Tropical Agricultural Research and Higher Education Center (CATIE)

Bioeconomic models and agroforestry policy analysis: applications to silvopastoral systems in Guanacaste, Costa Rica

By

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To Erika, Daniel Neptalí and Natalia Georgina

Blackbirds, buzzards, and doves
land on cathedrals and palaces
just as they do on rocks,
trees, and fences…

and they shit on them
with the complete freedom of one who
knows
that god and justice
belong to the soul.

Humberto Ak’abal, *Freedom*

A NOTE ABOUT THE AUTHOR

Adolfo Ottoniel was born in Guatemala City the 17th of June 1971. Guatemala’s political turbulence obligated his father and family to look for political refuge in Mexico in 1981. Adolfo Ottoniel was benefited from the Mexican public education. He graduated as an Agronomy Engineer at the Universidad Autónoma Metropolitana in 1993. He received a M.S. degree at the University of London, Wye College in Agricultural Economics in 1996.

From 1993 to 1995 he worked as a research assistant at the Universidad Nacional Autónoma de México, and worked for the Ministry of Agriculture in Guatemala from 1997 to 1999. He worked as a FAO national consultant at the Forest National Plan (PAF-G) during 2000.

In July 2001, he was admitted to the Ph.D. program in Tropical Agroforestry at the Tropical Agricultural Research and Higher Education Center (CATIE), graduating in December 2005. His research interests are natural resource economics, agricultural policy, rural development, and the applications of these fields to the analysis of tropical agroforestry. He is married and has two children. His contact address is ottoniel@catie.ac.cr.

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PREFACE

This research was supported by the Cerbastan Project, which was a multi-stakeholder project that CATIE in junction with Hacienda La Pacifica developed in the dry forests of Costa Rica. This was called Cerbastan honoring La Pacifica for developing at a commercial scale many of the ideas promoted by this project on their Cerbastan Farm. The Cerbastan Project aimed to develop a platform of knowledge regarding alternative and sustainable uses for degraded lands in the tropical dry forest. The project did not seek solely protection or pure conservation objectives; rather, it promoted trees and forests as investment tools to reduce environmental degradation in commercial farms. The project was particularly interested in understanding the economic and institutional framework influencing cattle ranchers' decisions about livestock, pastures and tree resources in the tropical dry forest of Costa Rica. The present research addressed this particular objective.

The Ph.D. program at CATIE is developed in cooperation with Universities in Europe and the US. I had the scientific support of the Department of Rural Development at the Georg-August-Universität Göttingen (Germany) and the Department of Agricultural Economics at Louisiana State University (USA). I thank Dr. Winfried Manig (Göttingen) and Dr. Hector Zapata (LSU) who helped me with the academic exchange in both universities.

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Monterroso Rivas, A.O. 2005. Bioeconomic models and agroforestry policy analysis: applications to silvopastoral systems in Guanacaste, Costa Rica.

Key words: biodiversity conservation; dispersed trees in pastures; farming systems; joint production economic theory; natural resource economic theory; non-linear optimization; payment for environmental services.

ABSTRACT

The main objective of this research was to analyze policies for increasing tree canopy in pastures as a mean to enhance biodiversity conservation and increase rural incomes. Chapter two reviews the evidence reported in the literature regarding the contribution of dispersed trees to biodiversity conservation and shows that dispersed trees act as habitat or stepping-stones for plant and animal species. Chapter three reviews the theoretical framework for policy analysis that is based on the natural resource economic theory. Economic theory suggests that a maximization model that considers the dynamics of timber and cattle resources can be used to obtain optimal resource-use paths over time. The optimal path, then, could be evaluated with a sensitivity analysis to simulate policy changes. The empirical analysis begins with the description of the social, economic and natural characteristics of the study area based on a farming systems approach (Chapter four). Depending upon farm size and cattle technology, three farming systems were identified: 1) small farm-size with low use of purchased inputs system (SFS-LIU), 2) medium farm-size with high use of purchased inputs system (MFS-HIU), and 3) large farm-size with high use of purchased inputs system (LFS-HIU). Chapter five presents the structure of the nonlinear bioeconomic model which simulates the three cattle systems in Cañas and Bagaces and the management of dispersed trees in the study area. Chapter five also shows the data to run the model as well as the procedures to estimate coefficients. Chapter six presents results and discussion of two main policies: 1) payment for environmental services (with four different payment schemes), and 2) tax policy to extensive cattle management. The chapter also analyzes a free trade scenario with lower meat prices and higher timber prices, as well as does a sensitivity analysis of cattle input prices, calving rates and use of different pastures.

