provision of direct and indirect incentives that promote a behavior amendment among stakeholders in favor of environment conservation. Here, three types of economic instruments could be considered: (1) based on compensatory mechanisms, when an economic activity generates impacts on the environment, (2) based on the benefit to the stakeholder, who contributes with a tax, toll or fee, or (3) based on the principle of payment by economic instruments, created explicitly for environmental purposes (Tomich et al. 2004, Viana et al. 2006).

4.2 Environmental services: the operational framework

Environmental services operationalization has become very complex because of the unequal degree of development between societies, and their divergent views concerning environmental issues (Costanza & Daily 1992, Costanza et al. 1997). Moreover, the great number of involved stakeholders demands greater institutional capacities, able to cater for their different social, cultural, political, and economic backgrounds (Swallow 2006).

The participant institutions should be able to understand the environmental services causal pathways, recognize the spatial extent and distribution patterns, and develop protocols for their easy recognition and monitoring, which would simplify and validate the measures towards facilitating negotiations among stakeholders (Tomich et al. 2004).

4.2.1 Operationalizing criteria

Regulating vs. rewarding

The institutional options to operationalize environmental management are limited and can be grouped into two broad categories: regulations and rewards. Despite the attainments developed below, it is important noticing that the choice between them is pretty circumstantial and involves a considerable degree of uncertainty.

Regulating is the more traditional approach usually considered as an administrative tool. In general, it establishes tolerable levels of management, such as ‘do not cross this line’ as in the case of air pollution, or ‘minimum allowed’ as in the case of drinking-water standards. However, with respect to maintaining biodiversity as an environmental service, we know little about stabilizing functions, which makes establishing thresholds a debatable way.

Rewards are market-based compensations for specific incentives to make the land use more worthwhile in financial terms for individuals and/or communities who use natural resources in the course of their economic activity (Dung et al. 2004). The rewards can be positive, e.g., payments, subsidies investment in services or infrastructure, but could also be negative, e.g., taxes, penalties, and other sanctions (Weitzman 1974). Logistically, rewards are classified into three groups: (1) financial rewards, in which system managers receive tax abatements, tradable permits, subsidized credit rates, higher prices for products and lower prices for inputs, in exchange for not carrying out activities in a sensitive area, or for doing them in an environmental friendly way; (2) rewards in kind, in which system managers receive free logistics, infrastructure or other services; and (3) rewards in the form of improved access to resources and markets, such as better land tenure, conditional access to credit, or preferred access to public or private markets (Dung et al. 2004).

However, in the case of environmental services, the purely economic decisions tend to focus more on regulations rather than on rewards.

Protection vs. regulation and cross-wise participation

Most biodiversity hotspots are located close to human populations who, generally, depend directly on natural resources provided by those ecosystems, and in absence of other alternatives, could also contribute to their degradation.

The imposition of the status of 'protected area' is generally made *de facto*, excluding the human population and ignoring their rights for development opportunities. There are even cases where the regulations of resource protection force the expulsion of the inhabitants from such area.

However, there are some attempts to integrate conservation efforts with productive components, which could generate benefits to local populations while protecting the environmental resources, such as involving local communities as a basis for the protection and management of biodiversity (Pagiola et al. 2002, Tomich 2004).

Various forms of co-management between national governments and communities have been attempted, where the key issue is making sure that the benefits do not bear a disproportionate cost of conservation and are shared fairly (Mellor 2002). Here, the government policies, incentives and programs related to environmental services should be coherent and not accelerate resource depletion, as in the case of agricultural expansion into natural habitats, or the over-use of freshwater and marine fisheries.

At international level, the conservation of the world's biological diversity has been prioritized since the 1992 signing of the Convention on Biological Diversity (CBD), which emphasizes that sustainable use of biodiversity is one of the most urgent issues of our time and demands commitment to address it collectively (UNEP 2007). Since then, there have been numerous initiatives, like the Global Environmental Facility (GEF), which, under the so called Clean Development Mechanism (CDM) scheme, links developing countries' initiatives with resources from developed countries, to support environmentally friendly projects, involving a series of stakeholders: farmer organizations, private companies, non-governmental organizations and civil society (GEF 2007).

4.2.2 Stakeholders characterization and perspectives concerning provision of environmental services

Stakeholders characterization

The stakeholders in the environmental services scheme can be broadly characterized into three groups according to the functions they perform: providers, intermediaries and consumers.

Ecosystem services providers, modifiers or sellers. They could be individuals, families groups or communities whose actions influence the availability of the services. They are located near the provider ecosystem and maintain a close cause-effect relationship with the ecosystem service; they enjoy rights to modify the ecosystem structure and to benefit from what it generates; they have officially recognized rights to reside in, use and modify the ecosystem; their levels of wellbeing and poverty affect the ecosystem's conditions; their most influential characteristics are demographic composition (gender, ethnicity, age), social organization, and involvement with external political, economic and social processes.

Ecosystem services intermediaries, brokers or facilitators. They could be public authorities, non-governmental organizations, or projects, which directly or indirectly shape interactions among ecosystem service providers and beneficiaries. They could be the source of authority and perform as such among partners through international conventions, national policy or customary laws. They influence the behaviors of ecosystem service providers and beneficiaries, for instance by imposing and enforcing regulations regarding the resource use within an environmental management regime; they also could manage financial and physical resources involved in ecosystem services provision.

Ecosystem services beneficiaries or buyers. They could be individuals, families, groups, corporations, towns or utility companies who benefit from ecosystem services. They are located outside the provider ecosystem but within the administrative area where the ecosystem is placed. Generally, their dependence on ecosystem services is at commercial operation level; their performance is influenced by their demographic composition (gender, ethnicity, age), their social organization and the degree of connection to external political, economic and social processes; companies could use ecosystem services in redressing an environmental damage caused by business operations, or to maintain or enhance the reputation of their business; they comply with current or future environmental regulations (Swallow 2006).

Stakeholders' perspectives

Since environmental services have to satisfy conflicting interests and demands of different social groups, finding an equilibrium among their different expectations is the only way to make the environmental services provision sustainable. The perspectives of the involved stakeholders are as follows.

Wildlife conservation perspective sees environmental services as a possibility for accessing sources of financing to complement or replace public funding and entry fees. In contrast, the environmental management perspective seeks for good environmental stewardships to go along with environmental regulations, while the poverty reduction perspective looks for alternative income sources for poor people settled near provider areas. Economic planners think about environmental services as a good tool for correcting market failures, while the social equity perspective considers that environmental services provide an opportunity to redress imbalances of power, rights and responsibilities between beneficiaries and providers. Finally, the peace and justice stakeholders look at environmental services as a mechanism for managing conflicts of resource use and/or benefit sharing (Swallow 2006).

4.2.3 Environmental services provided by land-use systems

Despite its wide possibilities, the promotion of environmentally-friendly land-use management at unit level has been vague. In general, policies have focused on the landscape level, where environmental matters seem graver though the resilience is higher too.

Up to date the importance of land-use systems as environmental services providers has not been sufficiently placed. Population pressure, globalization of trade and urban expansion has resulted in the increase in disturbances and environmental impacts, which have reduced the ability of the systems to perform multiple tasks. The larger the area, the larger the number of land users, the more difficult it is to develop an effective management strategy, as in the case of extensive monocultures, whose outputs are expected to be uniform and not a series of them.

The farmers have difficulties in including global (serependic) values into their local-scale management values, since their aim is defined in advance and usually in financial terms. In general, all the services are provided jointly (carbon sequestration and water treatment, for example), but they are not marketed as such, and hence, are financially unrewarded and only indirectly connected to their economic activities. And finally, there is the risk that environmental services could simplify inherent (agro)ecosystems complexity, and their profitability or even existence could only be justified on government subsidies as in the case of US and European farmers (Swift et al. 2004, Dung et al. 2004).

Based on the above stated, Swift et al. (2004) suggested consecutive steps for the promotion of a resources management scheme oriented to the provision of environmental services in a land-use system: (1) development of a set of indicators derived from the main functions that shape the current state of the agroecosystem; (2) detection of interventions that could externally modify the agroecosystem; (3) definition of management interventions regarding the resources, options and objectives; (4) definition of objectives and motivation that drive these management interventions; and (5) learning process along the known options, expanding as expectations are updated.

4.3 Environmental services: the social frame

4.3.1 Recognition and operationalization

Van Noordwijk (2004) sequenced the recognition of environmental services as a retribution mechanism: it starts with the recognition of a noticeable negative environmental episode, initially ignored until is not possible to overlook it anymore. Then the affected groups are compensated when they try to shield them against the negative impacts. Furthermore, mitigating activities are implemented, such as conservation measures, followed by the establishment of incentives for the modification of practices environmentally harmful, and finally the creation of market-based instruments or other means of control.

In the same way, the operationalization of the environmental services is only possible through the understanding of the issue by societies in general, and authorities in particular. Tomich et al. (2004) identified the stages of such evolution. It starts with an early perception by pioneers of slight changes of a particular environmental issue, which is not shared by the society at large. A development of initiatives by lobbyists follows, despite the little interest of stakeholders. Gradually, an extended acceptance of the environmental impacts is perceived, and at the same time pressure on the authorities for action arises. Then debates about cause and effect, and subsequently attribution of blame take place. These are followed by demands for inventories, assessments, prevention and mitigation alternatives in environmental, economic, financial and administrative terms, and normally end with negotiations on prevention or mitigation, and finally implementation and enforcement of prevention, monitoring and mitigation actions (Figure 4.3).

Figure 4.3 Evolution of public perception of the environmental services issue by social interaction and scientific advance.
Source: Tomich et al. (2004)

4.3.2 Social capital

Capital in economics alludes to any form of goods capable of being employed in the generation of wealth generally expressed in financial terms. The so-called five capitals concept is based on the participant types of capital transaction, i.e., natural, economic, infrastructural, social and human. It is assumed that the conversion among capitals is possible, e.g., natural to financial as in the case of wood logging; financial to natural in the construction of conservation infrastructure; or financial to human, in the case of capacity building activities.

Environmental services are seem as a natural capital investment, but also directly linked to human and social capitals, i.e., guardianship, stewardship and restoration. Therefore, this key social capital is defined by Coleman (1988) as "*the shared knowledge, understanding and patterns of interaction that a group of individuals brings to any productive activity*", given its quality of been addressed in form of well-built institutions.

4.3.3 The 'social justice' perspective

The millennium development assessment (MDA) states that by providing a minimum level of environmental services free or with a low charge, several disadvantaged segments of society could profit from the accomplishment of the millennium development goals (MDG), i.e., poverty alleviation, education, women empowerment, reduction of child mortality, improvement of women's health, fewer pernicious diseases, better environmental sustainability and increased partnerships for development (UN 2007).

It is well known that there is a firm linkage between poverty and land-use intensification, e.g., the poor access to public services and political recognition of inhabitants of remote regions, who paradoxically are rich in natural resources availability, or the ones who overexploit forests to get cash, degrading the landscape and their opportunities of subsistence and profit in the middle term or who live in degraded environments, with a high demand for public services and low opportunities of self-provision (van Noordwijk et al. 2004).

In such a frame, environmental services besides contributing to the sustainability of the systems can perform as a reassigning quotas mechanism. Therefore, providers' possibility to obtain incentives for doing so is not only an opportunity but a compensation instrument in a frame of equity and justice (Callo-Concha 2003).

4.4 Environmental services: the biophysical frame

Of the numerous aspects of the biophysical frame, addressed from different scientific viewpoints, we have included the main three, because of their controversial role in the current phase of the environmental services issue evolution.

4.4.1 Land-use systems as providers of environmental services

If we understand land-use systems as a range of practices between two extreme cases, i.e., forests and agricultural lands, the perceptions about the functions performed by each system are defined as conservation in one extreme against intensive exploitation in the other (Figure 4.6). Hence, from the environmental services point of view, our attention should narrow to woody systems, while production and generation of income should be come from agricultural lands.

But in reality, most services providers lie in between these two extremes, entailing both environmental and productive functions. This idea clashes with the decision to prioritize one: enclosing areas for conservation purposes or intensively using them, instead of enhancing the ecological functions at landscape mosaic level.

The most suitable region for environmental services (Figure 4.4) is the agroforestry area, which paradoxically suffers from the most negative impacts (deforestation and displacement by industrial forestation) and consequent loss of potential services provision, which at least influences the type and quality of services.

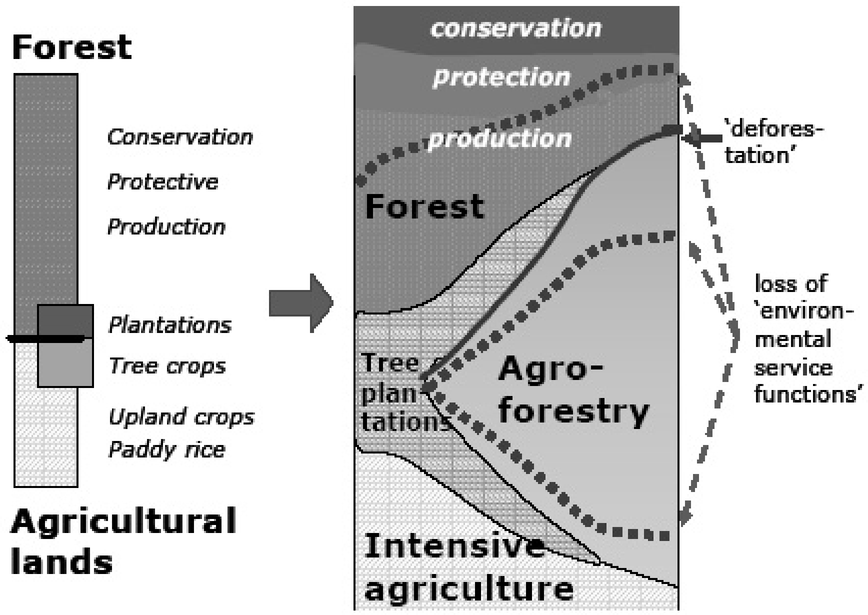


Figure 4.4 Potential environmental services provision along both extremes of land-use systems management types: conservation forests and intensive agricultural fields.
Source: van Noordwijk et al. (2004)

Nonetheless, certain practices are more suitable than others as environmental services suppliers, such as afforestation, where the three main types of services, i.e., biodiversity conservation, water retention and carbon sequestration, are all associated. In contrast conversion via slash-and-burn of forests into other land-use systems which generally leads via a domino effect to the depletion of the environmental performance of an (agro) ecosystem as a whole (Tomich et al. 2004, Dung et al. 2004).

4.4.2 Bundling environmental services

The provision of environmental services, e.g., clear air, clean water, preservation of biodiversity and other natural resource values are in most cases achieved jointly, and very rarely separately (Gouyon 2003, Dung 2004).

Ecological functions and services overlap naturally due to their interconnectedness, interacting positively and negatively. For example an increase in biomass by fast and diverse growing trees upstream can lead to the increase in biodiversity and carbon sequestration but reduction of water availability downstream. Furthermore, the different by anthropogenic needs determines whether they can be integrated or not for mutual benefit, for instance, the level of intensity with which a system is managed against the area occupied by such a system, or the tradeoff between trees' biomass production (carbon) against the lower strata biodiversity.

This association can bear some constraints, e.g., it can lead to ecological and/or economic double counting and the providers' decisions could be driven by the value of all environmental services, while their rewards are based on the degree with which each service is provided. This makes it necessary to develop dynamic and integrative models, which should include the interdependencies between ecosystem functions, services and values (Boumans et al. 2002, Dung et al. 2004).

4.4.3 Seeking for an optimization point: tradeoff between inputs, components and outputs

The Vitusek-Hooper hypothesis states that the number of ecosystem services at landscape scale is optimized by the land-use diversity and by the participation of a required number of factors, which is optimally rather small. Thus, it is implied that a limited number of different land-use types should be sufficient to satisfy the functional needs of the majority of ecosystem services (Hooper & Vitousek 1997).

The most evident example is the case of agriculture (at plot/farm level), where biodiversity is largely managed through simplification, decreasing connectivity and maintaining the agro-ecosystem in an early stage of succession, which in certain conditions can reach a threshold, where the system looses its resilience irreversibly. However, in most cases, the farmer can cope with disturbances and stress through adjustments in resources management (Swift et al. 2004).

Thus, the land-use system diversity and its abilities to perform functions at landscape scale follows the pattern showed in Figure 4.5: the transition from Curve 1 'biodiversity reaches a certain level in terms of the service provision' to Curve 2 'intensively managed agroecosystems, maintained through the constant addition of external inputs' is function of the efficiency in the provision of environmental services in exchange for reducing the alpha or gamma biodiversity. The shift from Curve 3 compared to Curve 1, 'greater essential biodiversity function of land-surface increase' to 4 'displacement due to human intervention', leads to an increase in alpha and gamma diversity in exchange for a reduction in the efficiency of the provision of environmental services (Swift et al. 2004).

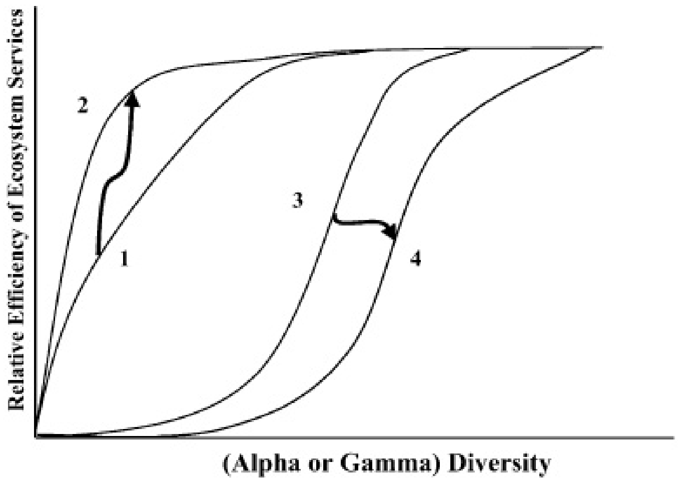


Figure 4.5 Two cases of variation of environmental services provision efficiency vs. biodiversity indices in land–use systems: changes from curves 1 to 2 based on addition of extrernal inputs, and curves 3 to 4 due to human intervention. Source: Swift et al. (2004)

The above suggests that the study of environmental services in co-evolved communities, which are more suitable for performing such functions, must be done separating the effects between and within them, and be conducted through a range of stress and disturbance conditions (Swift et al. 2004).

4.5 The Brazilian model: Proambiente

4.5.1 The Proambiente approach

The Proambiente: *Programa de Desenvolvimento Socioambiental da Produção Familiar Rural* (Socio-environmental Development Program for Rural Household

Production) is the result of the *Grito da Amazonia* (Amazonian scream), a debate about poverty and resources' management policy between 2000 and 2002, where civil organizations demanded rural development polices to improve populations' living conditions in harmony with environment conservation. The result was a mechanism of recognition and payment for environmental services, i.e., Proambiente.

The environmental services considered by Proambiente are: reduction of deforestation, recovering of deforested areas (carbon sequestration), soil, water and biodiversity conservation, progressive reduction of agrochemical use, fire risk reduction, change to renewable energies source, and transition to agroecology.

The financial funds come mainly from two sources: first the federal budget through the ministries of the environment, agriculture and social development, and specific funds for the environment, education and biodiversity, and second from the program itself, i.e., taxes and royalties applied to combustibles, electricity and mining, international agreements, voluntary donations and contributions from private companies'.

The Proambiente construction as an environmental services payment program was sorted out as follows: making feasible a financing mechanism of payment for environmental services; providing a legal basis for the recognition of the concept of environmental services; establishment of a public policy structure for the environmental services payment, making replicable the regional projects at the national scale; and accepting the conceptual economics background as an instrument.

4.5.2 The working unit: *pólo pioneiro*

Proambiente is conceived in the frame of territorial development, which targets specific spatial areas defined by their geographical, ecological, social and political boundaries, such as social organization strength, technical assistance availability, access to credit, certification and payment logistics and social control. The integrative name for this action unit is *pólo pioneiro* (pioneer pole).

Originally 13 pioneer poles were installed across *Amazônia Legal*(*) (legal Amazonia). Each pole consists of about 400 families, who depend mainly on natural resources management actors, i.e., colonizers, *extrativistas* (who perform mainly extractive activities), *ribeirinhos* (who inhabit areas near rivers and streams), fishermen, craftsmen, *quilombolas* (descendants of former black slaves), and traditional communities.

The implantation of a pioneer pole is a participative process, where land users together with a technical advisor set up a *conselho gestor* (management council) in charge of assessing the site's environmental services, developing of short and middle term management plans, and formalizing agreements and compromises for the accomplishment of the management plans.

4.5.3 Civil society participation and operationalization

In January 2004, Proambiente, beginning as a project outlined by civil society, was transferred to the federal government as part of the Ministry of Environment. A national management council, composed of representatives of public research centers, universities, development institutions, and local and national NGO's, supported policy makers in the implementation of the program and related tasks.

The Proambiente protocol considers the following steps. First, the provider site and baseline measures are characterized by an authorized federal institution. Second, once the state of art has been determined, the environmental services are evaluated, detailing the services offered, the procedures applied, the proposed institutional arrangements, the formal decision-making instruments and the financing sources. Based on the above data, a management plan per property unit is proposed, which is followed by an payment contract between providers and beneficiaries. This includes verifying and monitoring procedures, i.e., periodicity, length, type of verification, etc. At the same time, consultants for resources administration and certification of environmental

(*) Concept equally defined by geographical and ecological criteria, which clusters the states that shape the Brazilian Amazonian region: Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, Mato Grosso and Maranhão.

services are defined and hired via communitarian agreements (Proambiente 2004, Proambiente 2005 a,b, Viana et al. 2006, Shiki 2007).

While developing the objectives of this study, we bore in mind the Proambiente case, which shares the multicriteria approach as a methodological tool and territorial development as logistical paradigm.

5 THE WORKING SITE
Case study: Tomé-Açú situation, inhabitants and agroforestry systems

5.1 Biophysical and socioeconomic situation

This research was carried out in the municipality of Tomé-Açú, Pará state, northern Brazil (Figure 5.1). This area is well known for its great variety of agroforestry systems developed by the descendants of the Japanese colonizers, and their considerable influence in the surrounding communities.

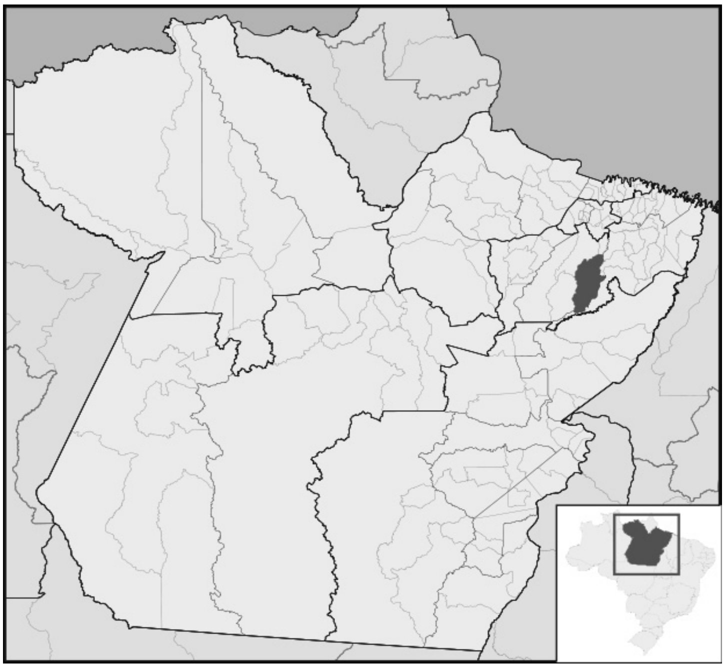


Figure 5.1 Location of Tomé-Açú municipality in the Pará state and Brazil

The municipality of Tomé-Açú is located in the northeast of the State of Pará, 110 km to the south of Belém do Pará, the state capital. It occupies an area of 5145 km^2 and is situated between the coordinates 2° 40’ 54” south and 48° 16’ 11” west, with a population of 50795 inhabitants (IBGE 2000).

The area is predominately flat with elevations varying between 14 m and 96 m above sea level. The soils are mainly weathered acid oxisols (Sanguino 2004, Yamada & Gholz 2002a). The climate is classified as the Ami–Köppen type classification with an annual average temperature of 27.9 °C oscillating between 20 °C to 35 °C. Humidity is always more than 80% and average annual rainfall is about 2,500 mm distributed irregularly throughout the year with a main rainy season from November to June and a less rainy season between July and October; the cloudiness and hours of sun follow the same pattern (CPATU 2003 cited by Sanguino 2004) (Figure 5.2).

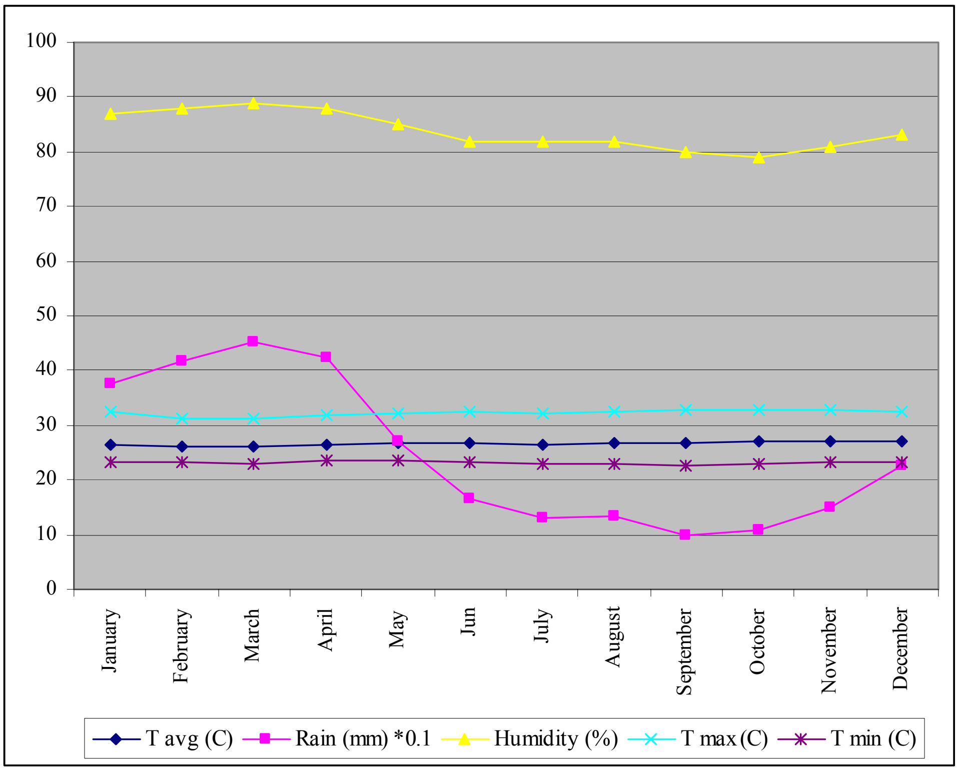


Figure 5.2 Annual climatic data Tomé-Açú, Para State, Brazil 2003.
Source: EMBRAPA/CEPATU 2003

The vegetation cover is composed mainly of secondary forest, a result of previous intense anthropogenic pressure related to selective wood exploitation and crop plantation. Remnants of species, indicators of precedent forest richness, are to be found such as Castanha do Brasil (*Bertholletia excelsa*), Cedar (*Cedrella odorata*) or Ipê amarelo (*Eucylophora paraensis*) (Sanguino 2004).