Five main conclusions can be highlighted. First, the promotion of better tree management, i.e. sustainable diameter structures, can be the first policy action for increasing tree cover and promoting higher rural incomes. Current tree structure in Cañas and Bagaces may not be sustainable since few trees belonging to low diameter classes are present in pastures. Second, if correctly designed, the payment for environmental services (PES) is a powerful instrument for increasing tree cover in cattle farms. The PES scheme that yields the lowest financial budget is paying for changes in basal area; this payment is also administratively friendly because the basal area indicator is easier to estimate in field. The PES for planting trees (which is the scheme followed by FONAFIFO in its PES for agroforestry) yields lower canopy levels with similar budgets than a PES that pays for standing trees or for changes in basal area. Third, a PES for agroforestry is not an instrument that can be used to address both conservation and poverty issues. Large-scale farms tend to benefit the more from a PES policy since they can obtain more financial profits. Poor farms tend to obtain the same profits; they only change the income sources. Fourth, a PES policy can be used in areas with specific conservation needs (such as biological corridors). In cases where conservation and development objectives are pursued, indirect incentives can be promoted. Fifth, a PES for silvopastoral systems focused on increasing tree cover in agricultural landscapes has economic and social advantages compared with a PES for forest plantation. The PES for dispersed trees is cheaper than current FONAFIFO payment for forest plantations; in addition, silvopastoral systems are holistic land-use system in which forest and crops are combined in systems that can fit social and economic characteristics of rural areas.

Monterroso Rivas, A.O. 2005. Modelos bioeconómicos y análisis de políticas agroforestales: aplicaciones a sistemas silvopastoriles en Guanacaste, Costa Rica.

Palabras clave: árboles dispersos en potreros; conservación de biodiversidad; optimización no lineal; pago por servicios ambientales; sistemas de finca; teoría económica de producción conjunta; teoría económica de recursos naturales.

RESUMEN

El objetivo principal de la investigación fue analizar políticas que fomenten cobertura forestal en fincas ganaderas como una forma de mejorar la conservación de la biodiversidad y aumentar ingresos rurales. El capitulo dos revisa la evidencia científica referente a la contribución de los árboles dispersos para la conservación biológica, mostrando que dichos sistemas actúan como hábitat o como puntos de reposo para plantas y animales. El capítulo tres aborda el marco teórico para el análisis de políticas, el cual se basó en la teoría económica de recursos naturales. La teoría económica sugiere que un modelo de maximización que considere la dinámica de los recursos arbóreos y ganaderos puede ser usado para estimar niveles óptimos de uso de los recursos en el tiempo. Después, dichos niveles óptimos pueden ser evaluados en un análisis de sensibilidad para simular cambios de políticas. El análisis empírico inició con la descripción de las características sociales, económicas y naturales del área de estudio, basando la descripción en el enfoque de sistemas de finca (Capítulo cuatro). Dependiendo del tamaño de finca y de la tecnología empleada, se identificaron tres sistemas de finca: 1) sistema de fincas pequeñas con bajo uso de insumos externos (SFS-LIU), 2) sistema de fincas medianas con alto uso de insumos externos (MFS-HIU) y 3) sistema de fincas grandes con alto uso de insumos externos (LFS-HIU). El capítulo cinco presenta la estructura del modelo bioeconómico no linear, el cual simula los tres tipos de finca en Cañas y Bagaces así como el manejo de los árboles dispersos en la zona de estudio. El capítulo cinco presenta además los coeficientes para correr el modelo así como los procedimientos para estimarlos. El capítulo seis presenta los resultados y discusión de dos políticas principalmente: 1) pagos por servicios ambientales (con cuatro esquemas de pago) y 2) política de impuestos en ganadería extensiva. Dicho capítulo también analiza un escenario de libre comercio con bajos precios de carne y mayores precios de madera, así también se presenta un análisis de sensibilidad donde se cambian

los valores de insumos de ganado, tasas de nacimiento de ganado y el uso de diferentes pasturas.