The principal economic activity is agriculture. Permanent crops, slash-and-burn systems and pastures occupy about 46% of the available land; while approximately 20% is assigned to conservation purposes (conservation forests and riparian zones). The unproductive areas cover less than 35%. The land tenure is based mostly on private property regime, and more than 98% of the farms are managed as such, with only a few under shared responsibility agreements (LBA 2007).

5.2 Historical background

In Japan during the Meiji period (1862-1912), which began with the re-opening of Japan to the western world after two centuries of voluntary seclusion, there were numerous social conflicts. Peasant riots broke out, as legislation limited severely access to the farming class by allowing only the eldest son to become farmer. Furthermore a heavy tax regime was imposed to support the Sino-Japanese war (1894-95) and the Russo-Japanese war (1904-05).

As result of these conflicts the Japanese government decided on the emigration option, and commissioned the Minister of Foreign Affairs Takeaki Enomoto to set up the division of emigration in 1881, and in 1893 the colonization society (Yamada 1999).

5.2.1 The Brazilian migration background

Brazil has received colonists since 1812, when Germans were invited to Bahía and Espirito Santo. In 1819, two thousand Chinese coolies were brought as a substitute for African slaves. But until the abolition of slavery in 1888, the proportion of immigrants compared to the imported slaves was around 1:100. It was the slavery abolition, and the consequent lack of manpower, that forced the Brazilian government to encourage immigration. Yet only on June 18th 1908, after several failed attempts, did the first batch of 793 Japanese arrive in Brazil on the ship *Kasato-Maru*, almost all of them already contracted as coffee plantation workers.

Initially, most Japanese arrived with the idea of making money and soon going back home, but they quickly realized that if they wanted to realize their expectations, they had to become landowners. Thus, the first settlements in São Paulo emerged, which, based on intercropping systems, focused on producing food crops of high demand. In a few years, those first settlers became economically independent and actively organized and were able to hire new immigrants (Yamada 1999).

5.2.2 The Amazonian adventure: Japanese arrival to Tomé-Açú and further development

The Brazilian Immigration Program in the 1920's suggested establishing settlements in the Amazon Region. And due to their success in São Paulo, the Japanese were strongly encouraged to be part of it. First attempts were not entirely successful, and vulnerability to illnesses, technical deficiencies, and environmental constraints forced some colonizers to go back or re-settle in better locations.

Tomé-Açú as an agricultural community was founded in 1929. At the beginning, Japanese settlers concentrated on the removal of forests to establish cacao (*Theobroma cacao* L.), which failed due to lack of knowledge of management techniques, and forced them to practice subsistence agriculture similar to local Brazilians. In addition to the common products like rice, corn, beans and manioc, they introduced the cultivation of vegetables, initially for self-consumption and later for selling, covering gradually bigger markets, such as Belém do Pará city, which brought them an important source of income (Anderson 1990, Smith et al. 1995).

In 1933, as a part of one of the immigration waves, Makinosuke Usui brought from Singapore a few seedlings of black pepper (*Piper nigrum* L.), a species that soon became the most widespread crop in the region, making Tomé-Açú the country's principal producer. In 1957, an epidemic of the fungal disease *Fusarium solani* sp. *piperis* badly affected the pepper fields, compelling the farmers to develop alternative production systems, diversify the fields and enrich them with perennial cash crops (Fearnside 1980 cit. by Smith et al. 1995).

In the last fifty years, the Tomé-Açú *nikkei* inhabitants, through their innovative attitudes have developed a large number of agroforestry systems, highly diverse and productive, and furthermore, a dynamic production paradigm based on perennials, with constant technical innovations and market-based feedback. Their success has depended to a greater part on their good organization of technical support in production, post-production and commercialization (Jordan 1987, Anderson 1990).

5.3 Target groups of the study

The influence of the Japanese community also became strong in neighboring areas, because of their interest in obtaining high revenues from black pepper plantations, and later because of the comparative advantages of polycultures in small plots. However, this has not been uniform, so in order to portray better the agroforestry systems practiced in the region, we decided to diversify this study by including neighboring sites with different characteristics, such as property size, management record, level of technology, land property regime and capacity for organization.

We stratified our analysis units in three groups: (1) the 'CAMTA partners', mainly descendants of the Japanese colonists, generally well-established owners of regular-size and market-oriented plots associated with the 'The Mixed Agricultural Cooperative of Tomé-Açú'; (2) the 'immigrated' middle-size farmers in terms of land size and technological level used and markets access, who had immigrated long ago and are poorly organized; and (3) the 'newcomers', small subsistence farmers, recently immigrated as beneficiaries of the agrarian reform and generally non-organized.

5.3.1 The CAMTA partners: Tomé-Açú and Quatro Bocas

The *Cooperativa Agrícola Mista de Tomé-Açú* (CAMTA), The Mixed Agricultural Cooperative of Tomé-Açú, was established soon after the first Japanese immigrants had founded Tomé-Açú to assist the farmers with credit, technical advice and market access facilities. After the black pepper production drop in the 1960's, CAMTA led the transition from monocultures to agroforestry systems via intercropping, with high-value perennial species.

CAMTA operates mainly in what became the core of the municipality, i.e., the surroundings of the villages of Tomé-Açú and Quatro Bocas, which concentrate the majority of the Japanese-descendant farm properties. The farm areas vary from 150 to 200 ha, but on the average only 20 ha are cultivated, generally maintaining the remaining area as secondary forest after the abandonment of pepper or previous slash-and-burning activities in hitherto undisturbed forests. CAMTA partners are the better-established farmers, owners of larger plots, and very well organized.

Figure 5.3 Characteristic CAMTA partners agroforestry system in Quatro Bocas with açai (*Euterpe oleracea*) and cupuaçú (*Theobroma grandiflorum*)

5.3.2 The immigrated: Igapú-Açú and Forquillas

The Tomé-Açú agroforestry model was gradually exported to neighboring areas, initially as a production pattern, versatile and varied in by-products, and later because of the demand for its production outputs.

The immigrated are part of this area of influence, with properties from 50 to 100 ha, generally administered by a second generation of colonists (usually Brazilian, non-Japanese immigrants) having a permanence of 20 to 30 years.

The selected locations are Forquillas and Igapú-Açú, the first about 15 km from Tomé-Açú and the second about 20 km. These sites do not constitute villages, but consist of households scattered in a radius of 5 to 10 km with a commercial center by the road.

Their production technology is at an intermediate level, supported by family manpower and sometimes hired workmen. Organization for commercialization is minimal. The structure of the agroforestry systems is less diverse than in Tomé-Açú, and the major emphasis is on fast cash species, such as cupuaçú (*Theobroma grandiflorum*) and açai (*Euterpe oleracea*).

Figure 5.4 Characteristic Immigrated agroforestry system in Igapú-Açú with cupuaçú (*Theobroma grandiflorum*), black pepper (*Piper nigrum* L.) and açai (*Euterpe oleracea*)

5.3.3 The newcomers: Miritipitanga and Tropicalia

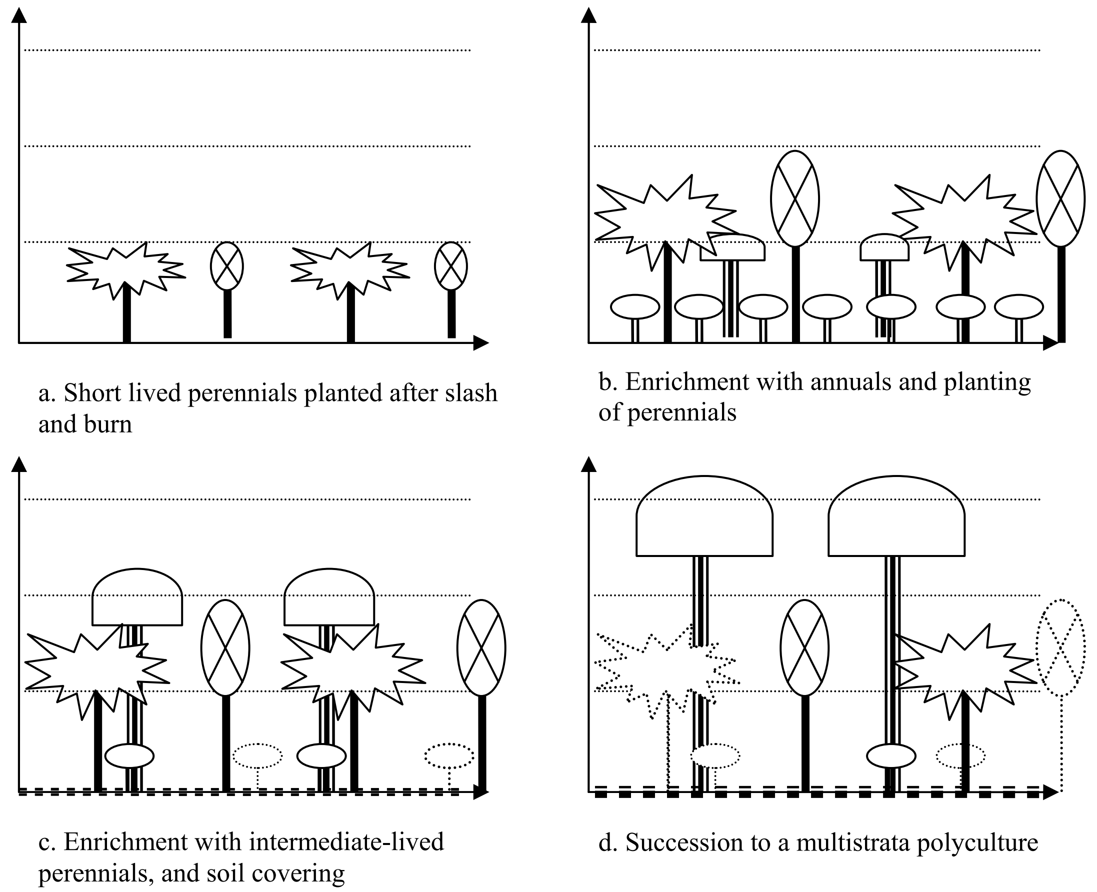
The newcomers are installed in the *assentamentos* (settlements), which constitute the basis of the Brazilian policy of land reform. This system is supported by governmental and non-governmental institutions and groups of organized farmers, that receive parcels between 25 and 100 ha and some complementary benefits, such as a starting fund and technical assistance during the establishment of their crops.

The degree of farming development of the newcomers depends on the date of the establishment of the settlement. The first selected sampling area is Miritipitanga, founded in the mid 1990's, located 27 kilometers from Tomé-Açú with a population of around 400 inhabitants, and 12 years-old agroforestry plots of woody species in the highest strata. The second is Tropicalia, founded just 11 years ago in 1997, located 40 km from Tomé-Açú, with a population smaller than in Miritipitanga and only a few recent agroforestry plots, based mainly on the *Taungya* model (temporal cultivation of crops in tree-based plots while the growth of these allow it). The conditions are quite similar in both areas, with subsistence production systems, young agroforestry parcels, medium or poor technological standards, and almost nonexistent community organization.

Figure 5.5 Characteristic newcomers agroforestry system in Miritipitanga with black pepper (*Piper nigrum* L.), açai (*Euterpe oleracea*) and mahogany (*Swietenia macrophylla*)

5.4 The Tomé-Açú model of land-use management

The agroforestry systems developed by the Tomé-Açú farmers have gotten international recognition due to their profitability and sustainability. This success is based on the development of a varied and variable production model. One of the most common variations follows these steps (Figure 5.6): (a) short-lived perennials, such as black pepper, are generally planted after clearing of forest or secondary vegetation; (b) depending on existing market conditions, annual species such as rice, beans, cucumbers, tomatoes or leafy vegetables are planted between the rows of perennials; (c) following these intermediate-lived perennials, such as black pepper, fruit trees or long-lived plants such as cacao, rubber, cupuaçú or forest-tree species, are interplanted; (d) when the short-lived crops are nearing the end of production, the longer-lived crops are ready to begin with their own production (Jordan 1987, Anderson 1990).



a. Short lived perennials planted after slash and burn

b. Enrichment with annuals and planting of perennials

c. Enrichment with intermediate-lived perennials, and soil covering

d. Succession to a multistrata polyculture

Figure 5.6 Succession stages in the Agroforestry 'Tomé-Açú model'.
Source: Based on Jordan (1987)

5.4.1 Management principles

The general principles on which the Tomé-Açú model is managed are as follows: (1) to use as much as possible tree species providers of biomass, fruit or latex that minimize disturbances in the soil; (2) to plant annual species of high economic value once or twice followed by species of lower economic value but less demanding of soil nutrients, when possible plant species that can both enrich the soil and provide economic benefit; (3) to maintain the ground cover as much as possible to minimize the deterioration of soil physical properties; (4) to maintain a high diversity of crops to fully exploit soil nutrients and sunlight and inhibit problems of diseases and insects; and (5) to recycle as much as possible, both animal and vegetal organic matter into the soil (Jordan 1987).

5.4.2 Guiding economic and ecological criteria

Tomé-Açú farmers acknowledge that the factors that influence their decisions to increase the diversity and complexity of their farms are basically economic. They respond primarily to changes in the crop prices, the cost of labor, and material inputs for the production of particular crops. In that framework, the use of commercial agrochemicals is extensive in order to optimize the profitability of the fields.

The diversity of species is also important. A number of perennial crops in different stages of production allows to farmers to have harvests from three or four crops at the same time, with the option of planting annual crops as the need arises. The farmers are able to spread the production risk over a number of crops, such as cocoa, coconut (*Cocos nucifera*), cupuaçú (*Theobroma grandiflorum*), passion fruit (*Passiflora edulis*), açai (*Euterpe oleracea*), mango (*Manguifera indica*), papaya (*Carica papaya*), guanábana (*Annona muricata*), bacurí (*Platonia insignia*), abricó (*Mammea americana)*, uxí (*Dipteryx alata*), cajú (*Anacardium occidentale)*, graviola (*Annona muricata*), etc. However, this flexibility in income generation comes with the burden of complex management, requiring higher technical knowledge of each individual crop, and with the need for increased physical resources and manpower, which in the end limit the size of the area under cultivation.

The most important factors for fulfilling these demands are the cultural discipline inherited by the settlers from their traditional Japanese values, and the participation of CAMTA in the support of production, postproduction and commercialization (Jordan 1987, Anderson 1990, Yamada 1999, Yamada & Holz 2002).

6 METHODOLOGICAL APPROACH
Applied analytical tools, further development and integration

6.1 Multicriteria Analysis (MCA)

6.1.1 Definition

Multicriteria Analysis (MCA) is a decision making tool that integrates a series of methods in order to give an integrative insight into complex, interdisciplinary problems, including different sources of data, different expert positions and different groups of interest. In other words: *"MCA breaks the problem into pieces, reassembles such data and judgments and presents a coherent overall sight"* (Dogson et al. n/d). In general, when a consensus is searched, different interests may prevent agreement on the relative importance of criteria or on the ranking of different alternatives. Here, MCA can assist each stakeholder to make his/her own decisions and judgments, and then channel all of them in a final and integrative conclusion (Dogson et al. n/d, Mendoza & Macoun 2002).

MCA is especially applicable in situations where a single-criterion approach does not satisfy the expected demands, as in the cases that involve environmental and social matters, where decision makers are compelled to include a wide range of social, environmental, technical and economic criteria.

This tool exhibits a hierarchical structure, where the highest level represents the broad overall objectives, e.g., improving the quality of life, often vaguely stated and hence, not very operational. These items are gradually broken down into lower-level objectives, successively more applicable and concrete, until the lowest level becomes very practical and easy to assess (Munasinghe 2007). Finally, MCA outputs are a series of stratified arguments on which a decision has been made, and a cumulative or partial index(es) of performance of each system which allow stratifying them from the most preferred to the least preferred (Mendoza & Martins 2006).

6.1.2 Sustainable forest management (SFM)

Among the main products of the Earth Summit (ECO 92) were the issue of binding documents: First the Rio declaration on environment and development, which is a statement of principles to guide the management, conservation, and sustainable development of all types of forests, second is the United Nations framework convention on climate change, and third, the convention on biological diversity. All three are considered milestones in the achievement of international recognition and promotion of concrete activities in the most crucial environmental issues. The summit agreed to carry out regular meetings towards the achievement of the proposed objectives, under the name of the Conference of the Parties (COP) (UNEP 2007).

In the COP 3 Buenos Aires (1996) on the Convention on Biological Diversity, a consensus was reached to focus immediate attention on two critical issues: assessing the human impacts on forest ecosystems, and developing criteria and indicators for forest quality and biodiversity conservation (Stork et al. 1997). Subsequent meetings strengthened these trends, ending with the revaluation of the concept of Sustainable Forest Management (SFM).

SFM is defined as "*... the process of managing forests to achieve one or more clearly specified objectives, with regard to the production of a continuous flow of desired forest products and services, without undue reduction of its inherent values and future productivity, and without undue undesirable effects on the physical and social environment*" (ITTO 1998).

The principle of SFM is holistically addressed by using a system oriented approach. Here, the interactions and linkages between indicators are examined that might have direct and indirect consequences on the sustainable use at the Forestry Management Unit (FMU) level (Wolfslehner et al. n/d). In SFM evaluations, two guiding principles, ecosystem integrity *and* people's well being, should be maintained and enhanced. Therefore, the physical and political boundaries of the forest area must be clearly demarcated, as well as the long-term management plan and objectives (Mendoza & Macoun 2002).

The SFM concept is restricted not only to forests as ecological systems, but also to forest as human-influenced environments, which are in many respects subordinated to the socio-economic background, i.e., food security, access to resources, heritage and identity, economic opportunity, justice and health (Prabhu et al. 1999, Prasad 2002).

SFM is considered the guiding resource management paradigm in forest landscapes (Loyn & McAlpine 2001), and in general made operative through MCA, which supports the selection, processing, and modification of component variables in a consistent and transparent way, according to a specified target (Mendoza & Macoun 2002).

Under this perspective, the application of SFM paradigms and protocols for the evaluation of environmental services provision by agroforestry systems is justified.

6.1.3 MCA operationalization: Criteria & Indicators

Definition, characteristics, components

The Criteria and Indicators (C&I) methodology operationalizes multicriteria analysis (MCA) for any particular scheme, such as in the present study, which assesses functional biodiversity in agroforestry systems. It operates along a series of vertical steps by fragmenting conceptual issues, such as poverty, into a series of smaller and more manageable subjects, e.g., food security, lack of income, etc. These are then divided further into more pragmatic and simpler items such as children's weight, calories consumed, etc. (CIFOR 1999).

The methodology is characterized by its ability to involve the participation and agreement of multiple interest groups using both qualitative and quantitative data. It can also incorporate two opposite insights on the same matter, such as top-down and bottom-up approaches, and finally allow the feedback of processes concerning the consistency of the judgments (CIFOR 1999, Stork et al. 1997). Practically, the C&I methodology is easy to understand and simple to apply, and is able to provide arguments to managers and policy makers that are relevant, scientifically sound and cost-effective (Stork et al. 1997).

The C&I set is based in a four-level hierarchy consisting of the components, principles, criteria, indicators and verifiers. Principle is a fundamental truth or law on which reasoning or an action is based. The principles give the primary framework for managing any system in a sustainable fashion, providing justification for criteria, indicators and verifiers. A criterion is a standard by which the progress towards meeting the principles of a system can be judged, adds meaning and operationality to a principle without being itself a direct measure of performance, and compiles the subordinated indicator weights in a single rate. An indicator is any quantitative, qualitative or descriptive attribute measured periodically, which indicates the direction of a change in one or various related elements. Finally a verifier is a specific data that reflects the condition of an indicator; verifiers must be meaningful and precise (Prabhu 1999, Mendoza et al. 1999, ITTO 1998, Prasad 2002, Mendoza & Macoun 2002).

Criteria and indicators and Sustainable Forest Management

The main purpose of sustainable forest management (SFM) is evaluating the factors that affect forest sustainability, emphasizing the ones related to management. The understanding of these processes will determine the optimization of the management actions, and eventually support the sustainable use of the forest (Stork et al. 1997, Loyn & McAlpine 2001).

The C&I methodology has performed successfully in supporting the development and monitoring of sustainable forest management schemes, and has therefore been chosen by many institutions, such as ITTO and CIFOR, who have developed a number of C&I sets for specific forest conditions (Stork et al. 1997, Loyn & McAlpine 2001).

Criteria and Indicators for biodiversity evaluation

Given its innate complexity, biodiversity is very difficult to assess. In general, traditional approaches based on taxonomic diversity, indicators groups or keystone species have limited usefulness, because of their lack of attention to examining the processes that generate and/or maintain biodiversity (Prabhu et al. 1996, Stork et al. 1997).

The C&I methodology is an option for filling such a gap, as during its operationalization, it links traditional evaluation tools with new ones and considers various stakeholder positions and demands. Compiling these into an understandable set where the correspondence, weight and linkages of each component of the set can be viewed, compared and eventually modified (Stork et al. 1997).

Conceptualization of indicators

Although the C&I methodology has been developed for all kinds of conditions, and can be used at various planning levels, i.e., global, regional (and eco-regional), national and local (Prasad 2002), the indicators are very much specific, and must match the particular conditions of each site (CIFOR 1999). In the selection/development of indicators, one has to take into account the ecological characteristics of the systems, the representation of natural disturbances, and overall, the indicators' operational relevance to assess ecosystems affected by anthropogenic practices (Kneeshaw et al. 2002). For this reason, it is essential to test the validity of the C&I set and, when necessary, to adjust it to suit the pursued objectives, because in practice, only a limited number of indicators can be used to evaluate spatial and temporal changes and at the same time meet the requirements of easy collection and application (Prasad 2002).

Stork et al. (1997) proposed a classification system of biodiversity-status indicators for any ecosystem (Figure 6.1). This system takes into account the progression of any phenomenon in time, pointing out the types of indicators: (1) human interventions that occur within the management unit, e.g., logging, grazing, land-use conversion, burning, collecting by-products, introduction of exotics species, mining, etc., (2) mediators, which are the impacts of human interventions on the generation and maintenance of biodiversity, e.g., fragmentation, change of area, pollution, loss of species, change in nutrient stocks, etc., (3) processes, which are responses to the mediators influence in determining the generation and maintenance of biodiversity, e.g., species dispersal, reproduction, natural disturbance, migration, trophical dynamics, ecosystem processes, local extinction, regeneration, etc. and (4) biodiversity status, identified at any point in the causal chain from human intervention, e.g., population structure, species richness, higher taxa, habitat diversity, etc.

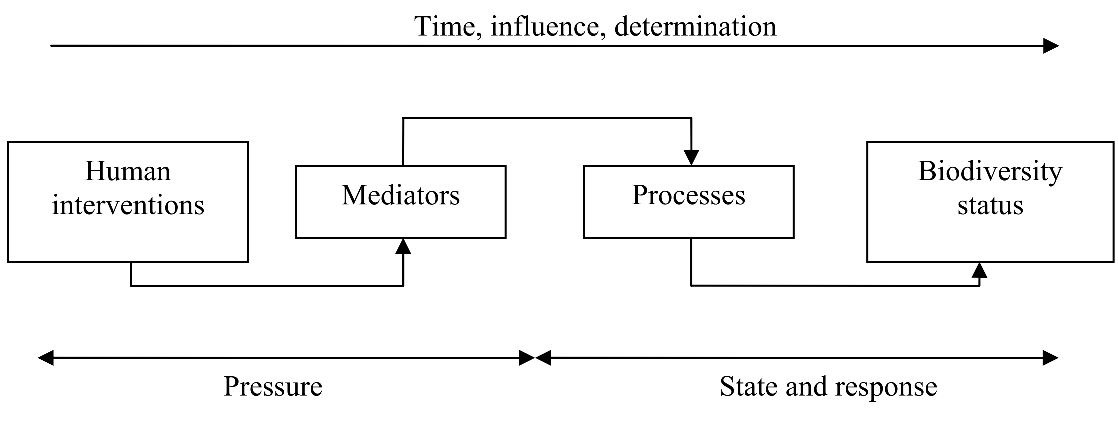


Figure 6.1 Definition of biodiversity assessment indicators triggered by human interventions and subsequent changes on related processes
Source: Based on Stork et al. 1997

Pressure indicators are easier to develop but provide less valuable information when the intention is to understand the functioning of the ecosystem. On the other hand, state and response indicators are potentially more useful, but are harder to develop and apply (Stork et al. 1997).

Required conditions for indicator selection

The usefulness of the C&I approach depends on the suitability of the selected indicators. Prabhu (1999) and Mendoza et al. (1999) listed the main requirements that a C&I component should fulfill. These are (1) relevance, all C&I components (verifiers, indicators, criteria and principles) should be relevant to the issues that define the agroecosystem in question; (2) coherence, each component should be closely related to the assessed goal in its vertical hierarchy, and thus each indicator has to be directly related to a criterion and each criterion to a principle, and finally all principles to the sustainable management index; (3) clarity, each component should be simple and unambiguously defined; (4) specificity, where subordinate components should provide, as far as possible, information that allows a direct interpretation of the upper-level component, e.g., criteria in relation to principle; (5) simplicity, components should be easy to detect, record and interpret; (6) reliability, components should provide trustworthy data; (7) representativity, component responses should be able to depict a range of levels of a targeted issue; (8) inclusivity, components should provide a summary over space and/or time of the targeted issue; and (9) appealing, C&I components should be user friendly (Prabhu 1999, Mendoza et al. 1999).

6.1.4 C&I development and application

Analytical hierarchy process

The analytical hierarchy process (AHP), suggests a vertical arrangement of a C&I set, with a hierarchical structure shaped like a tree, where the main problem (trunk) is divided into components (sub-trunks = principle), and these into more detailed components (branches = criteria), and so on, until a better depiction of the original problem is established.

There are two possible approaches in this process. First, the top-down approach, that starting from the conceptual view of an issue, descends until one shapes the most pragmatic matters of the issue, and second the bottom-up approach, which is based on primary data of the studied matter and brings the details into a more general and integrative concept (Prabhu et al. 1996) (Figure 6.2). In an optimal scenario, a balance between the two approaches is pursued, though usually one or another approach is prioritized.

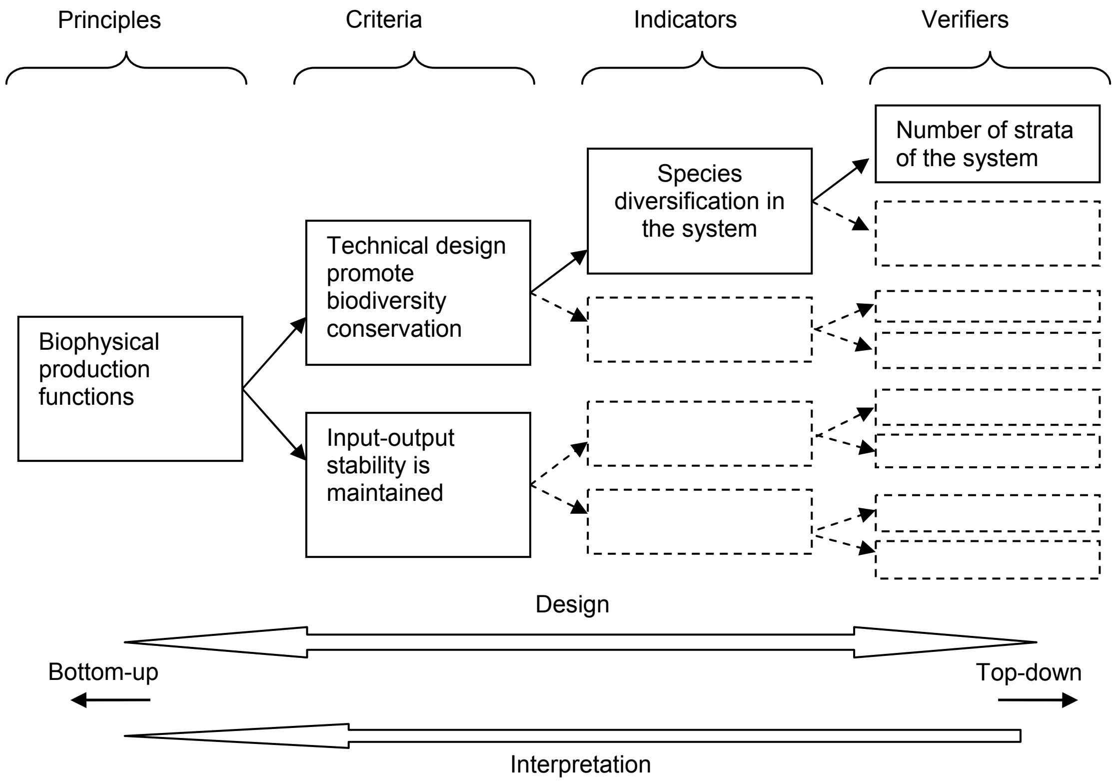


Figure 6.2 Definition and hierarchization of principle, criteria, indicators and verifiers applying buttom-up and top-down approaches.
Source: Modified from Mendoza & Macoun (2002)

Scoring, ranking and weighting

Once the set of C&I is defined and ordered in a hierarchical pattern, each indicator and its interactions with other indicators are tagged with scores in two steps. First, by rating, where each element is assigned with a perceived degree of importance based on a predefined scale, e.g., 5 (very high), 4 (high), 3 (moderate), 2 (low), 1 (none) or in an ordinal succession, e.g., 1^{st}, 2^{nd}, 3^{rd}, etc., and second by scoring, where each up-level indicator is assigned with the sum of the weighted scores of its subordinated items, e.g., the score of a principle is a function of the weights of its criteria (Mendoza & Macoun 2002). This weighting process is done through pair-wise comparisons, a method that contrast one-to-one elements of the same hierarchical level, each time assigning an arbitrary weight, and considering all the values of the related elements' (Mendoza & Macoun 2002).

This ascending procedure is continued until one obtains an overall indicator of the performance of the analyzed agro(ecosystem), i.e., the Sustainable Management Index SMI (named in CIMAT as 'Sustainable Forest Management' score), which compiles the relative weights of all C&I components (principles, criteria, indicators and verifiers), and intends to provide a sound representation of the performance of the whole system (Purnomo et al. 2000).

Criticisms to C&I approach

The C&I approach has received some criticism as its suitability for different ecosystems is doubted. Since land-use systems are highly variable, it is not feasible to develop C&I sets appropriate for all conditions. Therefore, the development of indicators, especially at lower levels that are modified and adapted to local conditions is necessary. Templates can be useful as guide-lining platforms, on which necessary modifications can be done (Stork et al. 1997).

On the other hand, using the C&I approach may not be practical in situations where land-use change is planned or scheduled, such as in slash-and-burn systems, tree plantations or urban and industrial areas, where these changes rapidly and seriously affect the systems, thus influence the C&I reliability, which is designed to deal with progressive but not sudden changes in parameters (Stork et al. 1997).

6.1.5 Criteria and Indicators Modification and Adaptation Tool (CIMAT)

The sustainable forest management assessment via the C&I approach was the focus of a project by the Center for International Forestry Research (CIFOR), who incorporated more than 1100 field-test locations in different systems in Austria, Brazil, Cameroon, Germany, Indonesia and Ivory Coast, covering all aspects of forest management (Prabhu et al. 1996).

As result of this project, the Criteria and Indicators Modification and Adaptation Tool (CIMAT) software was created. It allows the creation, modification, on-site assessment, ranking, weighting and navigation of criteria and indicator (C&I) sets. Starting from templates created for different biophysical and socio-economic conditions, it is then possible to adapt the C&I sets to specific needs and local conditions (Prabhu et al. 1996, Prabhu et al. 1999, Mendoza & Macoun 2002).

The CIMAT application depends strongly on external inputs, thus requiring several accessory data gathering methods. While the participation of stakeholders is very important, the involvement of experts in checking the validity, practicality, measurability of each indicator is recommended (Mendoza et al. 1999, Prasad 2002, Wolfslehner n/d.).

Although CIMAT has been developed for evaluation of forests, its structure is based on multicriteria analysis, making feasible its application in any condition where such an approach is considered, as in the case of the present study.

6.2 Multivariate Analysis (MVA)

6.2.1 Definitions and importance

Multivariate analysis (MVA) comprises a series of techniques for simultaneous analysis of data sets with more than one variable, focusing on their interaction in the same time, space and on how they influence one another in determining the degree and direction of the outputs (Hair et al. 1995, Abdi 2003). Multivariate analysis measures, explains, and predicts the degree of relationship among different variables; therefore its effectiveness lies in how the variables are combined and not in their number. To apply MVA, a set of variables should be variously and randomly interrelated in a way that the effect of each variable cannot be meaningfully interpreted separately (Hair et al. 1995, Abdi 2003, Preisinger 2005).

The results of MVA are not categorical in determining responses or tendencies; instead, its final products are models, adjustable and subject to interpretation, and thus they may not be right or wrong, but simply adequate or inadequate for the particular situation (Hair et al. 1995).

The ability of MVA to deal with various components and different inferences at the same time makes it useful for the analysis of complex data sets. MVA has been applied successfully in exploration of large matrices, detection of the correlation between complex factors (social, environmental, etc.), and in the development of functioning hypotheses, such as maintaining natural correlation effects without isolating individuals and variables (Abdi 2003).

6.2.2 Applied protocols and tools

Cluster analysis

The term cluster analysis encompasses a number of different algorithms and methods for grouping observations on the basis of meaningful, mutually exclusive properties, while maintaining links among them (Hair 1995, Stockburger 1998). In other words, it seeks sets of groups that both minimize within-group variation (association between two objects is maximal, if they belong to the same group), and maximize between-group variation (association between two objects is maximal, if they belong to the different groups) (Garson 2007, STATSOFT 2007).

Cluster analysis does not refer to statistical significance testing, and thus differs from other statistical procedures where typically a test is carried out. So it is common to apply cluster analysis without having an *a priori* hypothesis, and to just explore structures searching the most significant solution and data arrangement possible (Stockburger 1998).

Factor analysis

Factor analysis compiles a series of multivariate statistical methods that assist in defining the underlying structure in a data matrix with a large number of variables. It starts from the premise of existence of correlations between subsets of variables (eventually clusters).

Factor analysis summarizes the information contained in a number of original variables into a smaller set of new, composite dimensions or variables (factors) with a minimum loss of information, which should be able to replace partially or completely the original set (Hair et al. 1995, Field 2000).

Statistical protocols and software applied

The protocols applied were data assumptions (missing value analysis, outliers detection and data replacement, normality and linearity tests, data transformation, normalization, and standardization), cluster analysis (similarity measures through Euclidean distance and linkage rule using Ward's method), and factor analysis (derived using principal component analysis, factors extraction of higher eigenvalues and equamax as rotation method). The software Statistical Package for the Social Sciences (SPSS) v. 12.0.1 for Windows was used (Apache Software Foundation 2003).

6.3 Linking MCA and MVA

The two analytical phases of this study were linked (Figure 6.3).

In a first phase, multicriteria analysis (MCA) on the one hand homogenizes and converts diverse types of data into standardized inputs, and on the other hand, through assembling and comparing all the participating factors, generates an assessment protocol, which in turn, outputs an indicator of the system's performance, i.e., the sustainable management index (SMI). This index is applied to fulfill the first objective in the present study.

In a second phase, the results of the MCA are processed with multivariate analysis (MVA) in order to weight and filter the entire set of factors participating in the process, thus obtaining the ones more relevant (F_1, F_2…) and rating their performances (I_1, I_2…). These are the elements on which optimization of the overall performance of the system is based. This fulfills the second objective of this study.

Eventually the optimization model should provide feedback to the assessment protocol and/or the MCA, thus fine-tuning the evaluation protocol or upgrading it into a monitoring protocol. The assessment protocol could also provide input to the MVA.

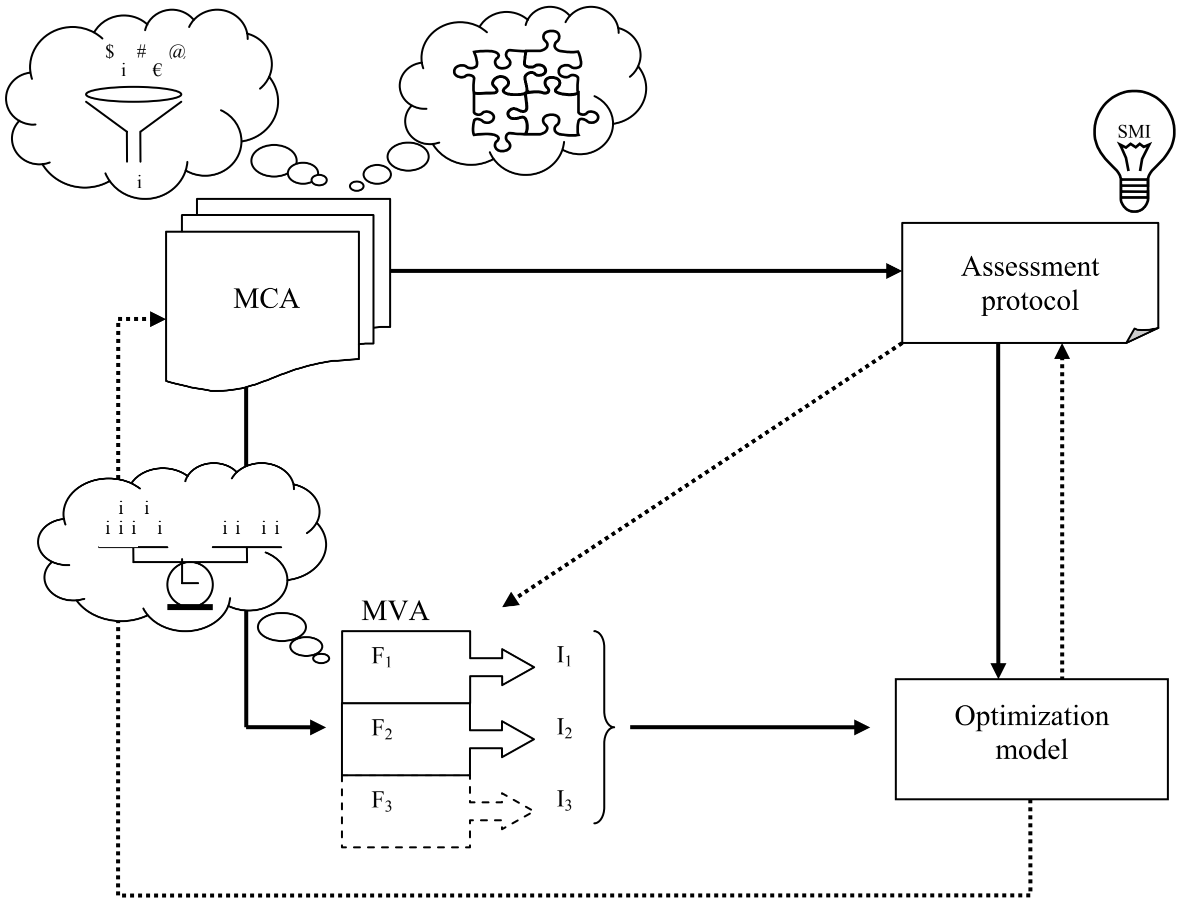


Figure 6.3 Flowchart of MCA and MVA procedures inegration: data integration, analysis, outputs generation and definition of an optimization model.

7 RESULTS AND DISCUSSION
Towards a functional biodiversity assessment protocol and its model

Besides the theoretical focus of this study, which is the development of a functional biodiversity approach for agroforestry systems, a pragmatic goal is also pursued: operationalization of the concept by converting it into a management tool for understanding and optimizing system performance. Two specific objectives were considered. First, based on the functional biodiversity approach and through the application of multicriteria analysis, a protocol for evaluating functional biodiversity was established. Second, based on the same principles, a procedure (model) for detecting core spots was developed in order to boost system performance for functional biodiversity maintenance and enhancement.

The developed evaluation protocol is described in section 7.1. Here, the physical and conceptual boundaries are established, the procedures of data collection and integration detailed and outlined, and a conceptual model is proposed, taking into account the most significant groups of participant factors. Those factors are then subdivided, each factor is briefly described, its importance explained, collection details provided, and homogenization procedures applied. Finally, the administrative software is detailed and its useful outputs highlighted. These are the sustainable management index (partial and cumulative), weighting and scoring indices and pair-wise comparison procedure.

The optimization model is described in section 7.2. The sustainable management index is analyzed by functions, localities, and groups. The analysis of variance test is carried out for the same parameters, while a cluster analysis is applied to groups and functions. Finally, through factor analysis, the most representative issues are extracted and, based on these, an interpretation is attempted and management suggestions proposed.

7.1 Evaluation protocol

In the previous chapters it is shown how various agroforestry practices are compatible with the conservation of biodiversity and the supply of other environmental services. Is also reviewed how the concept of functional biodiversity enlarges and supports a more pragmatic and versatile view of the environmental services provision. Finally, the need of an integrative and maneuverable approach is discussed and proposed as an alternative multicriteria analysis.

These arguments were taken into account in the development of an evaluation protocol, which attempts to fulfill the specific objective 1 which is: *'To develop a protocol for evaluating functional biodiversity in agroforestry systems …'*

Based on multicriteria analysis, a procedure for data collection, integration and analysis was developed. These steps were as follows.

7.1.1 Framing the study

The definition of multicriteria analysis levels (principles, criteria, indicators and verifiers), was done classifying them into three conceptual types of functions, i.e., ecological, productive (biophysical and socioeconomic) and operational. These levels were in turn re-classified with respect to their geographical scale of application, i.e., plot, regional and landscape. For example, operational functions, such as policy decisions are seen at landscape level, while biophysical production functions, such as the number of strata of tree species are considered at plot level.

The main social actors, the farmer-owners of the agroforestry systems, are also classified into three groups: the well-established 'CAMTA partners', mid-size farm owners associated with the The Mixed Agricultural Cooperative of Tomé-Açú, the long ago 'immigrated' small-sized farm owners, independent and poorly organized, and the recently immigrated 'newcomers', small-sized farm owners, not organized at all (see section 5.3).

The above defined classifications were integrated into a single evaluation protocol (Figure 7.1).

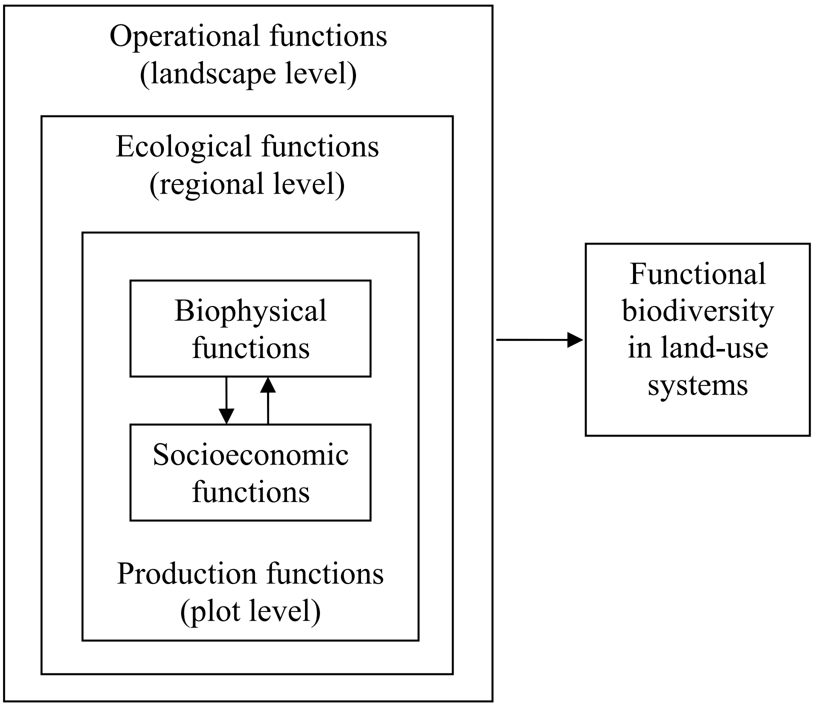


Figure 7.1 Overview of the evaluation criteria and their geographical scope of application on functional biodiversity assessment in agroforestry systems of Tomé-Açú, Pará State, Brazil

7.1.2 Data collection and integration

As the study area is defined politically (municipality of Tomé-Açú), most primary information, i.e., field surveys and field assessment, were collected at the regional level. Information, such as policy judgments, commercialization scale or proximity to biogeographical islands, were taken at landscape level, keeping in mind as unit of analysis, i.e., the farmer plot in the Tomé-Açú municipality with its inherent peculiarities (see section 5.4) (Figure 7.2).

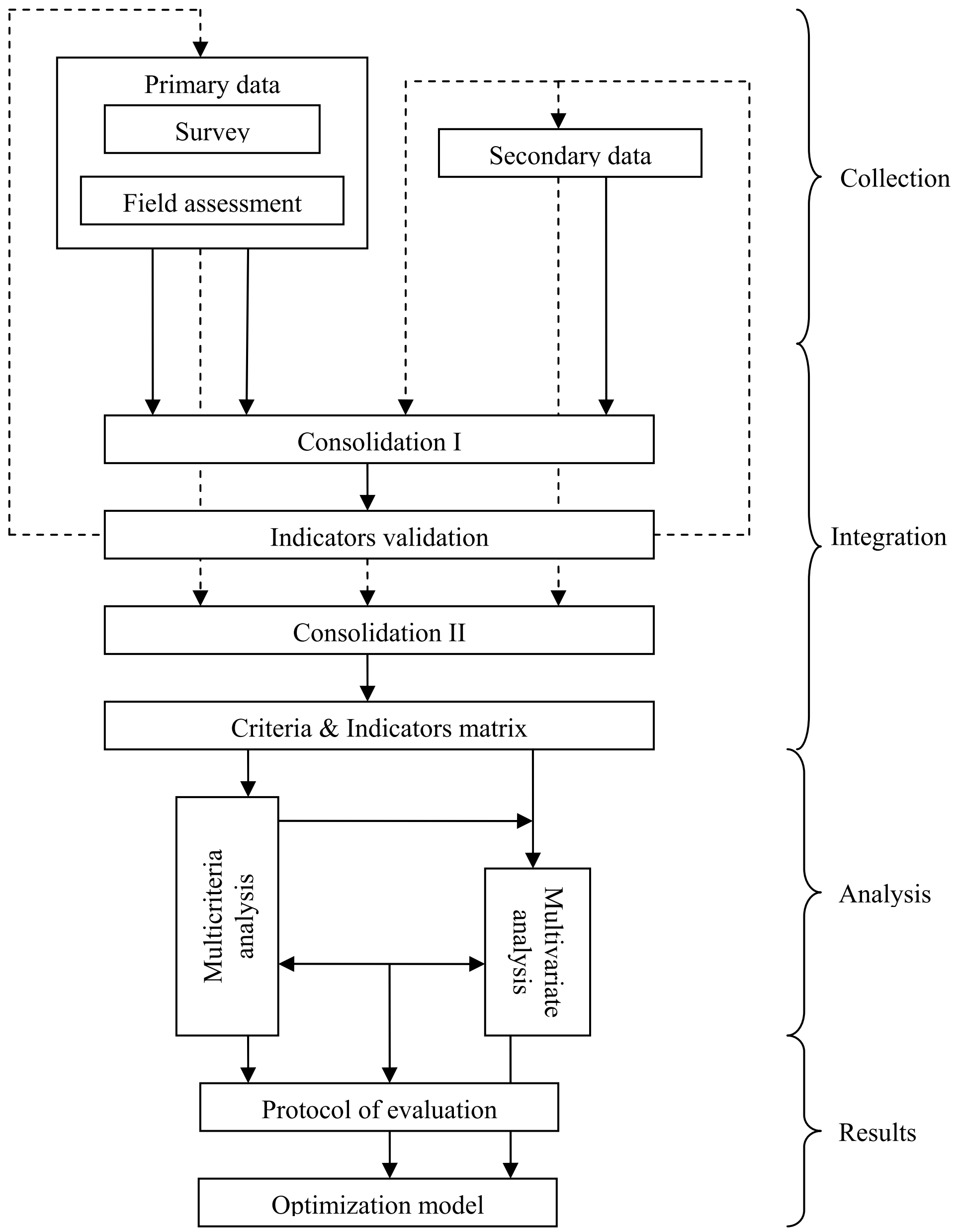


Figure 7.2 Steps in data collection, integration and analysis for assessment of functional biodiversity in tropical agroforestry systems of Tomé-Açú, Pará State, Brazil

7.1.3 Building a conceptual model

The conceptual model (Figure 7.3) shows how the functional components (principles) of agroforestry processes interact among one another and how they are integrated.

In detail, these components are: (1) ecological functions, mainly responsible for the maintenance of processes, (2) the biophysical production functions, i.e., the application of a sustainable technical management, adaptation to landscape preservation functions, sustainable use of by-products, impact minimization of neighboring systems and homeostasis maintenance are taken into account, (3) socioeconomic production functions including mainly system rationality and orientation of the production, and (4) operational functions, in which the most important item is a management plan.

This model portrays the framework on which the evaluation protocol is based, i.e., the most influential functions and criteria, the interactions among them, and their joint influence on functional biodiversity.

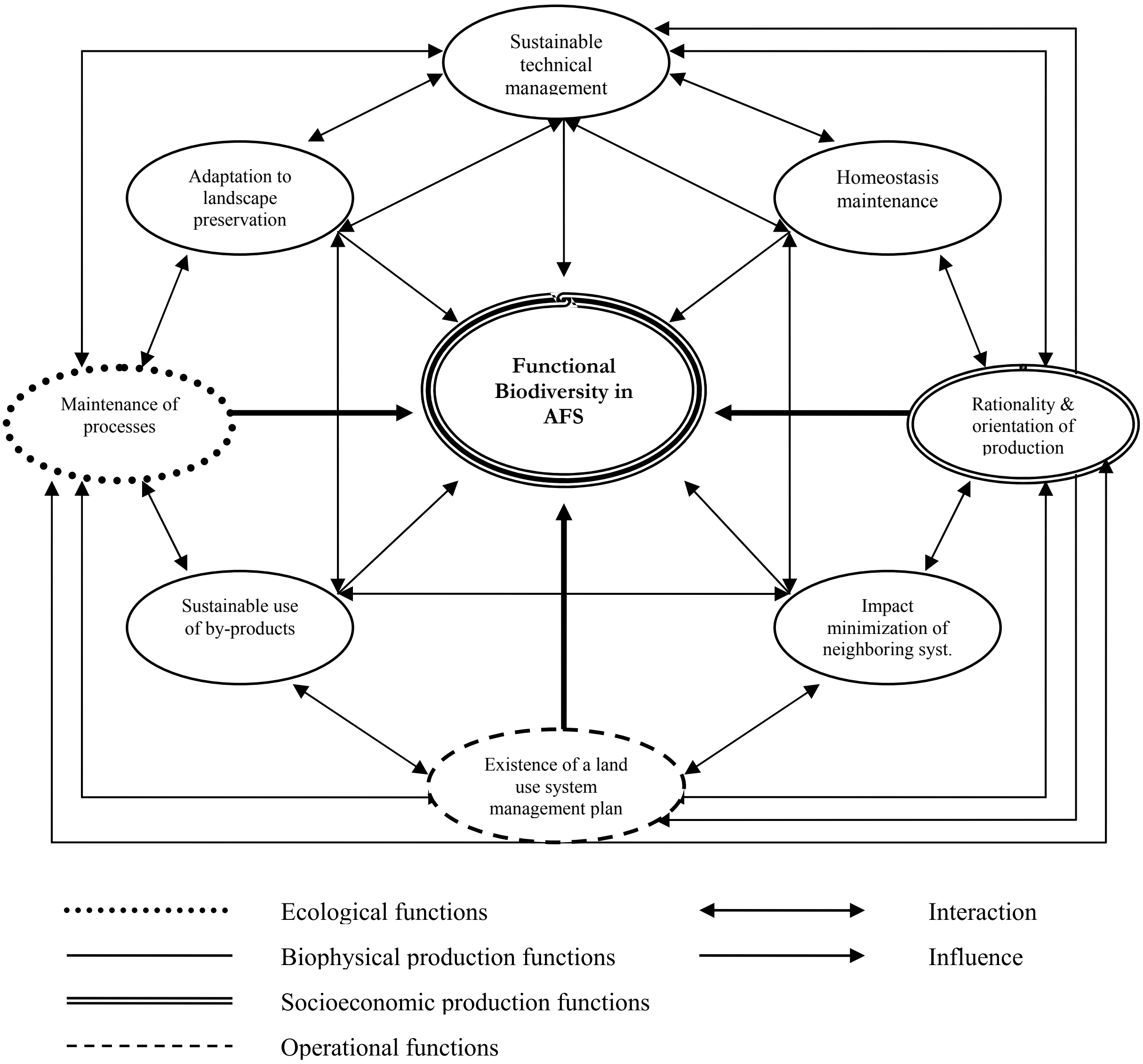


Figure 7.3 Conceptual model: main criteria and their integration into the evaluation frame of the functional biodiversity in agroforestry systems of Tomé-Açú,Pará State Brazil (for a broader explanation see 7.1.5.)