Se pueden mencionar cinco conclusiones del estudio. Primero, el fomento de un mejor manejo de árboles, i.e. una estructura diametral sostenible, puede ser una primera opción de política para incrementar cobertura forestal y promover mayores ingresos rurales. La estructura diametral actual en Cañas y Bagaces puede ser insostenible, ya que los pastos presentan un bajo número de árboles en las clases menores a 15 cm de diámetro. Segundo, bajo un diseño adecuado el pago por servicios ambientales (PSA) es un instrumento poderoso para incrementar cobertura arbórea en fincas ganaderas. El esquema de pago de PSA que derivó menores requerimientos financieros es el pago por cambios en área basal; este esquema, además, representa menos costos administrativos ya que el área basal como indicador es más sencillo de estimar en campo. El esquema de PSA que paga por plantar árboles (el cual es el usado por FONAFIFO en su PSA para agroforestería) tiene el menor impacto en el aumento de cobertura con un presupuesto similar al requerido en esquemas de pago por árboles en pie o por cambios en área basal. Tercero, el PSA en Cañas y Bagaces no es un instrumento que pueda usarse para abordar objetivos conjuntos de pobreza y conservación. Las fincas con mayor extensión obtienen más beneficios de una política de PSA ya que sus ganancias por unidad productiva son mayores. Fincas pequeñas y pobres tienden a no aumentar ingreso; lo único que modifican es la fuente del mismo. Cuarto, una política de PSA puede ser usada en áreas con necesidades específicas de conservación (tales como corredores biológicos). En casos donde se persigan objetivos conjuntos de conservación y desarrollo, políticas indirectas son más recomendables. Quinto, un PSA para sistemas silvopastoriles, enfocado en el aumento de cobertura arbórea en paisajes agrícolas, tiene ventajas económicas y sociales sobre un PSA para plantaciones forestales. El PSA para árboles dispersos es más barato que el pago actual de FONAFIFO para plantaciones; los sistemas silvopastoriles, además, son sistemas de uso de tierra holísticos, en los cuales se combinan árboles y cultivos en sistemas bien adaptados a las características sociales y económicas de las áreas rurales.

CHAPTER 1

INTRODUCTION

The tropical dry forest of Mesoamerica (from southern Mexico to Panama) is the most threatened of the major tropical forest types (JANZEN 1988; MURPHY & LUGO 1995). The province of Guanacaste, where most of the Costa Rican tropical dry forest is located (Figure 4.1), suffered one of the most dramatic deforestation patterns of the area. Most of the country's deforestation prior to 1940 occurred in Guanacaste (LEHMANN 1992; SADER & JOYCE 1988). By 1961, the primary forest of Guanacaste's tropical dry zone was totally deforested with the exception of remnants and secondary regeneration (SADER & JOYCE 1988). Much of the land was converted to pastures for cattle ranching.

The **environmental impacts** of the conversion of forest to pastures in Guanacaste's tropical dry zone are twofold. First, the transformation of forest represents the primary driving force behind the loss of biological diversity in Costa Rica (STONNER & TIMM 2004). Second, tropical soils are degraded after few years of deforestation. DOUBENMIRE (1972) reported evidence on soil loss and erosion in places that were converted into pastures in studies developed in Cañas County, which is one of the main locations of cattle ranching in Guanacaste.

In order to counteract deforestation, the Costa Rican government and international organizations have been successful in protecting one national park (Guanacaste–Santa Rosa) and one biological reserve (Palo Verde-Lomas de Barbudal) in the tropical dry forest of Guanacaste. These areas, along with the Chamela-Cuixmala Biosphere Reserve in Jalisco, Mexico, are the only protected sites that are large enough to possibly sustain dry-forest ecosystems in Mesoamerica (QUESADA & STONER, 2004). Recent studies (SÁNCHEZ-AZOFEIFA *et al.* 2003) demonstrate that Guanacaste's protected areas have successfully retained their forest cover in the last 20 years.

However, Guanacaste's protected areas (as in other parks in Costa Rica) are becoming isolated (MATA & ECHEVERRÍA 2004; QUESADA & STONER 2004). SÁNCHEZ-AZOFEIFA *et al.*

(2003) showed that there have been high rates of deforestation outside the park's borders (i.e. within a 10 km buffer zone), the surrounding landscape is highly fragmented, and there is a predominance of non-forested land uses around the park and the biological reserve. FRANKIE *et al.* (1994) evaluated the biological corridor La Mula (which connects Lomas de Barbudal with Palo Verde) and concluded that rice production has isolated these protected sites in recent years. STONER & TIMM (2004) argue that because of the extensive rice fields between Palo Verde and Lomas Barbudal, the movement of most terrestrial mammals between these two reserves is no longer possible.

If forest patches are too small or too isolated (such as in many protected areas in Costa Rica [SÁNCHEZ-AZOFEIFA *et al.* 2003]), they are susceptible to the loss of both genetic and species diversity. As a response to the isolation and limited size of protected areas in Central America, biological corridors have been proposed as a long-term conservation strategy (MILLER *et al.* 2001; MCCARTHY *et al.* 1997). To conserve Guanacaste's tropical dry forest, it is important to promote sustainable land use outside the current national parks and biological reserves. These land use systems must be compatible with biodiversity conservation goals, while also providing income for local people.

Agroforestry systems (AFS), the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land, may help to achieve the dual objective of biodiversity conservation and economic growth. There is comprehensive research related to the benefits provided by agroforestry, such as timber products (e.g. SOMARRIBA *et al.* 1995), non-timber products (ZAMORA *et al.* 2001), shade for animals (ABREU 2002; BLACKSHAW & BLACKSHAW 1994), and shade for agricultural products (MUSCHLER 2001). Agroforestry also provides environmental services such as wildlife habitat (NAUGHTON-TREVES & SALAFSKY 2004), soil-erosion control (NAIR & GRAETZ 2004), improved water quality (SCHULTZ *et al.* 2004), and carbon sequestration and storage (BEER *et al.* 2003).

Recent research (SCHROTH *et al*. 2004; BOSHIER 2004; HARVEY *et al.* 2004) has addressed the effectiveness of AFS for conservation of biodiversity in agricultural landscapes. SCHROTH *et al.* (2004) summarize in three points how agroforestry can contribute to conserve biodiversity: 1) agroforestry, combined with other conservation instruments, reduce pressure to deforest additional land for agriculture, 2) agroforestry systems provide habitat and resources for partially forest-dependent native plant and animal species, and

3) agroforestry creates conditions at the landscape level that facilitate the movement of species from natural vegetation areas across agricultural habitats (i.e. connectivity among natural areas) or can act as buffer zones around protected and natural areas. In the particular case of silvopastoral systems, HARVEY *et al.* (2004) have shown that live fences, windbreaks, and isolated trees can contribute to biodiversity conservation. HARVEY and colleagues (2003) have also investigated the potential use of silvopastoral systems (SPS) as tools for biodiversity conservation in the tropical dry forest of Costa Rica (chapter two presents a further discussion of SPS and biodiversity conservation). They conclude that retaining or establishing trees in cattle farms can be an important component of conservation strategies in fragmented landscapes since SPS provide landscape connectivity as well as habitat and resources for plant and animals (HARVEY *et al.* 2003; HARVEY *et al.* 2004).