7.1.4 Establishing a hierarchy among components

As was previously stated, multicriteria analysis demands a hierarchical definition of components, from the most general (principles) to the most specific (verifiers).

The factors are divided into more detailed components as they go down in the level of hierarchy: principles (P) into criteria (C), criteria into indicators (I), and finally, indicators into verifiers (V) (Figure 7.4).

The number of subordinate components is indeterminate, but in general, the more factors, the better explained the focused phenomenon. However, the complexity of their management also increases.

In the hierarchical arrangement of factors, the top-down approach is followed, where lower-level items respond to the needs proposed by upper-level items. However, the bottom-up approach facilitates interpretation of the model, where first-hand information from lower levels supports more general information at upper levels. Besides this vertical flux of information, horizontal interactions also occur among components at different levels.

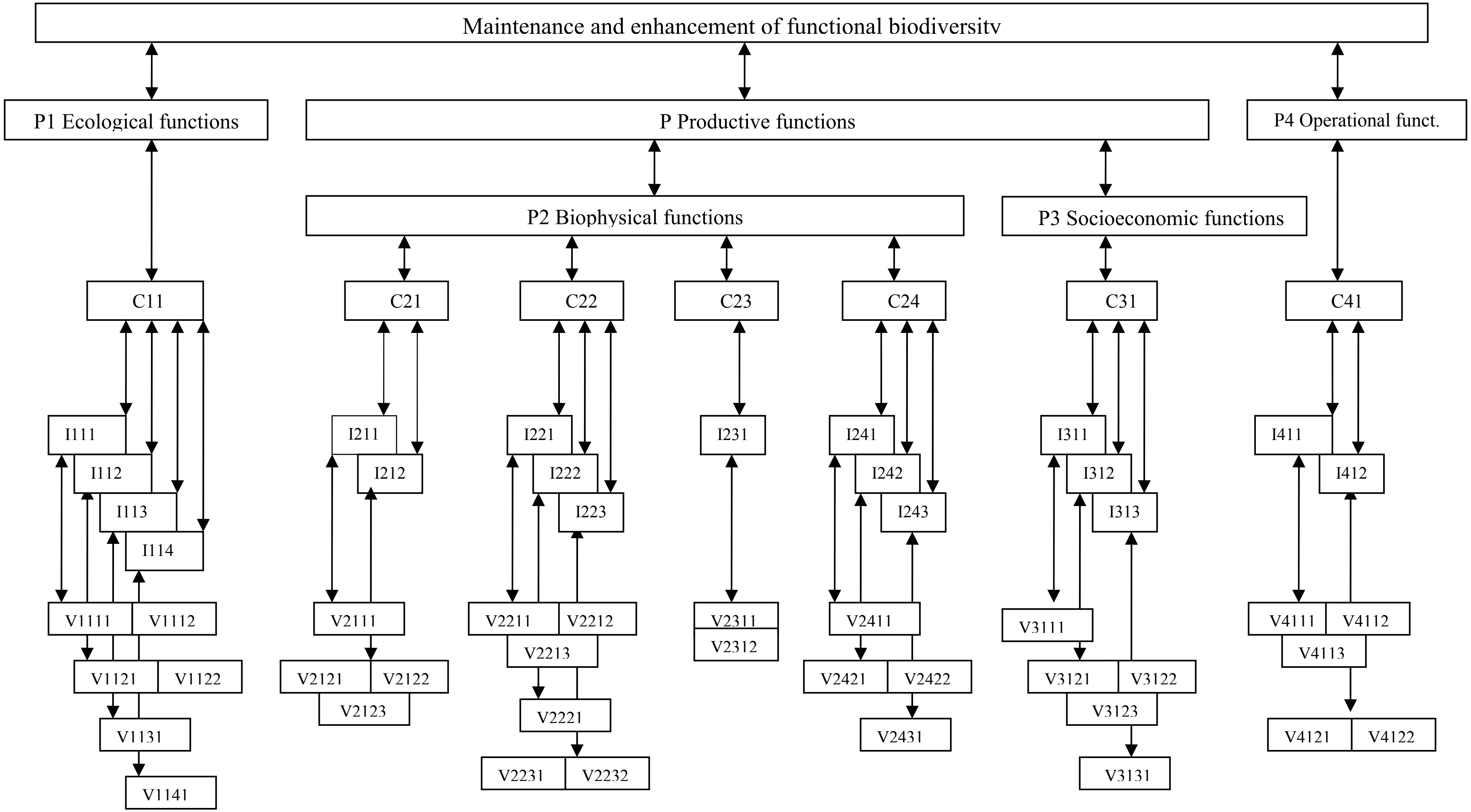


Figure 7.4 Hierarchical tree: components' interdependence within the C&I set of functional biodiversity in agroforestry systems of Tomé-Açú, Pará State, Brazil (see 7.1.5 for interpretation).

7.1.5 Components characterization

The process of nomination, election and definition of components (principles, criteria, indicators and verifiers), is based on selection of segments of several templates, similar research, case studies, and own judgment. The components were thereafter refined and consolidated through their conceptual re-evaluation, consultation with experts, workshops with stakeholders and field evaluations in a feedback cycle that was repeated several times (Figure 7.2).

The basis for selecting each component depended on its representativeness of the focused phenomenon, application feasibility depending on logistics and limitations, flexibility for extrapolation to a wider geographical area, and degree of integration into one coherent framework of application. The final set compiled, from the highest to the lowest level: 3 functions, 7 criteria, 18 indicators and 32 verifiers (from which have been applied 27), however, the whole set is showed to maintain the coherence of the approach.

(P.1.) Ecological functions

Ecological functions refer to the biomass and energy inflows and outflows in an ecological system, without taking into account the factors related to production.

(C.1.1.) Ecological processes that affect, maintain, strengthen or restore biodiversity are enhanced.

Focus on the ecological stability and resilience of the system as a function of the biogeochemical processes acting upon it.

(I.1.1.1.) Nutrient cycling ratios are maintained in standards that allow the efficiency and quality of the system's processes.

The stability of these ranks indicates the stability of the processes performed on the system (see sections 3.5.2 and 3.5.3).

(V.1.1.1.1.) Organic matter content in top soil

Soil organic matter (OM) is an indirect indicator of the degree of biological activity in the soil above and belowground.

The percentage of organic matter was measured within the first layer of soil (0-25 cm), where the processes depend mostly on biological factors, and the results were divided into quintiles in order to fit Criteria and Indicators Modification and Adaptation Tool (CIMAT) demands (see section 6.1.5) (Table 7.1).

Table 7.1 Organic matter content in topsoil

Score (% O in soil)	**CIMAT rate**
≤ 0.66	1.0
> 0.66 < 1.14	2.0
> 1.14 < 1.40	3.0
> 1.40 < 1.67	4.0
> 1.67 < 4.09	5.0

(V.1.1.1.2.) Content of nitrogen in the topsoil

Nitrogen (N) and Phosphorus (P) are the primary elements for plant nutrition, and their high demand in land-use systems is usually provided by fertilizers. Although the nitrogen content fluctuates seasonally, it is still a good indicator of the intensity of soil use.

The percentage of nitrogen was evaluated in the first layer of soil (0-25 cm) and the results were divided into quintiles in order to fit the CIMAT demands (Table 7.2).

Table 7.2 Content of nitrogen in the topsoil

Score (% N in soil)	**CIMAT rate**
≤ 0,05	1.0
> 0.05 < 0.07	2.0
> 0,07 < 0.08	3.0
> 0,08 < 0.10	4.0
> 0,010 < 0.16	5.0

(I.1.1.2) Diversity of species is maintained at acceptable levels

The larger diversity of species indicates a wider net of interactions and indirectly contributes to the stability of a system (see section 3.3.2).

Its evaluation focused on two of the three main levels of the study, on ecosystems and species levels (putting aside the genetic diversity). Standard richness and abundance indices were applied to the two functional groups of species trees and small trees (woody), and low herbs (non-woody).

(V.1.1.2.1) Richness and evenness of woody species

Woody species are a key component of agroforestry systems and their presence and their diversity add complexity to the ecological processes and their diversity even more. Therefore, perennial species diversity (richness and evenness) are indicators of the degree of interactions that take place in an agroforestry system.

The Shannon index was calculated per plot and the results were divided into quintiles (Table 7.3).

Table 7.3 Richness and evenness of woody species

Shannon index	**CIMAT Rate**
≤ 0.006	1.0
> 0.00 < 0.23	2.0
> 0.23 < 0.30	3.0
> 0.30 < 0.47	4.0
> 0.47 < 0.68	5.0

(V.1.1.2.2). Richness and evenness of non-woody species

Herbaceous non-woody species, although non-targeted participants in the agroecosystem are important participants in the ecological processes. These species are important because of the farmers' perception of them as crop competitors and their tendency to eliminate them. Thus their presence and diversity in the plot is an indicator of the system's resilience and the continuance of intrinsic ecological processes.

The Shannon index was calculated per plot and the results divided into quintiles (Table 7.4).

Table 7.4 Richness and evenness of non-woody species

Shannon index	**CIMAT rate**
≤ 0.00	1.0
> 0.00 < 0.27	2.0
> 0.27 < 0.57	3.0
> 0.57 < 0.74	4.0
> 0.74 < 1.10	5.0

(I.1.1.3) Biomass accumulation is maintained at standard levels

Biomass accumulation indirectly indicates the vitality, intensity, strength or weakness of the biological processes, and the productive capacity of a land-use system (see sections 2.4.2 and 3.1.3).

(V.1.1.3.1.) Amount of woody biomass (trees and palms)

Perennials species (trees and palms) are the main biomass suppliers in any agroforestry system, and therefore principally responsible for the above-described interactions.
The verifier was calculated applying pre-established allometric models (Table 7.5) and the results divided into quintiles (Table 7.6).

Table 7.5 Allometric models for biomass calculation

Case	**Allometric model**
Trees	0.118*DBH^2.53 (*)
Palms	SQRT(185.1209+(881.9471*(LN(H)/(H^2)))) (**)

(*) DBH = Diameter at Breast Height (cm)
(**) LN = Natural logarithm; H = Height (m).
Based on Brown (1997) and Márquez (2000)

Table 7.6 Amount of woody biomass

Biomass (t/ha)	**CIMAT rate**
≤ 4.61	1.0
> 4.61 < 24.94	2.0
> 29.94 < 53.27	3.0
> 53.27 < 172.98	4.0
> 172.98 < 4695.67	5.0

(V.1.1.3.2.) Amount of non-woody biomass

The abundance of non-perennial species in the plot indicates the intensity of the ecological processes.

The value was estimated collecting, drying and weighing the biomass per a known unit of area and the results divided into quintiles (Table 7.7).

Table 7.7 Amount of non-woody biomass

Biomass (t/ha)	**CIMAT rate**
≤ 0.08	1.0
> 0.08 < 0.89	2.0
> 0.89 < 1.36	3.0
> 1.36 < 2.06	4.0
> 2.06 < 4.88	5.0

(I.1.1.4) Soil erosion vulnerability

In tree-dominated ecosystems, soil is the second highest reservoir of biomass, and water erosion the determinant soil-depleting factor in humid areas. As this research focuses on systems that involve both characteristics, it makes sense to consider the level of soil erosion susceptibility.

(V.1.1.4.1.) Percentage of herbaceous soil cover

The degree of herbaceous species cover is used as an indicator of the plot's vulnerability to erosion, because it acts as a buffer against the impact of raindrops and provides adherent structures preventing the dragging of particles by water.
The covering parameters defined by Woda (2006) were used to quantify the verifier and the results divided into quintiles (Table 7.8).

Table 7.8 Percentage of herbaceous soil covering

Soil covering (%)	**CIMAT rate**
0	1.0
0 – 25	2.0
25 – 50	3.0
50 – 75	4.0
75 – 100	5.0

Based on Woda (2006)

(P.2.) Biophysical production functions

These are the factors that influence productive features of the studied systems, specifically the ones related to biophysical characteristics.

(C.2.1.) Input-output stability is maintained

The systems theory, the upper-level paradigm in this study, states that the maintenance of fluxes (of energy and goods) leads to system equilibrium, diminishing antagonisms and enhancing synergies along the process (Hart 1985).

(I.2.1.1.) The farmer has a precautionary attitude about controlling and monitoring noxious species and populations

This refers to the farmers' attitudes and their decisions regarding the admission of species and populations that eventually could lead to disturbances in the system, such as invasive species, pests, disease dissemination, and genetic pollution (see section 3.2.1).

(V.2.1.1.1.) Farmers are aware of the risk introduction of exotic species

This verifier focuses on the farmers' attitude towards the risks of introducing exotic species in a well established land-use system. This attitude was evaluated through a questionnaire in a pre-designed survey the results rated and their product divided into quintiles (Table 7.9).

Table 7.9 Introduction of exotic species

Do you know all plants on your property?	Rate	What do you do with the ones you do not know?	Rate
All	1.0	Eliminate	0.5
Many	0.9	Leave	1.0
Half	0.8	Isolate	0.7
A few	0.7	Other	0.7
None	0.5		

Table 7.9 cont.

Have you brought any foreign plant?	Rate	Dou you think was good bringing such a plant?	Rate
Many	1.0	Yes	5.0
Some	0.9	More or less	3.0
A few	0.8	No	1.0
Any	0.5	I don't now	3.0

(I.2.1.2.) Farmers maintain **an attitude that supports intra- and inter-species variability of the system**

This indicator refers to the farmers' awareness concerning the variability of land-use system components, i.e., varieties and functional groups (see section 3.3.3).

(V.2.1.2.1.) Number of strata in the system

The number of vertical strata is a direct function of the number of functional groups and the diversity of perennials, and has indirect influence on the degree of species' interaction and soil erodibility (Glover 2003) (see sections 2.3.5 and 2.4.2).

The verifier was assessed with direct measurements in the field, using parameters from ecological literature, and the rates ranked according to CIMAT requirements (Table 7.10).

Table 7.10 Number of strata in the system

Number of strata – height range (m)	CIMAT Rate
< 1,5	1.0
1,5 – 5	3.0
> 5	5.0

(V.2.1.2.2.) Number of varieties of main crops

Intra-specific variation is considered a key factor in agro-biodiversity, giving stability to the system in biophysical terms through provision of horizontal resistance, cross pollination, etc. (see section 3.3.2).

The factor was assessed through a questionnaire in a pre-designed survey and the responses divided into quintiles to feed CIMAT (Table 7.11).

Table 7.11 Number of varieties of main crops

List main cultivated species(*)	How many years do you cultivate such a species? (years)	Rate	How many varieties of that species? (#)	• Rate
(…)	1-2	0.2	1-2	1.5
	3-5	0.4	3-5	3.0
	6-15	0.6	6-10	4.0
	16-25	0.8	> 10	5.0
	Always	1.0		

(*) The species cultivated in the plot are listed

(V.2.1.2.3.) Number of by-product provider species

An interesting aspect of biodiversity functionality is the presence of species providing products that generate not so much ready cash, but that in high demand locally for medicines, spices, handicrafts, etc. These species were not counted but grouped, and their proportion compared with the global output (see sections 2.2.1, 3.3.2 and 3.3.3). The farmer was asked about the number of by-product provider species in his/her plot, and the results ranked according to CIMAT requirements (Table 7.12).

Table 7.12 Number of by-product provider species

Provided by-products (# provider species per plot)	CIMAT rate
1	1.0
1-5	2.0
5-10	3.0
10-20	4.0
> 20	5.0

(C.2.2.) System technical design (at plot, regional and landscape levels) promotes biodiversity conservation functions

This refers to the technical activities that enhance biodiversity functions in land-use systems, taking into account conservation and production tasks.

(I.2.2.1.) Changes in habitats as result of human interventions are as restricted as possible in order to prevent processes of fragmentation and conversion

This refers to the effect of conversion of existing ecosystems into new land-use systems (see sections 2.4.1, 3.2.1 and 3.3.2).

(V.2.2.1.1.) Physical system borders and limits definition

Delimitation of the land-use system area (plot) is essential for the landscape evolution in an environmental friendly framework. In an environmental services payment program, such a unit should coincide with the plot unit of analysis.

These borders were defined through direct observation in the field (Table 7.13).

Table 7.13 Physical borders delimitation

Delimitation of the plot border (%)	CIMAT rate
80-100	5.0
60-80	4.0
40-60	3.0
20-40	2.0
0-20	1.0

(V.2.2.1.2) Definition of spatial and functional limits at regional level

The political borders (verifier V.2.2.1.1.) are compared with the natural (e.g., rivers) and functional (e.g., roads) boundaries at community level, observing the degree of overlapping.

The remote sensing images of the areas with the evaluated plots were overlayed with the natural boundaries (Table 7.14).

Table 7.14 Correspondence of political and natural boundaries

Correspondence of political with natural boundaries (%)	CIMAT rate
80-100	5.0
60-80	4.0
40-60	3.0
20-40	2.0
0-20	1.0

(I.2.2.2.) Management activities are carried out in order to promote biodiversity conservation functions at landscape level

This refers to the impact of management activities related to production and biodiversity conservation.

(V.2.2.2.1.) Proportion and closeness of land-use systems to biogeographical islands at community level

It is well known that biogeographical islands (BI; forest patches, buffer strips, biological corridors and water flows), provide the best buffer structures for agricultural areas, through supplying habitats and corridors for species, and by enhancing biogeochemical processes in landscapes that are affected by homogeneous large-scale land-use systems. Therefore, the number, proportion and closeness of the BI to the targeted land-use systems serve as an indicator of biodiversity activity (see sections 2.3.1, 2.3.1, 3.2.1 and 3.3.2).

For the evaluation remote sensing images were used and the size, proportion and proximity of BI to the agroforestry plots (Table 7.15).

Table 7.15 Proportion and closeness of plot to BI

Presence of BI at community level (%)	Rate	Closeness of the plot to BI (km)	Rate
40-50	5.0	> 5	0.2
30-40	4.0	4-5	0.4
20-30	3.0	3-4	0.6
10-20	2.0	2-3	0.8
0-10	1.0	1-2	1.0

(I.2.2.3.) Influence on biodiversity conservation functions of spatial and temporal arrangements of land-use system components

This refers to the farmers' decisions responding diversification of groups of species at plot level (see section 4.2.3).

(V.2.2.3.1.) Proportion of monocultures (annuals) and polycultures (perennials)

The more functional groups present in a plot, the higher the spatial and temporal occupation and the higher the level of interaction. The proportion between the areas occupied by polycultures (slash-and-burn systems, primary and secondary forest and agroforestry systems) were contrasted with the total area of the property (see section 4.4.1).

For the calculation, an index of the different land management types was designed, which is equal to five times the area assigned to polycultures divided by the total plot area; the resulting values were divided into quintiles to feed CIMAT (Table 7.16).

Table 7.16 Proportion monocultures vs. polycultures

Land-use classification per plot (ha)	**Area polycultures (slash-and-burn, primary forest, AFS, …) (ha)**	**Area monocultures (cropfields, pastures, …) (ha)**	**Total area (ha)**	**Index**
…	a	b	c	(a*5)/c

(C.2.3.) Impact on neighboring systems is minimized to maintain upper-level ecosystem functionality

Harmful impacts from land-use systems toward neighboring areas can be sources of stress and disruption of landscape stability.

(I.2.3.1.) Special protection of most sensitive, rare or less abundant systems

This refers to the level of protection provided to the conservation and buffer areas near land-use systems, assuring their provision of ecological benefits (see sections 2.3.1 and 4.4.3)

(V.2.3.1.1.) Proportion of neighboring well managed sensitive systems

The vicinity to systems, such as plains, lagoons, primary forest or water springs is important, since these perform as buffering structures and ecological reserves.

Evaluation was done with direct quantification of previously stratified types of borders and a posterior division into quintiles of the responses to feed CIMAT (Table 7.17).

Table 7.17 Neighboring well managed systems

Type of neighboring systems	Rate	Proportion of covering (%)	**CIMAT rate**
Road, house, urban area	0.2	80-100	5.0
Pasture, grassland, plain, mono-crop field	0.4	60-80	4.0
Agroforestry system	0.6	40-60	3.0
Secondary forest, water spring, river	0.8	20-40	2.0
Primary forest	1.0	0-20	1.0

(V.2.3.1.2.) Proportion of borders installed to perform environmental functions

Linnear vegetation arrangements in agroforestry systems, e.g., hedgerows, living fences, windbreaks, designed originally to perform protection and delimitation functions, also contribute to optimization of system performance.

Evaluation was done with direct quantification of previously stratified types of borders and a posterior division into quintiles of the responses to feed CIMAT (Table 7.18).

Table 7.18 Border types proportion

Type of border	**Rate**	**Proportion of covering (%)**	**CIMAT rate**
Wire, wood, metal, cement, fences	0.3	80-100	5.0
Living fence, hedgerow (light)	0.6	60-80	4.0
Living fence, windbreak, hedgerow (dense)	1.0	40-60	3.0
		20-40	2.0
		0-20	1.0

(C.2.4.) Technical management is carried out in a sustainable way

Technical decisions based on a strong technical background and conservationist criteria in the medium term can determine the sustainability of the production process.

(I.2.4.1.) Soil erosion is adequately managed

Soil hosts essential processes that affect production and biodiversity conservation, such as decomposition or nitrogen transformation. Therefore, the measures for its protection and sustainable management influence the generation of outputs.

(V.2.4.1.1.) Level of application of soil conservation practices against soil erosion

Farmers were asked about the existence of soil erosion problems and whether they carry out (cultural, mechanical and/or infrastructural) soil conservation practices.

Assessment was done through a questionnaire in a pre-designed survey the responses rated and their product divided into quintiles to feed CIMAT (Table 7.19).

Table 7.19 Soil conservation practices

Do you have soil erosion problems?	Rate	Do you carry out conservation practices?	Rate	Which measures do you apply? (*)	CIMAT rate
Yes	1.0	Yes	1.0	1 of 3	3.0
No	0.2	No	0.4	2 of 3	4.0
				3 of 3	5.0

(*) Cultural, linear and structural practices

(I.2.4.2.) Production processes are adequately managed

This refers to the quality (technical background) and orientation (predominance of conservationist practices) of farmers' activities towards regarding more sustainable and less harming agricultural practices (see sections 2.4.2, 3.2.2, 3.3.2 and 3.3.3).

(V.2.4.2.1.) Farmers have sufficient technical background regarding the system design and management

This refers to the farmers' ability (expertise and technical qualification) to perform productive day-to-day tasks aiming at high yields.

The farmer was asked how many out of a given set of production practices he/she applies regularly, the responses were ranked and divided into quintiles according to CIMAT requirements (Table 7.20).

Table 7.20 Farmers' technical background

From the list (*) how many activities do you carry out? (#)	**CIMAT rate**
1-4	1.0
5-7	2.0
8-10	3.0
11-15	4.0
> 15	5.0

(*) Seeding: seed collection, storing, germination test,…; nursering: design, watering, protection, reseeding, ...; planting: design (spacing), watering, protection, replanting, ...; management: weedding, fallowing, watering, protection, manuring, sanitary control, hewing, pruning.

(V.2.4.2.2.) Farmers apply low-impact techniques, treatments and methods to maintain resources and yields

This refers to the farmers' knowledge (expertise and technical qualification) on productive day-to-day tasks in a conservationist frame.

The farmer was asked how many out of a given set of production practices he/she carries out regularly and the responses ranked and divided into quintiles according to CIMAT requirements (Table 7.21).

Table 7.21 Farmers' low impact techniques application

From the list (*) how many practices do you carry out? (#)	**CIMAT rate**
1-2	1.0
3-4	2.0
5-6	3.0
7-8	4.0
> 8	5.0

(*) Weedding (e.g., manual vs. herbicides), protection (e.g., wire vs. living fence), manuring (synthetic vs. organic); phytosanitation (e.g., adequate dosage, alternative methods).

(I.2.4.3) There is a feedback process in order to react to changing conditions

This indicates the flexibility of farmers' technical decisions regarding adaptation and recovery of stability in changing conditions. Environmental, social and political factors are taken into account (see sections 2.4.2, 3.2.2, 3.3.2 and 3.3.3).

(V.2.4.3.1.) Technical management plan changed in the last 5 years to adapt to changes

Farmers are asked about the changes in their production-related decisions due to changes in environmental, social, political and economic factors during the last five years. The responses were ranked and divided into quintiles according to CIMAT requirements (Table 7.22).

Table 7.22 Environmental-driven management plan changes

Have you changed your administration plan in the last 3-5 years?	CIMAT rate
Yes	5.0
No	1.0
We are always changing	3.0
Other answer	3.0

(P.3.) Socioeconomic production functions

This refers to the factors influencing the productive features of the studied systems, focusing on socioeconomic characteristics only.

(C.3.1.) The land-use system satisfies the requirements for eligibility as an environmental services provider

The following conditions should be satisfied: food security assurance, financial feasibility through provision of supplementary income, and reinvestment assurance (see section 1.3).

(I.3.1.1.) Food security is well maintained

This refers to the degree of food security of the households in terms of quantity and quality, generated directly or indirectly by the land-use system itself (see sections 4.2.2 and 4.3.3).

(V.3.1.1.1.) Income re-invested in food acquisition

It is assumed that in commercially linked communities, food security satisfaction extends, after the self-provision of basic supplies, to food acquisition in external markets. Therefore, the relative amount of money invested in food acquisition should reflect the household degree of self-dependence, i.e., the more external acquisitions, the more food-secure is the household.

Farmers were asked about their self-supply of key products, such as manioc, maize and beans, the products he/she has to buy from external markets, the origin of the money invested for such acquisition, and the balance of income-production vs. expenditure external acquisition.

Assessment was through a series of questions in a pre-designed survey the responses were ranked and divided into quintiles according to CIMAT requirements (Table 7.23).

Table 7.23 Income reinvestment in food acquisition

Do you use some crops for your own consumption?	Rate	Do you have to buy other food?	Rate
Yes	1.0	Yes	0.9
No	0.4	No	1.0

Table 7.23 cont.

Money for it comes from farming?	Rate	Was it enough last year?	Rate
Yes	4.0	Yes	1.0
No	2.0	No	0.4

(I.3.1.2.) Farmers actively seek the access to markets and diversification of their production

This refers to the farmers' access to markets and production diversification, and the relation this has with the generation of income (see sections 2.4.3, 4.2.2 and 4.2.3).

(V.3.1.2.1.) The system is considered economically feasible

This refers to the profitability of the agroforestry system. Farmers were asked about the production quantity and quality within the year of evaluation and their general opinion about the system's economic feasibility.

Its assessment was done through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.24).

Table 7.24 Agroforestry system's financial feasibility

How was the production this year?	Rate	Are AFS good business?	Rate
Good	5.0	Yes	1.0
More or less good/bad	3.0	No	0.5
Bad	1.0		
Other answer	3.0		

(V.3.1.2.2.) Degree of farmers' market access

The access to commercialization channels is the most forceful argument in searching the economic sustainability of the production process, and a pre-requisite for economic and social sustainability.

Farmers were asked about their participation in the market: frequency, type of connection (individual, collective), presence of intermediaries and their current state of satisfaction.

It was assessed through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.25).

Table 7.25 Farmers' access to the market

Do you bring your production to the market?	Rate	How frequently?	Rate	Which type of access you find best?	Rate
Yes	5.0	1-3 times/year	0.4	Associated	0.9
No	1.0	4-6 times/year	0.6	Individually	1.0
		1-2 times/month	0.8		
		once a week	0.9		
		> once week	1.0		

(V.3.1.2.3.) Diversity of products regularly brought to the market by the farmers

Diversification of production generates diversification of income and financial assurance to the households through the creation of market niches.

Farmers were asked about the types and number of products that they took to the market and whether he/she is satisfied or wishes to increase these.

This was assessed through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.26).

Table 7.26 Diversity of products brought to the market

How many products do you bring to the market usually?	Rate	Would you like to increase them?	Rate
1-2	0.4	Yes	1.0
3-4	0.6	No	0.9
5-6	0.8		
7-8	0.9		
>8	1		

(I.3.1.3.) System feedback processes keep the production at satisfactory levels

System sustainability requires processes that self-regulate themselves permanently, maintaining a constant flux of inputs and outputs.

(V.3.1.3.1.) Farmers' attitude towards reinvestment

Financial investment is essential for setting up and maintaining production factors (labor, land, capital and entrepreneurship) in the medium or long term.

Farmers were asked about their disposition to invest financially on their own farm, and whether they had done it in the past.

This was assessed through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.27).

Table 7.27 Farmers' reinvestment attitude

Do you invest the earned money in the same property?	Rate	Do you find it important?	Rate	Did you do it always?	Rate
Yes	5.0	Yes	1.0	Yes	1.0
No	1.0	No	0.4	No	0.8

(P.4.) Operational functions

This considers administrative and policy-related issues at local, regional, and national levels.

(C.4.1.) A landscape management plan appropriate to the environmental, social and economic circumstances exists

Upper-level institutions (normally advising and monitoring instances of national or local governments) perform an important role in monitoring environmental aspects of agricultural activities. Their competence and influence is evaluated here.

(I.4.1.1.) Institutions dictate rules about controlling production activities and their environmental implications

Institutions working on environmental issues related to productive activities are spotlighted; their activities and orientation of the normative framework are evaluated (see sections 4.2.1 and 4.2.3).

(V.4.1.1.1.) A technical institution is responsible for monitoring environmental damages caused by productive activities, and farmers obey its rules

The existence of an institution in charge of observing, monitoring and regulating environmental impacts of productive activities is evaluated. This was done through documentation and interviews with local stakeholders about the institutions' performance; farmers were asked about the presence and influence of such institutions and their own disposition to obey rules.

This was assessed through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.28).

Table 7.28 Environmentalist institutional participation

Is there an environmental institution?	Rate	Its rules are obeyed by farmers…	Rate
Yes	1.0	No	1.0
No	0.2	Poorly	2.0
		Partially	3.0
		Fully	5.0

(V.4.1.1.2.) There is an institutional feedback based on technical and scientific basis to define action strategies

This refers to the scientific and technical background on which the institutions base their strategies and actions, and how they are maintained with time. The assessment was done through documentation and interviews about such institutions with local stakeholders. The qualitative responses were categorized, ranked and assigned to CIMAT frame (Table 7.29).

Table 7.29 Institutional feedback

There is an institutional feedback based on technical and scientific basis	CIMAT rate
Yes	5.0
Sometimes	3.0
No	1.0

(V.4.1.1.3.) Institutional advice impacts substantially on farmers' activities

The accuracy of the institutions' advising is evaluated, contrasting their guidelines and impacts in the field.

This was done through documentation and interviews with local stakeholders about the institutions' impacts. Farmers were asked about the orientation of the institutions' advice, specifically about the provisory law 2166, which states that *"... in the Amazonian region it is allowed to use up to 20% of the area of a private property; 80% must be kept as a reserve"*.

This was assessed through a questionnaire in a pre-designed survey, the responses rated and their product divided into quintiles to feed CIMAT (Table 7.30).

Table 7.30 Impact of institutional ruling

The benefits of such a law are beneficial mainly for	Rate	Do you have contact with the institutions that support that law?	Rate	The situation improved after the law came into force?	Rate
The farmer	1.0	Yes	1.0	Yes	5.0
The community	0.9	No	0.9	No	1.0
The region	0.8				
The state	0.7				
The country	0.6				

(I.4.1.2.) Institutions provide incentives for diversifying the local economy, thus avoiding the dependence on only one or few products

This refers to the existence of institutions and organizations in charge of commerce and economic channeling, such as cooperatives, associations and government or private brokering offices, which encourage farmers to diversify their productive activities (see section 4.3.2).

(V.4.1.2.1.) The diversification of the production is encouraged at organizational and institutional levels

This pays special attention to local programs and their suitability with regard to the local conditions.

Farmers were asked about the performance and impact of the relevant institutions; stakeholders were also consulted, and the institutions mentioned were visited.

The qualitative responses were ranked and assigned according to CIMAT requirements (Table 7.31).

Table 7.31 Production diversification enhancement

Local organizations and institutions encourage the diversification of the production	CIMAT Rate
No	1.0
Poorly	2.0
Somehow	3.0
Yes	4.0
Always	5.0

(V.4.1.2.2.) There is a demand for the by-products generated by agroforestry systems

Farmers sell their by-products at local markets and sometimes regional ones; the role of such markets on farmers' diversification decisions is evaluated.

Farmers were asked about the existence and impact of markets for their production; stakeholders were also consulted, and eventually the mentioned institutions were visited. The qualitative responses were compiled ranked and assigned according to CIMAT requirements (Table 7.32).

Table 7.32 Demand for by-products

Local and regional demand for agroforestry by-products	CIMAT rate
Any	1.0
Poor	2.0
Average	3.0
Good	4.0
High	5.0

7.1.6 CIMAT: the data administration tool

Based on Criteria and Indicators Modification and Adaptation Tool (CIMAT; Figure 7.5), C&I data sets were developed for each sampling site. These data sets integrate the data collected on each plot, and facilitate multicriteria analysis, i.e., construction of hierarchies, ranking and rating processes, cross-wise comparisons and obtaining of the Sustainability Management Index (SMI).

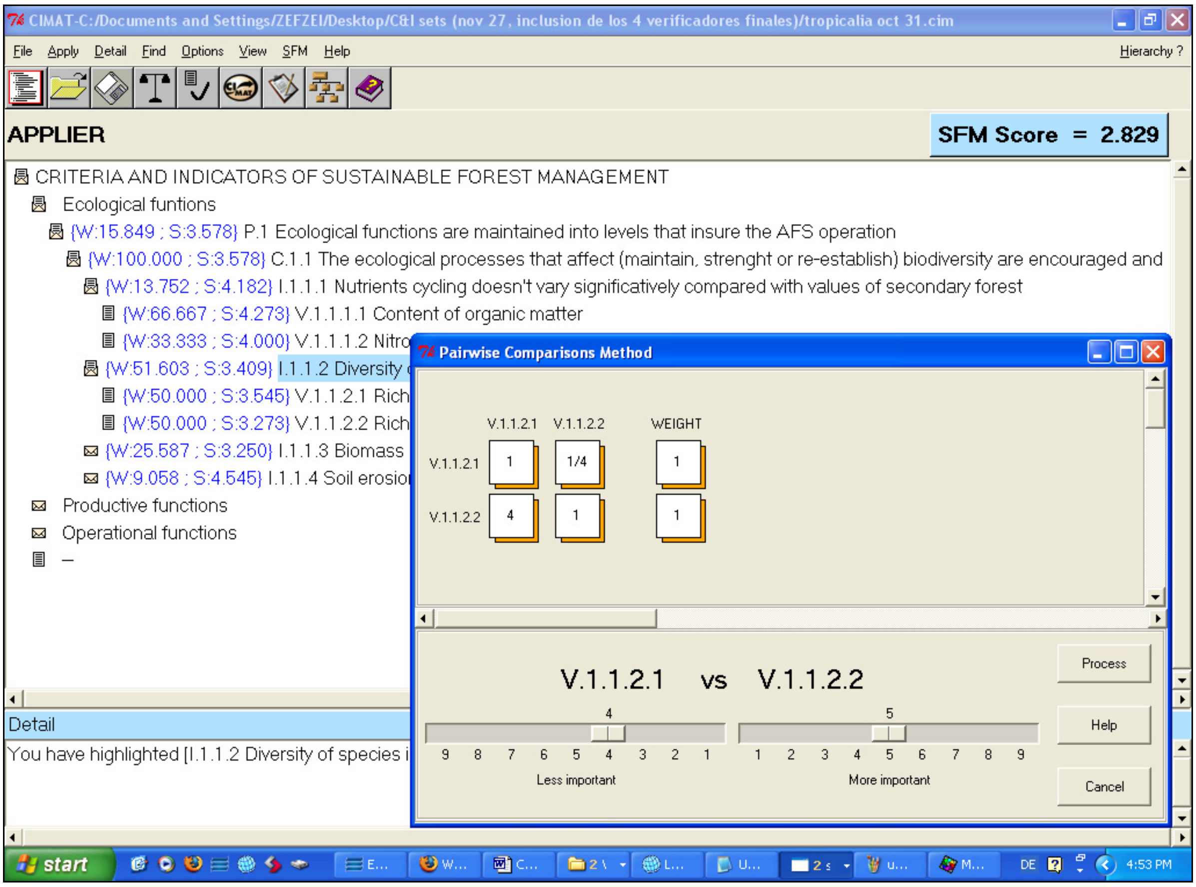


Figure 7.5 CIMAT data management interface: hierarchical weigting and scoring (working space), sustainable management index (upper right: SFM score) and pairwise comparison (active window).

Sustainable Management Index (SMI)

The sustainable management index (SMI) shown in Figure 7.5 as SFM score, considers the relative importance of each assessed component, and combines all of them into a single index reflecting the overall performance of the land-use system at a particular point in time.

SMI is calculated considering the weight of each component assessed on a zero-to-hundred scale, and the score on a one-to-five scale. For example, the verifier

V.1.1.1.1 content of organic matter represents two thirds {W: 66.667} of the weight of its immediate upper indicator I.1.1.1 nutrients cycling (…) and is scored with {S: 4.273}. This process is repeated successively until reaching the highest level, which will represent the overall performance of the system.

In the same way, it is possible to obtain partial indices of performance per groups or types of activities, as in the example where P.1. Ecological functions are maintained (…) has obtained {S: 3.578}, which indicates a considerably high performance. In this way, one can compare the efficiency of each factor in the system, or compare the performance of the same factor in various plots. The SMI can also be used as a monitoring tool, evaluating periodically the same plots and observing the evolution of the index (or indices) during a certain period of time.

Summarizing, this evaluation protocol can provide a basis for functional biodiversity in agroforestry system evaluation, through defining the physical and conceptual scopes of the work, collecting and integrating the required data, grouping and ulterior disintegration on manageable components, and weighing, comparing and scoring them.

7.2 Optimization model

The evaluation protocol resulting from the integration of the above described successive steps provides an analysis framework for a comprehensive view and understanding of the process in a given agroforestry system. However a procedure for examining the consistency of this evaluation protocol is also necessary. Such a procedure should be able to point out the most influential components in the system's performance as a functional biodiversity (environmental services) provider.

Thus, we have compiled these arguments in the development of the specific objective 2, which is *'To define a management optimization model of agroforestry systems for enhancing and maintaining functional biodiversity …'*.

Based on multivariate statistical analysis, a series of analyses was carried out to define the areas where farmers can change their practices to improve their performance.

7.2.1 SMI Statistics

SMI statistics per functions, localities and groups

The obtained sustainable management indices (SMI) of all evaluated plots were compared as a global indicator of the system performance and as an indicator of ecological, productive (biophysical and socioeconomic) and operational specific functions (see section 7.1.3). The indices were also analyzed with respect to the six studied localities (Miritipitanga, Tropicalia, Tomé-Açú, Quatro Bocas, Igapú-Açú and Forquillas), and with respect to the three farmer groups (CAMTA partners, immigrated and newcomers) (see section 7.1.1).

Statistics of SMI per locality

In general, the average SMI of the six localities reflect the three group averages. Localities corresponding to the group of newcomers (Miritipitanga and Tropicalia) show higher variations and lower averages, while in Tropicalia SMI scores are the lowest. In the group immigrated (Tomé-Açú and Quatro Bocas), the variations are smaller, the averages are higher than in the other four localities. In the third group CAMTA partners, the variation in Igapú-Açú is very high, i.e., second highest after Miritipitanga, although the average is similar to Tropicalia and Forquillas, which indicates a more disperse sample. In five of the six localities, the sampling distribution tends to be normal; Tropicalia is an exception, where the distribution is asymmetric and tends to lower scores. In general, localities and groups overlap one another, therefore working directly with groups instead of with localities is possible without a great loss of data (Figure 7.6).

As a general interpretation, three of the six localities (Miritipitanga, Tropicalia and Forquillas) perform in a disperse way and show high and low SMI, in contrast to Tomé-Açú and Quatro Bocas, where the SMI show less variation and tend to be higher than the average. Igapú-Açú scores are especially stable, maybe due to its small sample size.

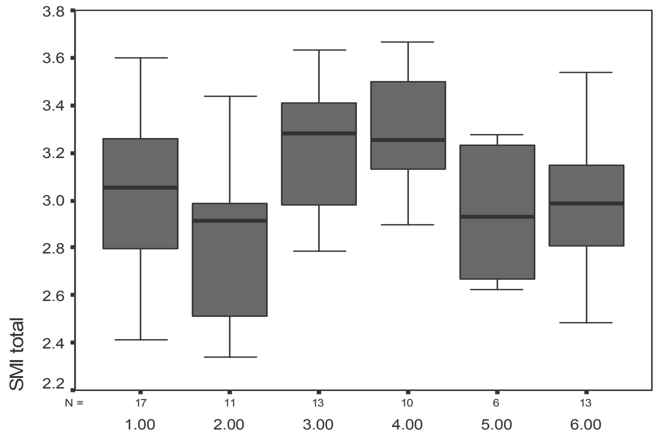


Figure 7.6 SMI for functional biodiversity per locality (1 = Miritipitanga, 2 = Tropicalia, 3 = Tomé-Açú, 4=Quatro Bocas, 5 =Igapú-Açú, 6 = Forquillas)

Statistics of cumulative SMI per group

The newcomer group shows the greatest variation of SMI and CAMTA partners the lowest. The SMI average in the three cases is located approximately in the center of the boxplots (Figure 7.7), which indicates a regular (normal) distribution. The lowest score (about 2.3) belongs to the newcomers group, and the highest (about 3.7) to the CAMTA partners. In all three cases high performances were obtained (about 3.6). However, concerning low extremes, CAMTA partners does better than the other two groups: 2.7 versus 2.3 and 2.5 in newcomers and immigrated respectively.There are no outliers, thus, we can accept the range between 2.3 and 3.7 as the lowest and highest SMI scores for any system's performance. (Figure 7.7)

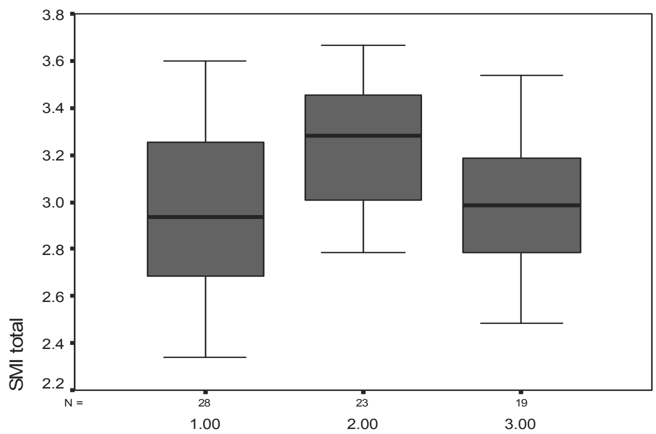


Figure 7.7 Cumulative SMI for functional biodiversity per group (1 = Newcomers, 2 = CAMTA partners, 3 = Immigrated).

Statistics of SMI of ecological functions per group

The averages of ecological SMI of newcomers and CAMTA partners are similar (around 3.5), although in theory, these two groups represent both extremes of the sampling in terms of organization, time of permanence and technical capacity. This means that newcomers have impacted the systems' ecological functions as much as the CAMTA partners, despite the fact that the first group arrived some 50 years later and has only about 10 years of experience in the zone.

The third case, the immigrated group with a level of experience between the other two groups, has an ecological SMI considerably lower (around 3.2), which is interpreted to mean that they have been settled long enough to have negatively affected the ecological quality of their systems, but not long enough to develop measures (technological or financial) to cope with them (Figure 7.8).

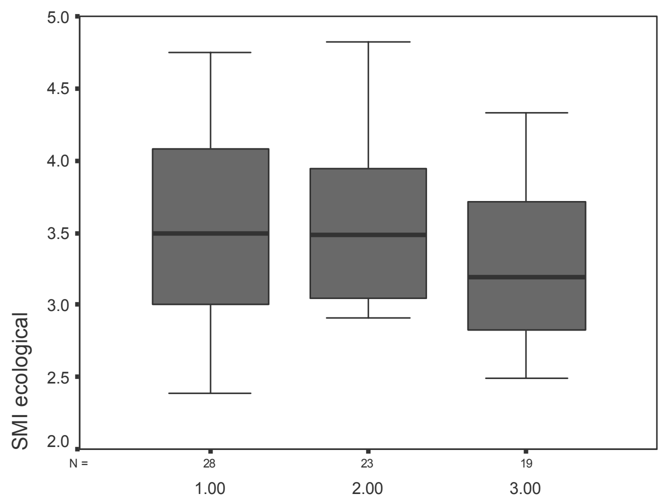


Figure 7.8 Ecological SMI per group (1 = Newcomers, 2 = CAMTA partners, 3 = Immigrated).

However, both the damage to the ecological systems and the recovery are both long-term phenomena, only noticeable in medium to large time frames.

Statistics of SMI of biophysical production functions per group

The SMI related to biophysical production functions show smaller variations than other functions among the three groups of farmers, which indicates a relative homogeneity among the qualities of their practices.

The group immigrated shows the highest average SMI, followed closely by CAMTA partners, and newcomers, who show an average considerably lower than the other two. Since the CAMTA partners are the better technically qualified group, the high value of the group immigrated was unexpected. The reason could be the scale of the plots, i.e., CAMTA partners are middle-sized farmers and the immigrated own smaller farms, which means that management in the first case is more extensive, and in the second case more intensive (Figure 7.9).

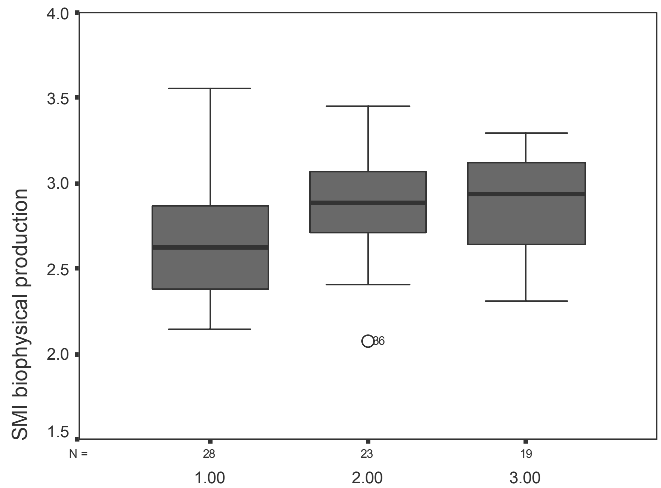


Figure 7.9 Biophysical-production SMI per group (1 = Newcomers, 2 = CAMTA partners, 3 = Immigrated).

Statistics of SMI of socioeconomic production functions per group

The average SMI of socioeconomic production functions clearly distinguishes two groups: newcomers with quite a high score against CAMTA partners and immigrated with lower ones. Variations of SMI in the three groups are similar, and compared to the SMI of other functions show a more sharp distribution.

Socioeconomic production functions deal mainly with the system's capacity to satisfy basic needs of a household. Thus, the superiority of the 'newcomers' could be explained with their greater social cohesion, characteristic of small farm-plots and communities recently established, compared to more developed and market-oriented systems like CAMTA partners, where needs, such as food security and market accessibility are taken for granted. Another factor explaining the newcomers superiority could be that the survey was done based on small farmers, which could have lowered the other groups' scores (Figure 7.10).

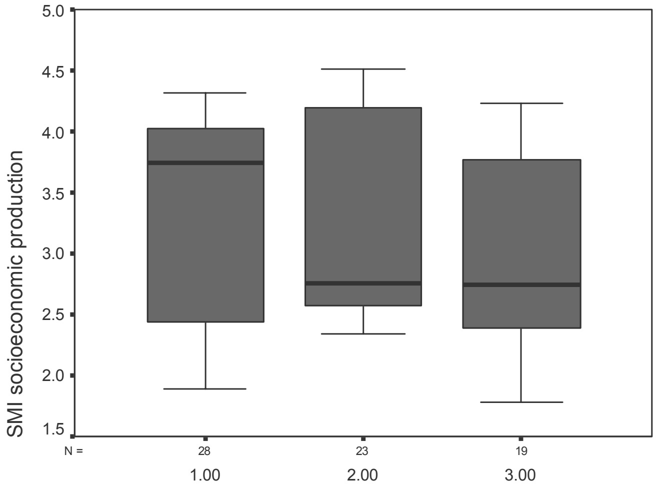


Figure 7.10 SMI of socioeconomic-production issues per group (1 = Newcomers, 2 = CAMTA partners, 3 = Immigrated).

Statistics of SMI of operational functions per group

Operational indicators vary less for all three cases with only a few outliers, as most of scores were assigned per groups instead of individually. The average SMI of 4.5 for CAMTA partners compared with 1.5 for immigrated and 2.2 for newcomers, is because CAMTA addresses most of the factors assessed for this function. The weaker the linkage with a supporting organization, the lower the SMI score, as in the cases of immigrated and newcomers (Figure 7.11).

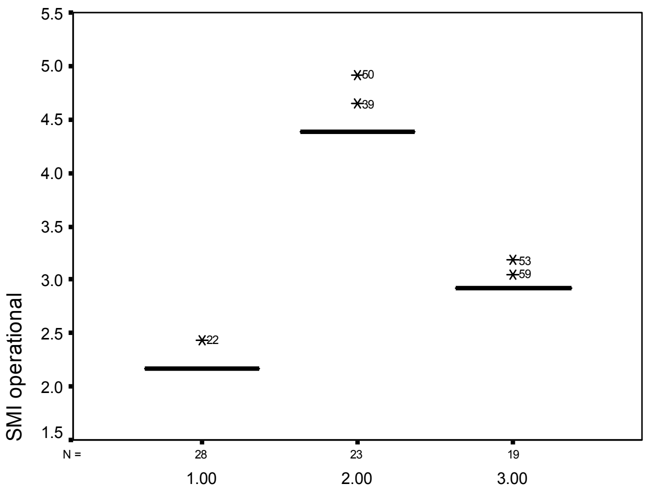


Figure 7.11 SMI of operational issues per group (1 = Newcomers, 2 = CAMTA partners, 3 = Immigrated).

SMI analysis of variance: per functions against groups

One-way ANOVA was used to test the quantitative differences in the SMI described above: considering the whole system performance (cumulative) and per function, splitting in into ecological, productive (biophysical and socioeconomic), and operational.

Test of homogeneity of variances

Since ANOVA assumes that samples have equal standard deviations or variances, it is pertinent verifying the data homogeneity; Levene's test was applied for this verification. The values rejecting the null hypothesis in all cases have equal variances ($P < 0.05$) means that the variances in the different groups are different. Therefore, the ANOVA procedure is applicable (Table 7.33).