1.1 Problem Statement and Research Objective

Agroforestry can potentially be used to conserve biodiversity at the same time that it can increase rural incomes. However, the environmental services provided by AFS (e.g. biodiversity conservation) are public goods or externalities, which farmers may not take into account because they do not receive compensation for them. The social benefits derived from trees (e.g. conservation of biodiversity) may be greater than the private benefits of having trees (e.g. timber), and given such a divergence, farmers may conserve and plant too few trees from a social perspective (CACHO & HEAN 2004; ALAVALAPATI *et al.* 2004; PAGIOLA *et al.* 2002).

The presence of public goods and externalities (and also imperfect information) in the economy are often referred to as 'market failures'. Three of the most important environmental services provided by agroforestry and forestry (biodiversity conservation, watershed management, and carbon sequestration) are cases of market failures (PAGIOLA *et al.* 2002).

Policy intervention such as regulation, economic incentives, and extension, can be implemented to correct market failures in the provision of environmental services. However, the design of environmental policies is not a simple task. Policy design requires the economic valuation of the environmental service, the estimation of the optimal externality, and the estimation of the resource steady state in a dynamic setting. Economic theory offers the framework for the valuation of the environmental service and estimation of the optimal externality (e.g. FREEMAN 1993; PEARCE & TURNER 1990; PEARCE & MOURATO 2004; ALAVALAPATI *et al.* 2004) as well as the theory related to natural resource management (e.g. CONRAD & CLARK 1987; CONRAD 1999; HARTMAN 1976). The relationship between biophysical components (such as agroforestry) and economics is addressed in economic theory through the use of 'bioeconomic models' (ZILBERMAN *et al.* 1993).

Unlike environmental valuation, theoretical bioeconomic models for environmental services are widespread in the literature but empirical applications are less common (STANDIFORD & HOWITT 1992). The scarce scientific literature related to bioeconomic models and agroforestry in developed countries has analyzed the use of trees to reduce soil salinization (CACHO 2001; KNAPP & SADORSKY 2000), manage non-point water pollution (POSNIKOFF & KNAPP 1996), and reduce agricultural carbon emissions (CACHO & HEAN 2004, PETERSEN *et al.* 2003). In developing countries, bioeconomic models have addressed topics such as soil degradation (BULTE *et al.* 2000), watershed management (BARBIER & BERGERON 2001), and carbon sequestration problems (CARPENTIER *et al.* 2000). However, there is a lack of empirical bioeconomic applications related to policies for biodiversity conservation in developing countries.

The lack of empirical bioeconomic analysis is mainly due to two factors. First, there is a high amount of biophysical information that is needed for empirical models; many of them are not yet available in developing countries (BARBIER & BERGERON 2001). Second, the procedures to solve theoretical models are complex and are not easy to implement (CACHO 2000; STANDIFORD & HOWITT 1992).

As a result, policy design in developing countries has been done with simple, but myopic, analytical procedures. In Costa Rica and Guatemala, for example, the design of the payment for environmental services was done based on tree plantation costs instead of valuing the externality (DIAZ 1998; PAGIOLA 2002). In other cases, mainly in environmental services related to watershed management, the environmental payment is designed based on the cost of the agroforestry/forest management plan (PAGIOLA 2002).

These simple approaches, although practical, cannot guarantee that the policy is optimal, e.g. that more/less money than needed is given to private farms. Besides, there is no certainty whether the policy instrument will have the desirable impact on the provision of the environmental service.

Therefore, there is a need for empirical research related to policy analysis for biodiversity conservation in agricultural landscapes. The main objective of this research was to study agroforestry policies that can achieve biodiversity conservation outside protected areas (through increasing tree cover in cattle farms) and increase rural incomes in the tropical dry zone of Costa Rica, through developing empirical bioeconomic models of cattle farms.

1.2 Research Questions and Specific Objectives

This study was developed in the **tropical dry forest** (bs-T) (HOLDRIDGE *et al.* 1971) in Cañas and Bagaces counties, in the province of Guanacaste, Costa Rica (Figure 4.1). This area has an extension of 570 km^2, representing 54% of the total dry forest of the country. The tropical dry forest is characterized by a six-month dry season and less than 1500 mm of precipitation. Soils in the area are mainly entisols and inceptisols (86%), which are dedicated to cattle ranching, but mollisols, vertisols and alfisols (14%), which are dedicated to irrigated crops are also found (ITCR 2000). Chapter three presents a detailed description of the area characteristics along with main farming systems found in the area.