Table 7.33 Test of homogeneity of variances of SMI cumulative and per function

SMI	Levene Statistic	df1	df2	Sig.
SMI cum	.749	2	67	.477 (*)
SMI eco	1.146	2	67	.324 (*)
SMI bio	.088	2	67	.916 (*)
SMI soc	.970	2	67	.384 (*)
SMI ope	2.472	2	67	.092 (*)

(*) Sig. P<0.05
SMI cum (Sustainable Management Index cumulative), SMI eco (Sustainable Management Index of ecological functions), SMI bio (Sustainable Management Index of biophysical production functions), SMI soc (Sustainable Management Index of socioeconomic production functions), SMI ope (Sustainable Management Index of operational functions)

Analysis of Variance

Only the means of the cumulative sustainable management index (SMI cum), the index of biophysical production functions (SMI bio), and the index of operational functions (SMI ope) in three groups evaluated (newcomers, CAMTA partners and immigrated) are statistically different at 95% significance. The index of ecological functions (SMI eco) and the index of the socioeconomic production functions (SMI soc), although arithmetically different, are similar statistically (Table 7.34).

Table 7.34 Analysis of variance SMI cumulative and per function

SMI		Sum of squares	df	Mean square	F	Sig.
SMI cum	Between groups	1.322	2	.661	7.047	.002 (*)
	Within groups	6.286	67	.094		
	Total	7.608	69			
SMI eco	Between groups	1.087	2	.543	1.624	.205
	Within groups	22.412	67	.335		
	Total	23.499	69			
SMI bio	Between groups	.732	2	.366	3.477	.037 (*)
	Within groups	7.052	67	.105		
	Total	7.784	69			
SMI soc	Between groups	1.138	2	.569	.823	.444
	Within groups	46.325	67	.691		
	Total	47.463	69			
SMI ope	Between groups	64.124	2	32.062	4408.431	.000 (*) (#)
	Within groups	.487	67	.007		
	Total	64.612	69			

(*) Sig. P<0.05
(#) As was noted above, 'SMI ope' F value is very high and the differences evident; thus, the value was removed from further analysis.
SMI cum (Sustainable Management Index cumulative), SMI eco (Sustainable Management Index of ecological functions), SMI bio (Sustainable Management Index of biophysical production functions), SMI soc (Sustainable Management Index of socioeconomic production functions), SMI ope (Sustainable Management Index of operational functions).

Post hoc analysis

Once the differences among means were determined, in a *post hoc* analysis the degree of the difference among groups was calculated through pair-wise multiple comparisons (P<0.05).

The LSD multiple comparison test was applied to SMI and SMI bio; SMI ope was excluded for the reasons given above.

For cumulative SMI, the three comparison tests gave similar results. At 95% interval of confidence CAMTA partners produce better SMI than newcomers and immigrated, the latter two performing statistically equally. All other possible comparisons are not significant at 0.05 (Table 7.35).

Table 7.35 Multiple comparison tests of SMI cumulative functions per group

Dependent variable	Comparison test	(I)	(J)	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
							Lower bound	Upper bound
SMI cum	LSD	Newcomers	CAMTA p.	-.30791 (*)	.08620	.001	-.4800	-.1359
			Immigrated	-.04382	.09104	.632	-.2255	.1379
		CAMTA p.	Newcomers	.30791 (*)	.08620	.001	.1359	.4800
			Immigrated	.26409 (*)	.09496	.007	.0746	.4536
		Immigrated	Newcomers	.04382	.09104	.632	-.1379	.2255
			CAMTA p.	-.26409 (*)	.09496	.007	-.4536	-.0746

(*) Sig. P<0.05
SMI (Sustainable Management Index)

In the case of SMI bio, the results are significant under the LSD multiple comparison test. The obtained differences show that CAMTA partners have higher SMI bio than newcomers. Immigrated also perform better than newcomers, but there is no difference between CAMTA partners and immigrated at 0.05 of significance (Table 7.36).

Table 7.36 Multiple comparison tests of SMI biophysical production functions per groups

Dependent variable	Comparison test	(I)	(J)	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
							Lower bound	Upper bound
SMI bio	LSD	Newcomers	CAMTA p.	-.21329 (*)	.09130	.022	-.3955	-.0311
			Immigrated	-.20284 (*)	.09643	.039	-.3953	-.0104
		CAMTA p.	Newcomers	.21329 (*)	.09130	.022	.0311	.3955
			Immigrated	.01045	.10058	.918	-.1903	.2112
		Immigrated	Newcomers	.20284 (*)	.09643	.039	.0104	.3953
			CAMTA p.	-.01045	.10058	.918	-.2112	.1903

(*) Sig. P<0.05
SMI bio (Sustainable Management Index of biophysical production functions).

7.2.2 Clusters analysis

Unlike in the ANOVA, in a cluster analysis it is possible to include the whole data set and to observe the matching where clusters are formed. These clusters were developed under two criteria: (1) per groups, CAMTA partners, immigrated and newcomers; and (2) per function: SMI eco, SMI bio, SMI soc and SMI ope.

Cluster analysis per group

Since the intention is to depict as well as possible the component clusters, the Ward's algorithm was the clustering method of choice, and the distances were measured using the Squared Euclidean Distance. In this case, cluster analysis performs as a confirmatory procedure, applied to the groups defined in advance, and the results validate the accurateness of their grouping. Figure 7.12 shows the correspondence between the dendrogram of cluster analysis and the predefined sampling groups (pies); the first group is mainly composed of newcomers, the second of immigrated, and the third of CAMTA partners.

Since cluster analysis only depicts the most similar groups, it is not able to detail the influential factors, which were therefore dealt with using factor analysis.

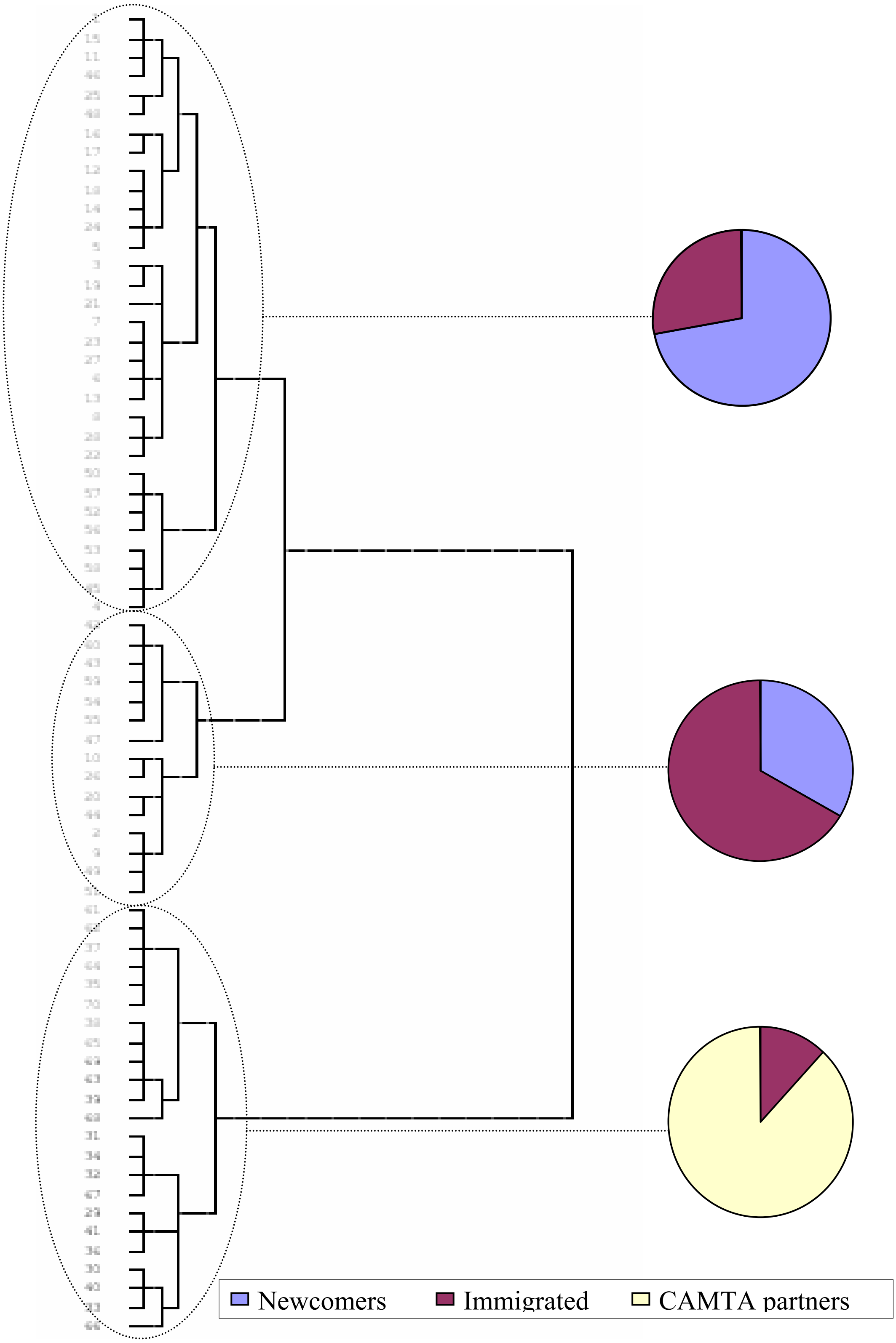


Figure 7.12 Matching obtained clusters and sampling groups (newcomers, immigratd and CAMTA partners)

Cluster analysis per function

Ward's clustering and squared Euclidean distance outputted a fuzzy correspondence among functions. The farmers' prioritization of activities does not match with the suggested categorization of functions in ecological and productive (biophysical and socioeconomic) and operational domains (Figure 7.13). This seems reasonable, since the logic that influences farmers' actions do not follow the used scheme, but rather the situation in reality.

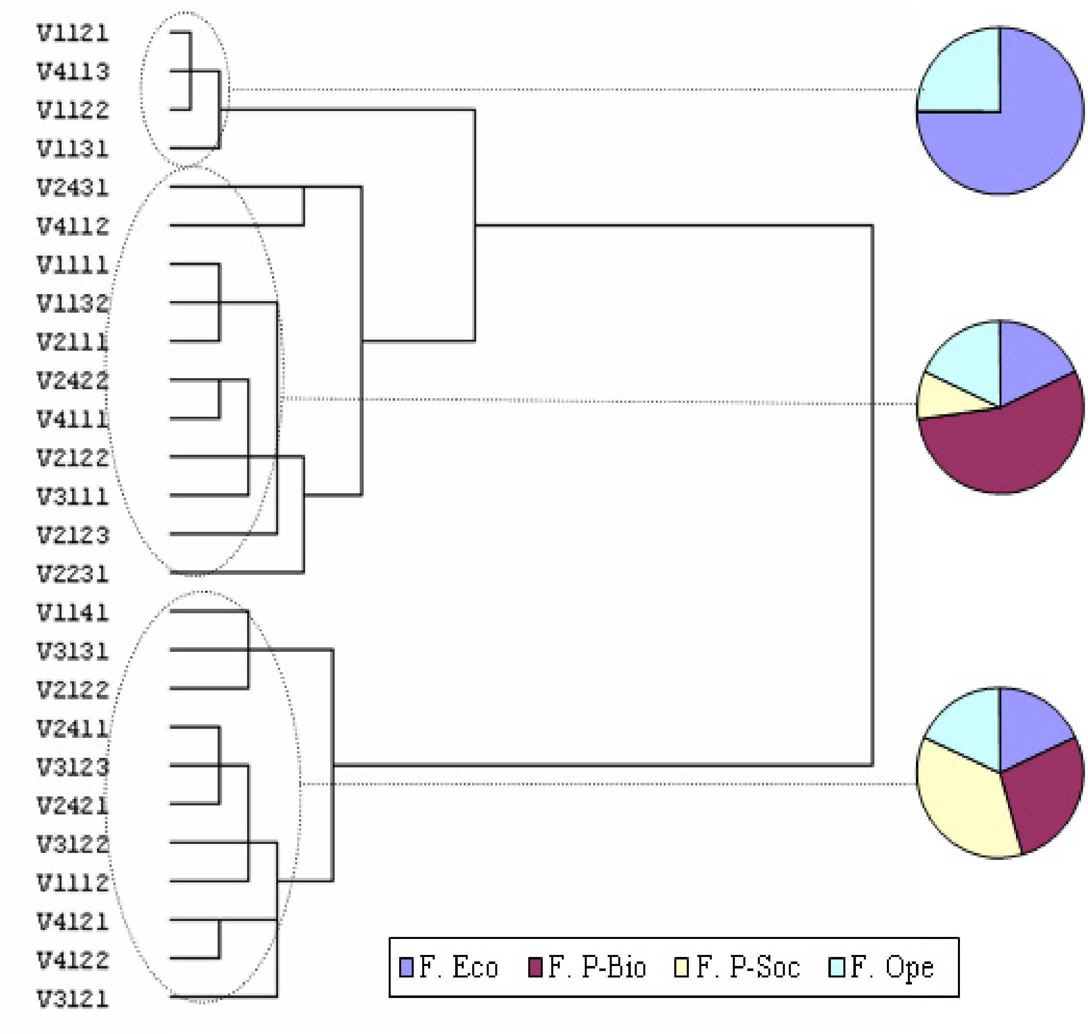


Figure 7.13 Matching obtained verifier clusters and pre-defined functions (ecological, productive-biophysical, produtive-socioeconomic and operational)

7.2.3 Factor analysis

It is assumed that from the full array of evaluated components, a reduced number of them exert stronger influence on the system performance (see section 6.2.1). Through factor analysis these components can be detected and grouped.

The Principal Component Analysis (PCA) extraction method was applied, and the number of factors was limited to four (with eigenvalues higher than one); the rotation method used was varimax with Kaiser Normalization.

Correlation and reliability of the data

The Kaiser-Meyer-Olkin measure of sampling adequacy tests whether the partial correlations among components are reliable. Values between 0.5-0.7 are considered acceptable for experiments that involve social factors. In the present analysis the value is 0.648.

The Bartlett test of sphericity evaluates whether the matrix is an identity matrix, in which case a full correlation (100%) is expected. In our case it is significant at 95%, which rejects such a possibility (Table 7.37).

Table 7.37 Kaiser-Meyer-Olkin and Bartlett tests

KMO Measure of sampling adequacy.		.648
Bartlett's test of sphericity	Approx. chi-square	88.949
	df	45
	Sig.	.000

Sig. P<0.05

Commonalities, variance per variable (verifiers)

The factor analysis attempts to reduce the number of components without losing representativeness, and the results show the degree of the common variance retained by each of the components after their extraction (Table 7.38).

Table 7.38 Communalities of factors after extraction

Code	Verifier	Initial	Extraction
V1121	Biodiversity indicator in woody species	1.000	.551
V1122	Biodiversity indicator in non woody sp.	1.000	.674
V1131	Biomass of woody species	1.000	.675
V2231	Monocultures vs. polycultures	1.000	.500
V2111	Introduction exotic species	1.000	.588
V2422	Low impact techniques	1.000	.638
V2421	Farmers technical background	1.000	.688
V2431	Administration plan change	1.000	.668
V3121	System considered profitable	1.000	.649
V4122	By-products provider	1.000	.560

From the 32 verifiers originally proposed, only 10 remained, with a high proportion of retained variance after extraction. The lowest among them is 'biodiversity in woody species' with about 55% of the original variance, and the highest 'farmer's technical background' with almost 69%. Values above 50% may be considered indicators of a good representativeness, therefore the extracted components represent the variables well.

Total variance in the whole set

The full set data variance is analyzed in three stages, giving initial, extracted and rotated eigenvalues (Table 7.39).

Table 7.39 Total Variance Explained

Variable	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	Variance %	Cumulat %	Total	Variance %	Cumulat %	Total	Variance %	Cumulat %
1	2.412	24.117	24.117	2.412	24.117	24.117	1.711	17.111	17.111
2	1.591	15.907	40.024	1.591	15.907	40.024	1.568	15.682	32.794
3	1.194	11.937	51.961	1.194	11.937	51.961	1.557	15.568	48.362
4	.993	9.934	61.894	.993	9.934	61.894	1.353	13.532	61.894
5	.878	8.784	70.679						
6	.699	6.988	77.666						
7	.659	6.594	84.261						
8	.595	5.947	90.208						
9	.580	5.797	96.005						
10	.400	3.995	100.000						

The first three variables with eigenvalues higher than 1 (minimum) constitute 48% of the sample variation. When the fourth one is included, cumulative variance reaches almost 62%. This means that four factors can explain almost 62% of the variability of the original 10 variables, with a loss of only 38% of the information.

Figure 7.14 depicts the number of factors to be extracted by intersecting the component number with the eigenvalues higher than one: the concavity of the curve makes it difficult to decide whether to select three or four variables.

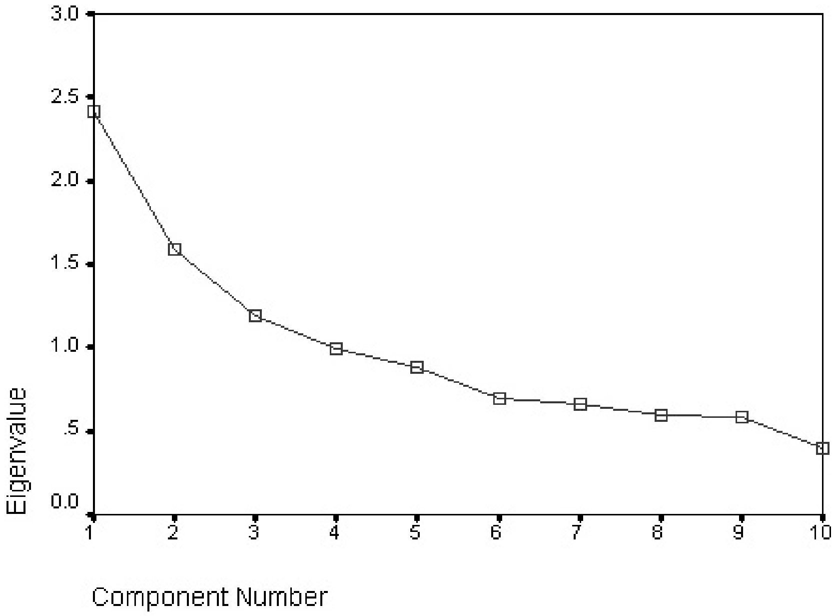


Figure 7.14 Scree plot crosscutting the number of defined factors vs. their respective eigenvalues

Rotated factors

The final step of the factor analysis is the identification of groups of variables and their interpretation in coherence with their eigenvalues and intrinsic linkages. Four factors can be distinguished, each constituting a number of mutually interrelated variables (verifiers).

Table 7.40 Rotated component matrix

Code	Variable	Component			
		1	2	3	4
V2422	Low impact techniques	.653			
V1121	Biodiversity indicator in woody sp.	-.635			
V2431	Administration plan change	.633			
V2111	Introduction exotic species	.574			
V1131	Biomass of woody species		.815		
V2231	Monocultures vs. polycultures		.614		
V4122	By-products provider			-.729	
V2421	Farmers technical background			.722	
V3121	System considered profitable				-.724
V1122	Biodiversity indicator in non woody sp				.674

Factors interpretation

Each of the four detected factors is interpreted according to the characteristics of the component verifiers (see section 7.1.5) and their attributes as a whole:

Factor 1 The productive domain: 'Farmers' technical decisions are conservationist-oriented and feedback is based on environmental, social and political changes' is emphasized.

- V2422 'Farmers use low-impact techniques to maintain yields and the resources stock'. Farmers have developed an expertise that allows them to carry out their production activities under ecological paradigms that prioritize the sustainability of production processes.
- V2431 'Technical management plan changed in the last 5 years to adapt to environmental-political-social changes'. Farmers consider their situation and react to it (resilience, adaptation), which allows them to keep their systems working.
- V2111 'Farmers are attentive to the introduction of exotic species'. This refers to the knowledge of the farmer about the risks of introducing new species into a controlled frame, and the possible consequences, i.e., dissemination of pests, diseases, invasive species, and genetic pollution.
- V1131 'Richness and equity of woody species'. Trees, palms and shrubs are indispensable components of agroforestry systems, and their high diversity implies a more intense components interaction and therefore a greater ecological stability of the system.

Production activities are carried out within a conservationist framework. Functional biodiversity maintenance and enhancement are positively affected by the selection of technical activities. Gray capital is essential; the knowledge for discriminating technologies, techniques and practices counts; moreover, these decisions have to feedback constantly; farmers, in order to optimize their results have to observe the political, environmental and social surroundings, perceiving changes in them and adjusting their action in order to maintain the standards that have gotten. Individual, collective, and institutional memories are the basis for it.

The key issues related to Factor 1 were summarized, and recommendations given concerning what the farmer should understand and do in order to optimize its performance (Table 7.41).

Table 7.41 Key issues factor 1

Key topic	Biophysical productive
Key words	'know how' and 'feedback'
Indicator	Indices of richness and equity of woody species
Conceptual suggestion	To know more about ecological cycles and conservationist procedures To be attentive to the changes in circumstances and react to them, do not be static
Technical recommendation	To build capacities on technical issues

Factor 2 The ecological domain: 'Agroforestry systems biomass and biodiversity increase, in particular of woody species' is emphasized.

- V1131 'Biomass of woody species'. Maintaining their capacity as producers of biomass is a direct indicator of the efficiency of the biological processes in any ecological system.
- V2231 'Proportion of monocultures (annuals) vs. policultures (perennials)'. A larger number of functional groups mean a more intense interaction and therefore higher ecological stability, i.e., the selection and specific arrangement of components aims at inciting interactions for the subsequent increase in outputs (production).

There is extensive documentation that shows the following relationships: first, the more biomass, the more interactions, and second the larger diversity, the more interactions. And therefore, the more interactions within a system, the more efficient it is. Functional biodiversity aims to make the system more efficient, addressing its production and conservation roles.

The Factor 2 narrows the attention to concrete ecological (non-productive) matters, such as taking care of the ecological index, generating more biomass and promoting interactions within a system to obtain more outputs.

The key issues related to Factor 2 were summarized, and recommendations given concerning what the farmer should understand and do in order to optimize its performance (Table 7.42).

Table 7.42 Key issues factor 2

Key topic	Ecological
Key words	'how much biomass', 'how many woody species'
Indicator	Amount of biomass, number of woody sp (per plot)
Conceptual recommendation	Increase the biomass in the plot. Interactions will increase, production will increase and biodiversity will increase.
Technical recommendation	General: Enrich, diversify plot composition. Specific: Allow and enhance woody species presence; increase the component that lacks: woody and non-woody.

Factor 3 The productive domain: 'Farmers care about their technical capacities; improving and promoting useful species diversity' is emphasized.

- V4122 'Number of by-product-provider species'. The presence in agroforestry plots of non-targeted species, which will outcome products with none, limited or periodical commercial value, indicates the farmer's priority with regard to satisfying supplementary household demands.
- V2421 'Farmers have enough technical background about the system design and management'. Farmers' try to improve their technical capacity to produce more and to produce well, based on conventional agricultural standards.

The farmer's technical talents are focused, on the one hand, on technical knowledge without any particular topic of interest, and on the other hand, addressed to a specific decision, e.g., the diversification of the plot with useful species. Unlike Factor 2, where the ecological value was highlighted, in this case the attention centers on productive diversity, which involves the farmers' technical ability to include species providing by-products at the same time strengthening the system's ecological stability.

The key issues related to Factor 3 were summarized, and recommendations given concerning what the farmer should understand and do in order to optimize its performance (Table 7.43).

Table 7.43 Key issues factor 3

Key topic	Biophysical productive
Key words	'how much the farmer knows', 'how deep is the farmer's knowledge'
Indicator	General: the day-by-day technical decisions Specific: how many non-marketed species exist (per plot)
Conceptual suggestion	Learn more, know more, study more, train more
Technical suggestion	General: apply what has the farmer learnt Specific: include in the plot local species of various uses

Factor 4: The operational domain: 'Farmers pursue the profitability of the system and encourage the low-strata species diversity' is emphasized.

- V3121 'The system is considered economically feasible'. Profitability assurance refers to another level of sustainability, where the farmers have a financial incentive through getting closer to market mechanisms. Households that are profitable and involved in a market scheme are ready to become environmental services providers.
- V1122 'Richness and equity in non-woody species'. Non-woody species even when not the main crop species are still important components in ecological processes. Despite this, farmers frequently try to eliminate them as they regard them as weeds.

Once any agricultural process ends, post-harvest activities begin. In order to optimize the revenues, the activities, such as conservation, transformation, storage, packaging, marketing, and distribution, require particular management skills and certain levels of organization. A cumulative indicator of whether these actions are carried out properly is the profitability of the system.

The key issues related to Factor 4 were summarized, and recommendations given concerning what the farmer should understand and do in order to optimize its performance (Table 7.44).

Table 7.44 Key issues factor 4

Key topic	Socioeconomic productive
Key words	'how much he knows', 'how well he knows' (of post-production)
Indicator	General: post-harvest technical decisions (many) Specific: earning standards
Conceptual suggestion	Learn more, know more, study more, build more capacities
Technical suggestion	General: apply what has been learnt Specific: organize better, add value to the product

8 GENERAL DISCUSSION
Conceptual and operational accomplishments and prospective research

The general discussion is organized in three sections. First, at the operative level, the most relevant issues of the proposed protocol for functional biodiversity evaluation are examined. Second, at the conceptual level, the findings that support the hypotheses in relation to the functional biodiversity approach are detailed. Third, some recommendations for further research are given.

8.1 Operational issues: protocol of functional biodiversity evaluation

Building a data administration tool based on functionality principles and with the aim of understanding and optimizing system performance, demanded a series of intermediate steps and inherent tradeoffs. The most relevant of these are summarized and discussed below.

8.1.1 Definition of boundaries

Along the development of this research, it became clear that the conceptual definition of principles, that should be wide enough to cover most influential issues and restricted enough to be precise (Prabhu 1999, Mendoza et al. 1999, Prasad 2002). Thus, ecological, productive (subdivided into biophysical and socioeconomic) and operational groups of analysis were defined, based on their importance for the agroforestry paradigm: prioritization of a production style which focuses on productive diversity, environmental sustainability, economic profitability, social equity, and cultural diversity (Callo-Concha 2003).

The definition of these groups of analysis was contrasted with the scale of application of the protocol, seeking for an optimal fitting between the groups and their spatial and temporal frame of application (Stork et al. 1997). In the case of production-related functions, the indicators were mainly obtained at plot level, while ecological-related functions were collected at regional level and operational-related functions at landscape level. This stratification allowed both, a more versatile target-oriented data collection, and later on, when the main influential factors were identified, a more accurate determination of action pathways to influence functional biodiversity.

Nonetheless, the intrinsic overlapping of processes was kept in mind along the development of criteria, indicators and verifiers.

As a byproduct of this boundary definition, a conceptual model was obtained, which framed the study within eight key criteria: (1) maintenance and enhancement of natural processes, (2) application of sustainable plot management techniques, (3) maintenance of the plot input-output stability, (4) minimization of the impact on neighboring systems, (5) sustainable production and use of generated byproducts, (6) adaptation of plot management decisions to higher-scale demands, (7) farmer rationality and his/her decision making about production, and (8) existence of a mind-map about the land-use system management and post-harvest use of agricultural products.

8.1.2 Establishing hierarchies and participative methods

A core matter in multicriteria analysis (MCA) is the construction of a set of C&I (criteria and indicators) to characterize the studied systems. Although their number is indeterminate, it is assumed that the more components dealt with, the better explained a referred issue (Dogson et al. n/d). Concerning their focus, in this study there is an evident bias towards biophysical productive issues, which fits with the aim of the research: to portray the indicators that better represent the land-use system qualities regarding biodiversity encouragement and conservation, and at the same time generating profit through productive practices.

In the vertical arrangement of the C&I tree, top-down and bottom-up approaches have been combined, and in their fine tuning, participative methods, such as workshops with stakeholders at various levels were stressed (Mendoza & Macoun 2002) (Appendix 3).

All these steps were framed within a scheme that allows a continuous feedback on the components argumentation, formulation, and corresponding gathering methods (CIFOR 1999, Stork et al. 1997), which is essential when seeking for extrapolation possibilities for the proposed protocol.

8.1.3 Sustainable management index

An indicator of the system performance is the sustainable management index (SMI), which compiles all subordinate weighted components of the protocol into a single comparable value (Purnomo et al. 2000). As the SMI can be obtained at the highest level (the overall system performance), it can be also disaggregated to represent partial weights of specific issue or group of issues, e.g., operational, impact on neighboring systems, etc.

The advantage of SMI is that makes possible to compare different management options at various levels, from the most detailed, e.g., organic matter content or living fences contribution to system performance, to the overall system functioning wit respect to environmental services. Then is possible to rate systems, regions, technological practices and every quality attributable to any system, and compare the results.

In this study, SMI is used for comparison of the land-use management profiles (Section 8.2.2).

8.1.4 Protocol feasibility concerns

Across this research, a series of issues concerning the feasibility of the protocol arose, such as whether the C&I set includes all key indicators or not, and therefore the obtained results might not be representative. We assume that the selected indicators are not the only ones; neither is there a right set of indicators, nor is there a set large enough to represent precisely functional biodiversity in agroforestry systems. The indicators are selected according to their relevance, reliability, representativeness, inclusiveness, specificity and collection feasibility (Prasad 2002), and to whether they fit with the circumstances where the set is applied (Kneshaw et al. 2002).

Another issue is whether extrapolation of this research might contrast with the limited spatial conditions where it has been developed, and whether this could lead to bias. The municipality of Tomé-Açú with its characteristic agroforestry model is recognized as an exceptional case in Amazonia (Jordan 1987, Anderson 1990), and was chosen as a study site based on the high number of spatial and temporal arrangements, which are indispensable conditions for calibration purposes. In addition, plots with different degrees of technological assimilation were sampled (newcomers, immigrated and CAMTA partners), and agroforestry systems in an early stage of development, representative of conventional Amazonian farms.

The adaptability of the proposed protocol was observed, while most of its phases, i.e., indicator definition and structuring, hierarchy establishing, and data processing and integration, are flexible enough to be adapted and refined to fit the demands of any tropical land-use system.

It might also be questioned that the approach is very input-demanding, since it requires a large amount and different types of data from several sources, different collection methods and extended time schedules. It is known that data standardization is one of the strengths of MCA (Dogson et al. n/d, Mendoza & Macoun 2002), and we have shown how MCA outputs are easily accepted by multivariate analysis (MVA) therefore, the constraint reduces to logistic rather than methodological terms. However, these arguments have to be contrasted with the beneficial trade-off of the approach, and it is better to invest in a detailed approach and obtain wide-based and supportive data, than to simplify and thus obtain a simplified view of the studied issue.

8.1.5 Data gathering constraints and software applied

The protocol application depends strongly on the participation of stakeholders at different levels via questionnaires, interviews and workshops. Here some logistical constraints were detected, such as the stakeholders' slow understanding of the multicriteria approach, which can lead to delayed or erroneous feedback. This was experienced in face-to-face cases, e.g., questionnaires and interviews, and was solved through the formulation of neutral and topic-oriented questions (Appendix 2), and during the workshops, by applying step-by-step subroutines (Appendix 3). Thus, participants received orientation for developing the most representative indicators. Especially during workshop development, a monitoring by specialists is highly recommended.

Another perceived issue was that stakeholders might loose sight of the driving concepts, such as 'functional biodiversity enhancement' or 'environmental services provision', and substitute them by their own personal/professional/academic interests. In this case, the previous definition of the research framework and a continuous monitoring along the stakeholders' participation are advisable.

Finally, since the protocol demands wide and diverse categories of data, different collection methods were used that keeping in mind the limited logistical capacities of developing countries, might limit its applicability. For that reason, procedures for data collection and management, i.e., laboratory methods, equipment and software were simplified as much as possible.

Concerning the software used, the CIMAT (Criteria and Indicators Modification and Adaptation Tool) was used as the main MCA data manager, since our approach (functional biodiversity) shares some principles with the sustainable forest management approach, such as conservation, use and sustainable management (Loyn & McAlpine 2001, Kneshaw et al. 2002) for which CIMAT was designed. Therefore, few modifications were necessary. Nevertheless, the creation of a specific C&I template for CIMAT might be useful, or even better, the modification of CIMAT itself to cover agroforestry systems and functional biodiversity demands. Concerning MVA, the conventional statistical software packages can be applied.

8.2 Conceptual issues: functional biodiversity accomplishments

The theoretical contribution of this research is based on the concept of functional biodiversity, its better aptitudes for enhancing the sustainability of land-use systems, and the considerations to take into account in its evaluation. These issues were addressed through the elucidation of the proposed hypotheses, which are discussed on the basis of the obtained results.

8.2.1 General hypothesis

The general hypothesis states that: '*Agroforestry systems maintain functional biodiversity at levels sufficient to keep the production sustainable and the environmental processes stable'*.

Factor analysis results affirm that the productive issues: '*strong technical qualification, preference of conservationist choices, adaptation to environmental, social and political changes, and enhancement of useful species'* are the most important characteristics that a land-use manager has to have in mind when optimizing farm performance in terms of functional biodiversity provision.

However, an adequate technical background, preference for environmentally-friendly practices and awareness of changes in the surroundings are not qualities attributable to agroforestry practitioners only, but to any farmer with an updated training and access to contemporary sustainable production concepts (Altieri & Nicholls 2004), with the exception of the 'preference for useful species', which demands specific knowledge and training in agroforestry topics and understanding of the local circumstances (Nair 1997, Huxley 1999).

Nonetheless, some of the issues to be attended, e.g., pest management or changes in commercialization channels, can only be addressed through a broader insight of the problem and a widening of the scope of its management. This adds a crucial factor to be taken into account, i.e., the organization and centralized planning that is decisive for the success of agroforestry, as a productive and environmentally friendly alternative (section 8.2.2).

The ecological issues detailed as '*the system's capacity for accumulating biomass and hosting a high diversity of components, in particular woody species'* were determined as being the most significant ecological characteristics that reflect functional biodiversity strength in agroforestry systems.

By definition, agroforestry plots include more than one species and at least one woody species (Nair 1985, Young 1989); woody species, by nature, store more biomass than herbaceous ones. In addition the agroforestry systems (AFS) management stress on their dynamism and at the same time pays attention to multiple objectives (Krishnamurthy & Avila 1999, ICRAF 2000). These two issues are considered the most relevant qualities of AFS with respect to biodiversity conservation (Sánchez 1995, Dobson et al. 1997, Leakey 1999, Bates 1999).

In this study, although a positive correlation between ecological indicators exists, the statistical tests indicate that operational issues are the most influential. This supports our approach, which advocates a most integrative treatment as possible of all involved factors, instead of focusing on only a few. Ecological factors are nevertheless important, and greater diversity of components and higher biomass storing capacity are still basic conditions for biodiversity conservation. However within the functional biodiversity approach proposed, the attention on factors has to be diversified and a series of other domains incorporated.

The operational issue stresses that '*(...) pursuing the system's financial profitability'* is a characteristic that any land-use manager must posses to optimize the system's overall performance regarding enhancement of functional biodiversity.

Economic profitability has proved to be a condition for the sustainability of any change induced in land-use systems (Leakey 1999), and is therefore pursued as a primary aim of most technological proposals, including the agroforestry one (ICRAF 2000).

As in the case of productive issues, factor analysis affirmed that the scope of influence surpasses the individual decision frame, demanding a wider and organized insight and attending to linking procedures, such as post-harvest management, organization for commercialization or the search for market niches. Here again the organization and central planning emerge as the key aspects for optimizing agroforestry system performance as functional biodiversity providers.

Summarizing, it is not possible to affirm whether agroforestry-related practices keep functional biodiversity on levels adequate for keeping production processes stable and ecological processes sustainable, but it is accurate to say that some agroforestry system characteristics, such as biomass storing capacity and species diversity, are very important. However, these must be supported by a strong and updated technical qualification of the system manager, and a market-oriented focus.

8.2.2 Specific hypothesis 1

The specific hypothesis 1 states that: *'The degree of functional biodiversity in agroforestry systems depends on the level of technical management'.*

The factor analysis results point out technical qualification as a decisive factor for maintaining higher levels of functional biodiversity in agroforestry systems. Complementarily, the ANOVA of SMI allows linking this issue with the most relevant characteristics of the three evaluated farmer groups; it was found that 'CAMTA partners' were statistically superior to 'immigrated' and 'newcomers' only concerning cumulative and operational SMI's, and equivalent to 'immigrated' about productive biophysical functions.

The importance of operative and productive biophysical issues in system performance was revealed, and the better functioning of 'CAMTA partners' identified. This indicates the influence of the CAMTA in strengthening the capacities of agroforestry systems as functional biodiversity providers.

The mandates of the CAMTA involve productive and operational matters, through gradual building-up of the technical capacities of the farmers and strengthening of their self-organization. CAMTA activities focus principally on sustainable production via promotion of conservational and eco-friendly cultivation methods, postproduction intensification through adding value to raw products, and improvement of market orientation by channeling the production process towards higher commercial standards and by searching for new market niches.

The results of this study can serve as guidelines for land-use systems' management optimization for functional biodiversity enhancement and environmental services provision. This is currently the case of the Tomé-Açú agroforestry model, where its advantages have been perceived, and are progressively spreading from the Tomé-Açú municipality to neighboring regions, with a variable degree of assimilation depending on the physical proximity and time of permanence of the settlers (Jordan 1987, Anderson 1990, Yamada 1999, Yamada & Holz 2002).

Summarizing, the results demonstrate that better system performance concerning functional biodiversity enhancement and conservation are linked with good technical qualification of the farmers, and can be optimized when complemented by administrative talents within an efficient organizational framework.

8.2.3 Specific hypothesis 2

The specific hypothesis 2 states that: '*A model derived from the criteria and indicators approach should provide a better understanding of agroforestry systems efficiency to maintain functional biodiversity*'.

Prerequisites for a model are first, that it must be able to represent the state-of-the-art of a given case study, and second, that it must be able to simulate and eventually predict the progress of the targeted study issue in time.

MCA through a vertical and horizontal integration of components at various levels, via procedures, such as weighting, ranking and linking, provides a comprehensive view and facilitates the understanding of agroforestry systems in supporting and intensifying functional biodiversity. This should fulfill the first conceptual demand of a model: to replicate what is happening in reality.

The statistical analysis of SMI allowed defining the hotspots where the characterized groups (CAMTA partners, immigrated and newcomers) differ. In a second phase, MVA through principal component analysis narrows the participant components into a reduced number of factors, well characterized and in consequence, susceptible to influence. With this second step, an operational value is attached to the model, detecting the most sensitive factors of an agroforestry system with regard to enhancement and maintenance of functional biodiversity.

Nonetheless, this model is not iterative. Though it is able to depict a targeted land-use system from multiple perspectives, establish connections among components, and extract the most cost-effective ones on which to exert influence, it does not show how components interact with each other, or predict the consequences of modifying a component. This limitation and some others concerning the protocol itself need to be attended to, thus, the following section provides some recommendations about.

8.3 Prospective issues and further research

Besides the conceptual contribution to functional biodiversity, this research is driven by a pragmatic *leitmotif*: the development of a protocol for evaluation of functional biodiversity in tropical agroforestry systems, and eventually its extension to a protocol for evaluation of environmental services in tropical land-use systems.

The intrinsic flexibility of the protocol, an evaluation framework rather than a fixed set of rules, which can be modified at almost every stage of analysis through fine tuning and eventually widening components definition and related collection methods, should permit coping with main environmental services, i.e., carbon stocks, watershed functions and landscape beauty assessments with characteristics different to the ones that affect biodiversity.

Bearing this in mind and assuming that the obtained results are reliable as an initial platform, it is recommended:

- To convert some of the evaluated plots into permanent ones, where measurements are taken periodically and continuously. This would provide a behavior trend of the selected indicators, confirming the accuracy and stability of the C&I set and suggesting changes for establishing a monitoring protocol.

- To test the protocol in distant but similar sites, considering conceptual matters such as indicator definition, calibration, consolidation and analysis, and logistical matters such as data collection and integration. The use of case studies would validate the indicators and procedures applied, and highlight the weak ones. The flexibility of the protocol to adapt to new circumstances will be also tested.
- To standardize the data management procedure, since the number and type of assessable indicators is variable. The inputting procedure is well defined by CIMAT, and it would be useful to establish standard guidelines for data handling.
- To build a C&I set template for CIMAT, modify CIMAT to operate with functional biodiversity or create a similar data administration tool. The C&I approach operates more efficiently within pre-established templates for specific purposes and ecological conditions, which assist the user in obtaining better and quicker depictions of the studied systems. This also would facilitate its diffusion. Additionally, such an administration tool would also set up the basis for its upgrading into a template for environmental services evaluation in land-use systems.
- Finally, although most relevant factors were considered, the interactive influences among components were not determined. In other words, we know which the most relevant factors are but we do not know how they interact. A complementary phase compatible with MCA and MVA outputs might answer this question. Two alternatives are foreseen: a model of sensitivity, e.g., the Sensitivitätsmodell Vester ®, or a bioeconomic model, e.g., SEAMLESS.

9 CONCLUSIONS AND OUTPUTS

9.1 Conclusions

9.1.1 General conclusion

The general objective was: '*To assess the factors that influence the processes that determine the capabilities of agroforestry systems to maintain functional biodiversity (case study: municipality of Tomé-Açú, Pará state, northern Brazil), underlining the management as a key factor to improve the systems towards making them more productive and sustainable'*.

The results of this study show that the most influential factors are ecological, productive and operational issues.

The first factor stresses the system's species diversity (particularly woody species) and capacity for accumulating biomass as the main characteristics for conserving and enhancing functional biodiversity. Therefore, farmers should be aware of the status of these components and decide proactively to promote them on their farms.

The second factor affirms that a farmer's technical and management capacities determine his/her ability to conserve and encourage functional biodiversity. It means that the farmer should have a strong technical background, show preference for low impact techniques, have an administration plan, aim at diversifying species composition, prevent the introduction of exotic species, and be attentive to the monoculture-polyculture balance in the plot.

The third factor emphasizes the role of the farmer's internal organization and the capacity to bond with external institutions. Thus, a successful farmer should care about environmental-socio-political adaptation, and pay attention to market-related matters such as postharvest, marketing, and information feedback.

9.1.2 Conclusion specific objective 1

The specific objective 1 stated: *'To develop a protocol for evaluating functional biodiversity in agroforestry systems …'*.

Based on Multicriteria Analysis (MCA), a protocol for the evaluation of functional biodiversity was developed. This protocol involves a wide array of data of different types determined with the participation of a diverse group of stakeholders. This makes the protocol management highly demanding, but it is able to take various factors into consideration. The proposed protocol demands the definition of a Criteria and Indicator (C&I) set, which through a number of indicators, determines the performance of the agroforestry systems. The protocol can output numeric indices related to the performance of each system (sustainable management index) by types of issues, groups of farmers, and as a whole, such an index can be used for ranking, rating, comparing and monitoring land-use systems, and as a proxy for evaluating functional biodiversity.

9.1.3 Conclusion specific objective 2

The specific objective 2 stated: *'To define a management optimization model of agroforestry systems for enhancing and maintaining functional biodiversity …'*.

Through Multivariate Analysis (MVA) the most sensitive/important factors were detected, i.e., those with greater influence in optimizing agroforestry system performance related to functional biodiversity. Once these influential factors are identified, it is possible to group them, thus deriving general and pragmatic management recommendations for optimizing the performance of the whole system.

Nevertheless, neither MVA nor the designed protocol as a whole, allow us to depict the inner cybernetics of the system, which is an essential issue, because only by determining the flows and effects of factor interaction is it possible to set new action pathways and to predict the behavior of the systems by means of simulation, and thus to define an optimization model.

9.2 Expected outputs

9.2.1 Output 1: protocol of evaluation

The Output 1 is: '*A protocol to characterize, evaluate, analyze, rate, weigh and interpret functional biodiversity in agroforestry systems, able to extrapolate to similar conditions'*.

The proposed protocol for evaluation of functional biodiversity includes a series of complementary steps to operationalize MCA, permitting the administration of the database through a series of user-friendly routines.

The extrapolation feasibility of the protocol is quite high, since there are no restrictions for data collection or for their analysis. Each data gathering method can be applied, and data procedures were designed bearing in mind ease of use. The Criteria and Indicators Modification and Adaptation Tool (CIMAT) software permits creating, changing, routing and standardizing different types of inputs at all levels; feedback procedures (workshops and consultancy) can be carried out in any situation.

All mentioned procedures were tested and outputted satisfactory results. However, monitoring and validation (new trials) are recommended when the protocol is applied at new sites.

9.2.2 Output 2: criteria and indicators set

The Output 2 is: *'A Criteria and Indicators (C&I) set for functional biodiversity assessment in tropical agroforestry systems: clustered, hierarchized, and interrelated; developed ad hoc but eventually able to extrapolate to similar conditions with some arrangements'.*

A C&I set for evaluating functional biodiversity in tropical agroforestry systems was developed. The complete set of indicators consists of 3 functions (ecological, productive -biophysical and –socioeconomic, and operational) at the highest-conceptual level, 7 criteria, 18 indicators and 32 verifiers at the lowest farm-application level. Such a C&I set was a template for the studied region, therefore when extrapolation is considered, it must be modified.

9.2.3 Output 3: optimization model

The Output 3 is: *'A dynamic model of the systems' functioning, defining topics of action, support and prediction, and eventually performing as a political negotiation argument in an environmental services payment framework'.*

As stated above (section 9.1.3), the proposed protocol lacks complete insight on the systems' internal dynamics, and therefore cannot respond to demands of simulation and prediction. Nevertheless, it has been considered to link it with a sensitivity or a bioeconomic model to satisfy such a demand.

On the other hand, we have obtained a static procedure that can highlight the issues with the strongest influence on functional biodiversity. The main advantage of the model is that it can support decision making, as it can detect higher-ranked and more rewarding indicators, thus enhancing indirectly system performance. When repeatedly applied, it could serve as a monitoring tool and consequently support negotiation schemes and rewards for environmental services payment whenever the program paradigms agree with the MCA premises, as in the case of the Brazilian program Proambiente.

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11 APPENDICES

Appendix 1: Field sheet

BIODIVERSIDADE FUNCIONAL NOS SISTEMAS AGROFLORESTAIS

(Folha para a coleção de dados de campo)

Nome do agricultor .... Código ....

Nome da propriedade .... Coordenadas ....

Declive .... Altitude .... Tamanho da propriedade ....(ha)

Tamanho do SAF ……........................(ha) Data ..../......../.........

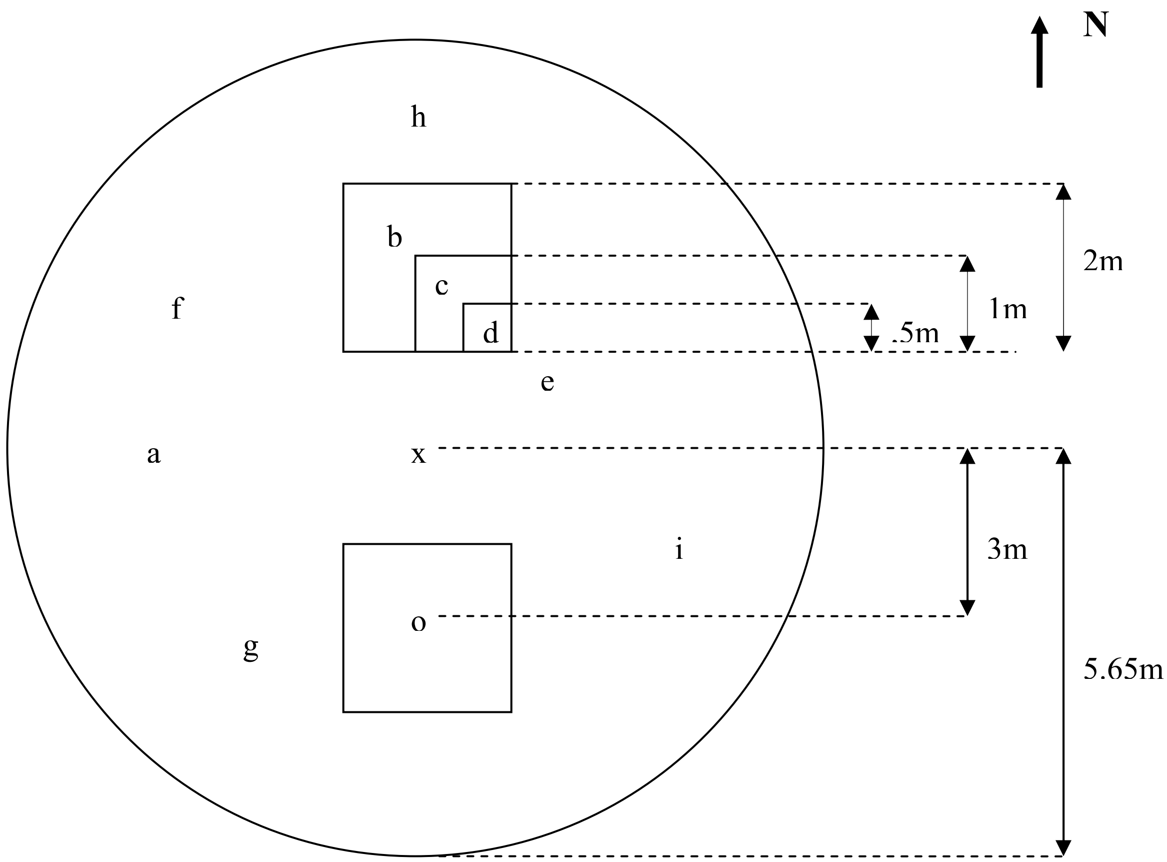
Comentários ....

...

...

I. Definição da parcela da amostra

1. Definição do ponto X (aleatoriamente), e geoposicionar.
2. Definição da parcela a estendendo uma corda de 5.65 m.
3. Definição dos pontos "o" (dois). Definição da direção N-S, três metros nas duas direções.
4. Definição das parcelas b 2 x 2m.
5. Definição das parcelas c 1x1.
6. Definição das parcelas d 0.5x0.5m.
7. Definição dos pontos e, f, g, h, i (aleatoriamente)



II. Amostragem

1. Parcela a. (árvores e árvores pequenas, palmas: > 2m de altura; > 2.5 cm DAP)

#	Nome comum	Variedade, raça, clone	Uso[1] (1,2,3,4)	Altura (palmas)	AP (cm)	Fase de crescimento[2] (1,2,3)

2. Parcela b. (arbustos, cultivos anuais ou bi-anuais <2m de altura; < 2.5 cm DAP)

#	Nome comum	Variedade, raça, clone.	Uso (1,2,3,4)	Fase de crescimento (1,2,3)

[1] 1. alimento, 2. medicinal, 3. combustível, 4. outro.
[2] 1. jovem, 2. intermediário, 3. adulto.

3. Parcela c. (Porcentagem de cobertura do solo)

%	Total
0	
-25	
5-50	
0-75	
5-100	

4. Parcela c. (ervas: não lenhosas; < 0.5m de altura)

Peso fresco total (g/m^2)	Peso fresco sub-amostra (g)

5. Parcela d. (serrapilheira)

Peso fresco total (g/0,25 m^2)	Peso fresco sub-amostra (g)

6. Pontos o-1, o-2. Densidade

Peso fresco total (g/vol)

7. Pontos e, f, g, h, i (materia organica, nitrogênio total e fósforo)

Peso fresco total (g/vol)
check

III. Esboço do sistema (horizontal em vertical): espaçamento, ordenamento, número de andares, etc.

Appendix 2: Questionnaire

BIODIVERSIDADE FUNCIONAL NOS SISTEMAS AGROFLORESTAIS

(Questionário)
Nome do agricultor .... Código ....
Nome da propriedade .... Tamanho da propriedade ....(ha)
Data ..../.........../.........

Perguntas de homogenização

1. Quanto tempo você mora aqui? .... (anos).

Se a resposta é por menos de cinco anos, agradeça o agricultor e termine o questionário.

2. Em todo esse tempo você trabalhou na agricultura?
   a) Sim
   b) Não
   c) Outra resposta ....
   ....

   Se a resposta insinua que nos últimos cinco anos o agricultor não investiu pelo menos a metade de seu tempo para administrar sua propriedade (por exemplo, foi empregado do tempo completo ou emigrou), agradeça o agricultor e termine o questionário.

3. Em todo esse tempo, quais culturas foram cultivadas? ....
   ....

   De acordo com a reposta anterior, olhe se nas respostas são incluídas espécies perenes. Se elas não são incluidas agradeça o agricultor e termine o questionário.

4. Você faz associações entre seus cultivos?
   a) Sim

   Quais?
   ....
   ....

   b) Não

   Se a resposta é por esta, agradeça o agricultor e termine o questionário.