Silvopastoral systems (SPS), the interaction of woody perennials with forage and animals in an integrated system (PEZO & IBRAHIM 1999), are present in most cattle farms in the tropical dry zone of Guanacaste, mainly in the form of dispersed trees in pastures, live fences, and riparian trees (see Chapter 3). This research focused on dispersed trees in pastures found in cattle production systems located in the tropical dry forest of Guanacaste. Other kinds of tree arrangements, such as riparian trees, secondary regeneration, or plantations, as well as other agricultural production systems were not considered in the analysis. Nonetheless, the exceptions do not diminish the applications of the research since the main land uses in Cañas and Bagaces are pastures with trees (54% of total area), forested areas (38%), and agricultural areas without trees (8%) (FLORES in prep.). The results of the model can easily be extended to live fences and other tree arrangements, as it will be explained in the discussion section.

Since SPS are present in most cattle farms, the **first research question** considered the likely future scenario of SPS (focused on dispersed trees in pastures) in the study area. Specifically, will tree cover in cattle farms increase or decrease over time? Formally structured, this question focused on the determination of the steady-state of the tree biomass within cattle farms. Thus, the **first specific objective** was:

- To determine future scenarios of dispersed trees in pastures of cattle farms located in the tropical dry area of Cañas and Bagaces, Guanacaste; in other words, to determine which is the steady-state of dispersed trees in pastures and which could be the best way to reach it.

There is a lack of expertise on agroforestry policy research in tropical countries. For instance, the low availability of biophysical information and the complicated procedures to solve empirical models (BARBIER & BERGERON 2001; CACHO 2001) limit policy analysis in the region. In addition, policy-makers face a situation of constrained fiscal budgets and low availability of policy instruments; then, *ex-ante* policy evaluation is needed to better invest scarce resources. There is a need to evaluate economic incentives that can increase the area covered with trees and thus enhance biodiversity conservation in the dry tropical forest.

The **second research question**, then, asked about the likely impact of economic incentives in the promotion of dispersed trees in pastures in the tropical dry forest of Guanacaste. Which policy instrument is likely to increase areas covered with trees? The **second objective** was:

- To evaluate different policy instruments (e.g. environmental service payments and taxes on cattle farms with low tree density) that can be used to increase the area covered by dispersed trees in pastures in order to achieve biodiversity conservation and economic growth in Cañas and Bagaces, Guanacaste.

Socioeconomic conditions should not be neglected in achieving conservation goals. The Human Development Index (HDI), estimated by the Costa Rica government (MIDEPLAN 2001), rates Cañas and Bagaces counties as having ‘low social development’ (the index has four ratings: high, medium, low, and very low social development). The **third research question** centered its attention on whether silvopastoral systems (i.e. dispersed trees in pasture) can increase rural incomes under current social and economic scenarios. The **third specific objective**, then, was:

- To determine the impact of dispersed trees in pasture in promoting economic growth of cattle farms located in the tropical dry forest of Cañas and Bagaces, Guanacaste.

1.3 Research Contributions

The central contribution of this research is to analyze agroforestry policies to enhance biodiversity conservation in cattle farms in the dry tropics of Guanacaste. As presented above, policy analysis in Central America has been carried out with analytical instruments that do not guarantee the policy applications are socially optimal or will reach the desired environmental objective. By using bioeconomic models, these two problems are addressed. In addition, this research explains what other policy instruments compatible with open markets and fiscal budgets can be applied to environmental service problems. This research discusses five policy instruments that can be used to improve landscape connectivity in the tropical dry zone of Guanacaste, Costa Rica.

In addition to the main objective, this research has three parallel contributions. The first parallel contribution is related to the empirical design of bioeconomic models. Specifically, the empirical application was faced with the challenge of developing a tree growth model compatible with both agroforestry and economic theory. Foresters have a wide experience in timber growth models (PENG 2000), but few applications are reported for silvopastoral systems in the literature. This research contributes with the debate of timber growth models applicable to silvopastoral systems.

The research also answered an empirical silvopastoral problem: what is the optimal mix of the trees, pasture and livestock components that maximizes farmer profits? Several studies (e.g. ESQUIVEL *et al.* 2003; ABREU 2002; RESTREPO 2002) have reported the densities of dispersed trees in pastures that farmers maintain in their farms. While these reports are good examples of the number of trees a farm can have, they may not represent the optimal combination of components.

WOJTKOWSKY & CUBBAGE (1991) and WOJTKOWSKY *et al.* (1991) developed nonlinear optimization models to find the optimal combination of trees and agricultural crops in an agroforestry system. Their models use net present values for the forest components. The research presented in this document extends the agroforestry discussion of methods to obtain optimal combinations of agroforestry components by presenting a stylized technique for optimization of a silvopastoral system.

Finally, this research also contrasted economic theory with empirical findings and answered the following questions: do empirical findings correspond with theoretical predictions? Are theoretical assumptions coherent with real-world situations? The lack of applied studies from developing countries justifies these kinds of questions.

1.4 Document Overview

This document has seven chapters. **This chapter** introduces the study, where the overall objective, research questions and main contributions are stated. Then Chapters 2 and 3 present the theoretical framework for this research. **Chapter 2** reviews the literature related to the roles and functions of dispersed trees in pastures for landscape connectivity and biodiversity conservation. Chapter 2 also presents the background for farming systems research, which is a transversal element of the research.

Chapter 3 reviews the natural resource economic theory that is used to analyze cases of environmental services and externalities in natural resource management. This chapter firstly presents the neoclassical production function theory as well as the economics of renewable natural resources as the framework to analyze agroforestry policies in Guanacaste. The renewable natural resource model is analyzed with optimal control theory. However, direct numerical solutions of these kinds of problems may not be feasible with complex models (such as those presented in this research). Therefore, the chapter further develops the general characteristics of nonlinear programming models as the basis to undertake empirical analysis.

Chapter 4 presents the biophysical and socioeconomic characteristics of the study area based on farming systems theory. The chapter combines a quantitative analysis (i.e. cluster analysis) and a qualitative analysis (i.e. description of the system components).

The main objective was to identify farm types (farming typology) where policy instruments could be simulated. The farming typology summarized the social complexities of the study area and helped to identify main variables to be used in the empirical model. Farm types were an initial input for policy analysis, offering a holistic vision of the cattle production situation in the study area.

Chapter 5 presents the structure of the nonlinear programming model and is divided into two sections. The first section, ‘the empirical bioeconomic model’ shows the structure of the bioeconomic model. In addition, this section presents the model validation and the policy simulation methodology. The second section of Chapter 5 presents the methodology and results of the estimation of coefficients for the empirical model. Coefficients were estimated from real-world situations and from literature sources, depending upon the availability of information. Production data was obtained from a multiple-visit interview with cattle producers; biophysical data was obtained from secondary sources and data reported in the literature. Future prices were modeled with time series econometrics.

Chapter 6 firstly introduces the validation of the model as well as the baseline scenario per farm type. The chapter presents two kinds of policies: 1) policies that intervene with the tree component, and 2) policies that intervene with the cattle component. The analysis includes a simulation of a free trade scenario, with low meat prices and high timber prices as the two scenarios. A sensitivity analysis is also presented with changes in hay prices and cattle technology. The chapter discusses the impact of policies on the level of cattle and tree stocks as well as on farmer incomes. Finally, **Chapter 7** presents the main conclusions and recommendations from this study.