5. Quanto importante são estas associações na sua propriedade? (*sistemas agroflorestais*)
   a) Muito importante
   b) Importante
   c) Mais ou menos importante
   d) Menos importante
   e) Não é importante

   Se a reposta é por d) ou e), agradeça o agricultor e termine o questionário.

BIODIVERSIDADE FUNCIONAL NOS SISTEMAS AGROFLORESTAIS
(Questionário)
Nome do agricultor .... Código ....
Nome da propriedade .... Tamanho da propriedade ....(ha)
Data ..../......../.........
Os produtores estão atentos aos riscos da introdução de espécies exóticas (2.1.1.1.)

6. Você conhece as plantas que estam na sua propriedade?
   a) Todas
   b) Muitas
   c) A metade
   d) Poucas
   e) Nehuma
7. Que você faz com as plantas que você não conhece, mas ficam na sua propriedade?
   a) Elimino
   b) Deixo-as
   c) Isolo-as
   d) Outra resposta ....
   ....
8. Você ha trazido alguma planta estrangeira?
   a) Muitas
   b) Algumas
   c) Poucas
   d) Nehuma
9. Você pensa foi bom trazer esas plantas?
   a) Bom
   b) Isso depende da planta
   c) Mais ou menos
   d) Mau
   e) Não sei

Presença de espécies provedoras de sub-produtos nos SAFs (2.1.2.2.)

10. Você mantém plantas para outros propósitos no seu SAF?
    a) Sim
    b) Não *(pule a pergunta 13)*
11. Quantas dessas plantas existem no seu SAF?
    a) 1
    b) 1-5
    c) 5-10
    d) 10-20
    e) > 20
12. Quais propósitos? -comida, forragem, medicinas,
    ....
    ....
    ....
    ....

Número e proporção de variedades das colheitas principais dentro do campo de cultivo. (SAF) (2.1.2.1.)

13. Quantos anos você cultiva esse(s) cultivo(s) (*Defina sobre as espécies predominantes no seu SAF*)

	Sp1	Sp2	Sp3
a) 1-2 anos			
b) 3-5 anos			
c) 6-15 anos			
d) 16-25 anos			
e) Sempre			

14. Quantas variedades dessa espécie ficam no seu SAF?

	Sp1	Sp2	Sp3
a) 1-2 variedades			
b) 3-5 variedades			
c) 6-10 variedades			
d) > 10 variedades			

Os índices de aproveitamento sustentável estão claramente definidos para cada subproduto específico. (2.4.1.1.)

Sobre as mesmas espécies mencionadas arriba.

15. Esse cultivo é muito importante, não é?

	Sp1	Sp2	Sp3
a) E essencial!			
b) Sim é importante			
c) E mais ou menos importante			
d) Menos importante			
e) Não é importante			

16. Comparado com anos anteriores, este ano a colheita foi...?

	Sp1	Sp2	Sp3
a) Melhor			
b) Pior			
c) Mesma			

A regeneração das espécies provedoras não diminui. (2.4.1.2.)

Sobre a(s) mesma(s) especie(s) da pregunta anterior

17. Você deixa essas plantas crescerem novamente? *(observe a atitude e razões)*

	Sp1	Sp2	Sp3
a) Sim, deixo			
b) Sim, planto			
c) Só as aguardo cresceram sozinhas			
d) Outra resposta			

18. Têm problemas de regeneração com essas plantas? Quais? *(propagação, crescimento, enfermidade, etc.)*
    a) Sim, quais? ....
    b) Não, nenhum *(pule a pergunta 19)*

Proporção entre monoculturas e policulturas no sistema (2.2.3.1.)

Proporção entre espécies anuais e perenes no sistema (2.2.3.2.)

19. Como é classificado o uso da terra na sua propriedade? *(Podem ser valores aproximados)*

Uso da terra	(ha)
Mata primária, floresta	
Capoeira em uso	
Capoeira em descanso	
Lavouras permanentes	
Pastagens	
...	
Total	

20. Das terras dedicadas a lavouras permanentes, quantas são dedicadas a mono-cultivos e quantas são dedicadas a poli-cultivos? E quais são essos:
21. Das terras de lavouras permanentes, quantas são dedicadas para policulturas com espécies perenes? **(SAF)**

Uso da terra		Nome do(s) cultivo(s)				(ha)
Monocultura						
Policultura	1					
	2					
	3					
	4					
	5					
	6					

São desenvolvidas práticas de conservação que tomam cuidado da erosão do solo (2.5.1.1.)

22. Tem algum problema de dano do solo na sua propriedade? *(a pergunta tem que ser feita para que seja entendida pelo produtor)*
    a) Sim
    b) Não, tudo está bem *(pule a pergunta 25)*
23. Faz alguma atividade para tentar resolver o problema?
    a) Sim, qual? ....
    ....
    b) Não, *(pule a pergunta 25)*
24. Quais são as atividades que você está desenvolvendo? *(considere práticas culturais, medidas técnicas, etc.)*

Atividades do controle	**Sim**	**Não**
a) Práticas culturais (cobertura com resíduos de colheita, rotações, etc.)		
b) Práticas lineais (cultivos do contorno, cercas vivas, poda, etc.)		
c) Práticas estruturais (muros de contenção, obras de engenharia, etc.)		
d) Outras		

Os agricultores têm conhecimento técnico suficiente sobre o desenho do sistema. (2.5.2.1.)

25. Da lista de atividades (tabela abaixo), quais você pratica no seu SAF?

(O entrevistador tem que tomar cuidado que o agricultor fale baseado sobre atividades fixas-que faz habitualmente-)

Atividades		**Realiza?**	
Grupo	**Detalhe**	**Sim**	**Não**
a) Semente	Coleta		
	Armazenamento		
	Prova da germinação		
b) Viveiro	Desenho		
	Rega		
	Proteção		
	Reposição		
c) Plantação	Desenho (espaços)		
	Rega		
	Proteção		
	Reposição		
d) Manejo	Capina		
	Rega		
	Proteção		
	Adubação		
	Controle sanitário		
	Desbaste		
	Poda		

Os agricultores aplicam técnicas, tratamentos e métodos de baixo-impacto, para manter os recursos e rendimentos. (2.5.2.2.) viveiro

26. Das atividades listadas (tabela abaixo), quais são feitas de modo que promoven a sustentabilidade e o mantimento da produção e produtividade do SAF?

(O entrevistador tem que tomar cuidado sobre a relatividade das repostas dos agricultores; as que dependem das caracteristicas do sistema. Critique tecnicamente)

Atividades		
	☺	☹
Capina (P.ex. manual vs. herbicida?)		
Proteção (P.ex.. arame vs. cerca viva)		
Adubação (P.ex.. químico vs. orgânico)		
Controle sanitário (P.ex.. dose adequada vs. abuso)		
Desbaste		
Poda		
Rega		

O plano de administração mudou nos últimos 3 anos para se adaptar as variações ambientais. (2.5.3.1.)

27. Você mudou sua administração (manejo técnico, financeiro, político, etc.) por assuntos naturais nos últimos 5 anos?

a) Sim
b) Não
c) Um poquinho, sempre estamos mudando
d) Outra resposta...

Por quê? ....

....

....

Parte da renda investida na compra de comida. (3.1.1.1.)

28. Usa algumas das suas colheitas para seu próprio consumo?

a) Sim
b) Não

29. Mais algumas outras tem que comprar?

a) Sim
b) Não

Quais são essas?...

....

....

(Tente fazer uma lista curta; nao é importante o conteúdo, importa a familiaridade –a frequência, importância,etc. na compra)

30. E o dinheiro para aquelas compras vem da produção?
a) Sim
b) Não
31. Aquele dinheiro foi bastante no ano passado?
a) Sim
b) Não

O sistema é considerado economicamente viável (3.1.2.1.)
32. Como foi a produção do seu SAF este ano?
a) Boa
b) Mais ou menos
c) Má
d) Outra resposta ....
33. Você pensa que seu SAF é bom negócio?
a) Sim
b) Não
Por quê? ....
....

O grau de acesso ao mercado pelos produtores (3.1.2.2.)
34. Leva sua produção para o Mercado?
a) Sim
b) Não, só para consumo familiar *(pule a pergunta 42)*
35. Com que freqüência?
a) 1 a 3 vezes por ano
b) 4 a 6 vezes por ano
c) 1 a 2 vezes por mês
d) Cada semana
e) Mais de uma vez por semana
36. Qual é a forma de conexão com o mercado você prefere?
a) Eu prefiro ir sozinho
b) Eu prefiro ir associado
c) Outra forma *(detalhe)*..
37. Existem atravessadores que compram diretamente na sua propriedade?
a) Sim
b) Não
38. Essta é uma opção melhor para você?
a) Sim
b) Não
39. Por quê? *(Preste atenção ao interesse nas oportunidades dele para participar do Mercado)*..
....

A diversidade de produtos que os agricultures trazem ao mercado normalmente. (3.1.2.3.)

40. Quais produtos você traz para o Mercado normalmente, - pelo menos uma vez por ano?- *(Tente fazer uma lista que considera a orden de importancia)*

1. ....
2. ....
3. .... ☺
4. ....
5. ....
6. .... ☺ ☺
7. ....
8. ....
9. .... ☺ ☺ ☺

41. Gostaria aumentar o numero e a diversidade dos produtos que traze para o mercado?

a) Sim
b) Não
Por quê? ....
....

Há uma atitude de re-investimento no agricultor. (3.1.3.1.)

42. Você re-investe em sua propriedade o dinheiro ganhado pela mesma propriedade?

a) Sim
b) Não *(pule a pregunta 45)*

43. Considera importante re-investir na sua propriedade?

a) Sim
b) Não
Por quê? ....
....

44. Sempre fez essto?

a) Sim
b) Não
Por quê?...
....

Os regulamentos normalmente são obedecidos pelos agricultores. (4.1.1.3.)

(Pergunte sobre 1. A medida provisória 2166: averbação da mata só pode usar 20% y tem que deixar 80% como reserva)

45. Sobre aquela regra (ou jogo da regras) que você acha?

a) É boa
b) É má
Por quê? ....
....

46. Você pensa que estas regras são importantes?

a) Sim
b) Não
Por quê? ....
....

47. Você as aplica?
a) Sim
b) Não *(termine a entrevista e agradeca o agricultor)*
48. Pensa que seria necessário ter mais desstas regras?
a) Sim
b) Não
c) Outra resposta...

Há um impacto real das sugestões dadas pelas instituições aos agricultores. (4.1.3.2.)
(Sobre a mesma regra discutida anteriormente)
49. Os benefícios da regra são principalmente para:
(Pode marcar mais da uma opção)
a) A pessoa (o agricultor)
b) A comunidade
c) A região
d) O estado
e) O país
f) Outra resposta...
50. Tem contato com as instituições que apoiam estas regras
a) Sim
b) Não *(termine a entrevista)*
51. Pensa que a situação tem melhorado desde que as regras foram projetadas e aplicadas
a) Sim
b) Não *(termine a entrevista)*
Por quê? ....
....
52. E feliz? ....

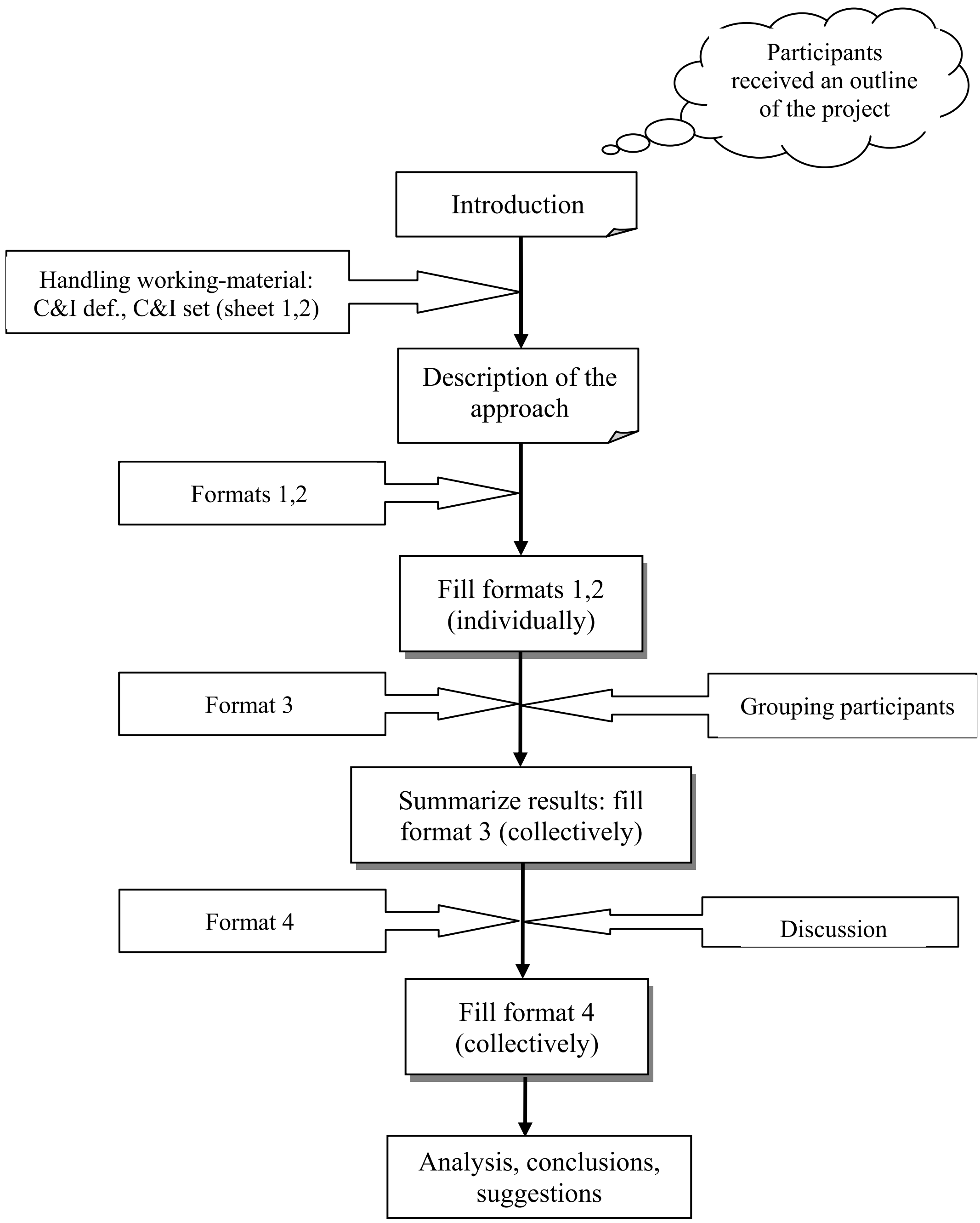
Muito obrigado pela sua colaboração!

Appendix 3: Workshops guidelines

Definition and validation of indicators

A core element of this approach is the definition and refinement of the criteria and indicators set; one of the supporting procedures based on the participation of local experts on their detection, filtering and weighting.

Below the diagram shows the steps and linked activities to them; complementary the formats cited in the diagram are attached.



Definição de Critérios e Indicadores

Princípios: "Uma suposição básica que apoia um raciocínio ou uma ação". No contexto de ASF é visto como o vigamento administrando primário.

Critério: "Um aspecto que é considerado importante pelo qual administração de floresta sustentável pode ser avaliada". Os critérios dá os “standards” pelos quais a evolución para atingir os princípios pode ser julgado.

Indicador: "Um atributo quantitativo, qualitativo ou descritivo que periodicamente medido indica a direção da mudança"; indica o estado ou condição requereda pelo critério.

Verificadores: "São os dados ou informações precisadas para avaliar um indicador".

(Mendoza et al., 1999; ITTO, 1998 e Ritchie al de et., 2000 cit. por Prasad, 2002; Prasad, 2002).

Jogo de indicadores

Criteria	Indicator	Verificador
1. Funções ecológicas (FE)		
1.1. Os processos ecologicos que afetam (mantem, fortalecem ou restabelecem)a biodiversidade são encorajados e levados a cabo	1.1.1. A reciclagem de nutrients não mostra nehuma mudança significativa	1.1.1.1. Conteúdo da matéria orgânica no solo
		1.1.1.2. As proporções do N e P no solo são as esperadas
	1.1.2. A diversidade de especies e de ecossistemas é mantida	1.1.2.1. A riqueza e equitatividade de certos grupos funcionais de espécies (em comparação a floresta primaria) tem valores semelhantes.
		1.1.2.2. Estão representadas todas as fases de crescimento das espécies
	1.1.3. A acumulação do biomasa de sistema	1.1.3.1. Quantidade da biomassa nos diferentes estratos
	1.1.4. Danos no solo pela erosão	1.1.4.1. Extensão e proporção de diferentes graus de erosão do solo
2. Funções biofísicas de produção (FBP)		
2.1. O equilíbrio de entradas-saídas dos componentes é monitorado (na ideia do diminuir os antagonismos e encorajar as sinergias)	2.1.1. Há um "princípio de precaução para o controle e monitoreamento da introdução de espécies exóticas	2.1.1.1. Os produtores estão atentos aos riscos da introdução de espécies exóticas
	2.1.2. Há uma atitude do produtor que favorece a diversidade intra e inter específica do sistema	2.1.2.1. Número e proporção de variedades das colheitas principais dentro do campo de cultivo.
		2.1.2.2. Presença de espécies provedoras do sub-produtos nos SAFs (uso familiar, indígena, etno-botânicos, etc.)
2.2. O desenho dos sistemas e sua extrapolação ao nivel do paisagem promove as funções de conservação de biodiversidade	2.2.1. As mudanças na diversidade de hábitats como resultado de intervenções humanas são mantidas dentro de limites críticos para a prevenção de processos de fragmentação e conversão.	2.2.1.1. As bordas das propriedades estão definidos e os limites deles fixados
		2.2.1.2. Os limites espaciais e funcionais estão bem definidos ao nível sistema-local.
		2.2.1.3. A estrutura da paisagem é mantida no tempo
	2.2.2. Algumas variantes técnicas são implementadas e são mantidas para promover as funções de conservação de biodiversidade.	2.2.2.1. O número e proporção de ilhas biogeographicas (florestas, “patches”, faixas da amortiguação, corredores, etc.) ao nível de comunidade.
	2.2.3. Os arranjos espaciais e temporais dos grupos de componentes promovem as funções de conservação de biodiversidade.	2.2.3.1. Proporção entre monoculturas e policulturas no sistema
		2.2.3.2. Proporção entre espécies anuais e perenes no sistema
		2.2.3.3. Proporção de estratos de sp lenhosas no sistema.
2.3. Os impactos nos sistemas vizinhos são minimizados para manter a funcionalidade do ecossistema de nivel superior	2.3.1. Há uma proteção especial dos sistemas mais sensiveis, raros ou menos abundantes (planícies, bancos de fluxo, declives íngremes, lagoas, floresta primária, etc)	2.3.1.1. Proporção dos sistemas sensíveis manejados corretamente para preservar a funcionalidade deles.
		2.3.1.2. Proporção de margens desenvolvidos para executar funções ambientais
2.4. O aproveitamenteo de subprodutos	2.4.1. As práticas que envolvem a extração de	2.4.1.1. Os índices de aproveitamento sustentável estão claramente definidas para cada

é feito numa base sustentável	subprodutos renováveis (óleos, seivas, látex, resinas, produtos etnobotanicos, animais, etc.) são feitas considerando suas qualidades de regeneração.	subproduto específico.
		2.4.1.2. A regeneração das espécies provedoras não é diminuída.
2.5. A administração técnica do sistema é feita numa base sustentável.	2.5.1. A erosão do solo é corretamente manejada.	2.5.1.1. São desenvolvidas práticas de conservação que tomam cuidado da erosão do solo
	2.5.2. O processo de produção é corretamente manejado.	2.5.2.1. Os agricultores têm conhecimento técnico suficiente sobre o desenho do sistema.
		2.5.2.2. Os agricultures aplicam técnicas, tratamentos e métodos de baixo-impacto, para manter os recursos e rendimentos.
		2.5.2.3. São levadas a cabo medidas para o aumento de rendimentos agrícolas
	2.5.3. Há um procedimento de retroalimentação para enfrentar o manejo dos danos ambientais.	2.5.3.1. O plano de administração mudou nos últimos 5 anos para se adaptar as variações ambientais.
3. Funções socioeconómicas de produção (FSP)		
3.1. As atividades de produção dos sistemas deveriam se esforçar para: 1ª segurança alimentar, 2ª viabilidade econômica (ingressos suplementarios) e 3º assegurar os investimentos para manter a produção biofísica.	3.1.1. A segurança alimentaria é bem mantida.	3.1.1.1. Parte do ingresso investido no compra de comida.
	3.1.2. Há uma atitude dos agricultures para a diversificação da produção e acesso ao mercado	3.1.2.1. O sistema é considerado economicamente viável
		3.1.2.2. O grau de acesso ao mercado pelos produtores
		3.1.2.3. A diversidade de produtos que os agricultures trazem ao mercado normalmente.
	3.1.3. O sistema é retroalimentado para manter seu nível de produção em niveis aceitáveis.	3.1.3.1. Há uma atitude de re-investimento no agricultor.
4. Funções operacionais (FO)		
4.1. Há um plano de administração da paisagem ajustado às circunstâncias ambientais, sociais e econômicas.	4.1.1. Há regulamentos institucionais sobre as atividades de produção e suas implicações ambientais.	4.1.1.1. Há uma(s) instituição técnica responsável para monitorar os danos ambientais devido as atividades produtivas.
		4.1.1.2. Há um jogo de regulamentos sobre os danos ambientais devidos as atividades produtivas.
		4.1.1.3. Os regulamentos normalmente são obedecidos pelos agricultores.
		4.1.1.4. Há uma retroalimentação institucional baseada em fundos científicos e técnicos para definir as estratégias de ação.
	4.1.2. Há um incentivo institucional pela diversificação da economia local, evitando a dependência de um único produto ou poucos.	4.1.2.1. A diversificação da produção é encorajada pelos níveis organizacionais e institucionais.
		4.1.2.2. Há uma demanda local dos subprodutos que vêm dos SAFs
	4.1.3. Há um sistema de monitoramento da paisagem, consistente e reproduzible no tempo para permitir comparações.	4.1.3.1. Há um sistema de mapeamento dinâmico que permite reconheçer e facilitar o manejo de limites fisicos, uso atual da terra, funções de produção, etc.
		4.1.3.2. Há um impacto real das sugestões dadas pelas instituções aos agricultores.

Formato 1. Avaliação individual de indicadores[3,4]

Clase	Indicador	Chave	O objetivo é alcançado direito e sem dúvidas (1-5)[5]	O indicador é fácil do aplicar, registrar e interpretar (1-5)	O indicador provê duma medida integral e resumida (1-5)	O indicador é adequado a uma gama da mudanças do nivel do stress (1-5)	O indicador é importante e prioritario (sim = 1 não = 0)[6]
Funç.ões ambientais							
Funções biofísicas							
F. soc-ec.							
F.oper.s							

[3] Considere-se os seguites pontos definição dos items:
- É um indicador pertinente para a região?
- É um indicador pertinente para a avaliação da sostenibilidade?
- Há outro indicador que seja melhor para expressar o criterio ou indicador?
- É possivel sugerir limites superiores e inferiores para o indicador analisado?

[4] Dê preferência aos:
- Indicadores fáciles de medir e de entender
- Indicadores integradores vs. os mais detalhados

[5] 1=Pobre, 2=Justo, 3=Satisfatório, 4=Bom, 5=Muito bom

[6] 0=Não aceito para avaliações posteriores, 1=Aceito para avaliações posteriores

Formato 2. Avaliação individual de verificadores

Clase	Indicador	Verificador	Chave	O objetivo é alcançado direito e sem dúvidas[7]	O verificador é facil de aplicar, registrar e interpretar	O verificador provê duma medida integral e resumida	O verificador é adequado a uma gama de mudanças no nível de stress	Média
Funções ambientais	1.1.1.	1.1.1.1.	1					
		1.1.1.2.	2					
	1.1.2.	1.1.2.1.	3					
		1.1.2.2.	4					
	1.1.3.	1.1.3.1.	5					
	1.1.4.	1.1.4.1.	6					
Funções biofísicas	2.1.1.	2.1.1.1	7					
	2.1.2.	2.1.2.1	8					
		2.1.2.2	9					
	2.2.1.	2.2.1.1	10					
		2.2.1.2	11					
		2.2.1.3	12					
	2.2.2.	2.2.2.1	13					
	2.2.3.	2.2.3.1.	14					
		2.2.3.2.	15					
		2.2.3.3.	16					
	2.3.1.	2.3.1.1.	17					
		2.3.1.2.	18					
	2.4.1.	2.4.1.1.	19					
		2.4.1.2.	20					
	2.5.1.	2.5.1.1.	21					
	2.5.2.	2.5.2.1.	22					
		2.5.2.2.	23					
		2.5.2.3.	24					
	2.5.3.	2.5.3.1.	25					
Funções soc-econ.	3.1.1.	3.1.1.1.	26					
	3.1.2.	3.1.2.1.	27					
		3.1.2.2.	28					
		3.1.2.3.	29					
	3.1.3.	3.1.3.1.	30					
Funções operacionais	4.1.1.	4.1.1.1.	31					
		4.1.1.2.	32					
		4.1.1.3.	33					
		4.1.1.4.	34					
	4.1.2.	4.1.2.1.	35					
		4.1.2.2.	36					
	4.1.3.	4.1.3.1.	37					
		4.1.3.2.	38					

[7] 1=Pobre, 2=Justo, 3=Satisfatório, 4=Bom, 5=Muito bom

Formato 3. Consolidação das avaliaçãos individuais dos verificadores das funções ambientais

Score / Verif.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	χ
1																
2																
3																
4																
5																
6																

Formato 4. Avaliação coletiva dos verificadores das funções ambientais

Clase	Verificador	Chave	Avaliação		
			Discussão (items chave)		O verificador é importante e prioritario (sim = 1, não = 0)
			☺ (verde)	☹ (vermelho)	
Funções ambientais	1.1.1.1.		- - -	- - -	
	1.1.1.2.		- - -	- - -	
	1.1.2.1.		- - -	- - -	
	1.1.2.2.		- - -	- - -	
	1.1.3.1.		- - -	- - -	
	1.1.4.1.		- - -	- - -	

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