PART I

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

CHAPTER 2

CONCEPT REVIEW: SILVOPASTORAL SYSTEMS, BIODIVERSITY CONSERVATION AND THE FARMING SYSTEM APPROACH

> Blackbirds, buzzards, and doves / land on cathedrals and palaces
> just as they do on rocks, / trees, and fences…
> and they shit on them / with the complete freedom of one who
> knows / that god and justice / belong to the soul.
>
> Humberto Ak'abal, *Freedom*

This chapter presents a review of concepts and foundations of two different topics that are transversal to the research: 1) the contribution of silvopastoral systems to biodiversity conservation, and 2) the farming system approach for applied policy simulation. The first topic, presented in section 2.1, reviews the recent scientific work focused on the potential use of silvopastoral systems for biodiversity conservation in tropical countries. The second topic, section 2.2, centers on the concepts of the farming system approach (FSA) and its use in applied policy analysis. The FSA offers a framework where policies can be analyzed.

2.1 Silvopastoral systems and biodiversity conservation

2.1.1 Definition of silvopastoral systems and dispersed trees in pastures

PEZO & IBRAHIM (1999) define a silvopastoral system as an animal-management option where the traditional components (pastures and livestock) interact with woody perennials (trees or shrubs). Some examples of silvopastoral systems are living fences, windbreaks, alley pastures, livestock grazing in plantations, and dispersed trees in pastures (PEZO & IBRAHIM 1999). This research only addresses dispersed trees in pastures.

Dispersed trees in pastures (DTP) can be of two types (PEZO & IBRAHIM 1999): 1) DTP can be man-made systems, and 2) DTP can be naturally generated systems. Examples of man-made systems are the trees that are left when the forest is cleared to cultivate pastures (which are also referred to as isolated remnant trees [GUEVARA *et al.* 1992]), as well as natural regenerated trees and trees planted by farmers (HARVEY & HABER 1999). Natural dispersed tree systems can be climax vegetation, such as the *caatinga* system in Northeast Brazil and the *matorrales* system in the Northeast of México (PEZO & IBRAHIM 1999), or intermediate phases of successional vegetation. An example of the latter is when pastures are abandoned and several species of shrubs and pioneer tree species are established, which can result in a young secondary forest after 25-30 years (SPITTLER 2001).

Dispersed trees in pastures can be found as single isolated trees and/or as clustered trees that are not part of a consolidated stand of vegetation (ESQUIVEL *et al.* 2003; FISCHER & LINDENMAYER 2002).

Several positive and negative biophysical interactions occur among the tree, pasture, and livestock components. Trees can contribute to animal production by improving the microclimate beneath their canopies, which reduces the animal caloric stress (BLACKSHAW & BLACKSHAW 1994), by serving as shelter and protection to animals (PEZO & IBRAHIM 1999), or by providing fruits and foliage to feed animals (CONKLIN 1987). Trees can also benefit from animals that graze in the early years of tree establishment by reducing the management cost of tree plantations (PEZO & IBRAHIM 1999). Some negative effects of the tree-animal interaction are the damage caused by browsing of tree foliage and damage to the tree stem (PEZO & IBRAHIM 1999). The shade of trees can affect the production of pastures, although some pasture species are highly tolerant to shade (such as *Brachiaria miliformis* and *Paspalum conjugatum*) whereas other are less tolerant (such as *Brachiaria decumbens* and *B. humidicola*) (PEZO & IBRAHIM 1999). In other cases, the tree component has positive effects on pastures, such as the reduction of soil erosion and wind-generated stress on pastures (PEZO & IBRAHIM 1999).

2.1.2 Contribution of dispersed trees to biodiversity conservation

Agroforestry systems are important instruments for conserving biodiversity in human-dominated landscapes (SCHROTH *et al.* 2004). Silvopastoral systems (e.g. windbreaks, live fences, and dispersed trees) can actively contribute to biodiversity conservation (Harvey *et al.* 2004). The literature reports at least five ways in which dispersed trees in pastures can contribute to biodiversity conservation. They are briefly reviewed in the following paragraphs.

Dispersed trees in pastures enhance the vegetation and structural complexity within the agricultural landscape (Harvey & Haber 1999; Guevara *et al.* 1998; Esquivel *et al*. 2003). In many tropical countries, there is a great diversity of tree species dispersed in pastures, many of which are primary forest tree species. For example, Harvey & Haber (1999) surveyed 5583 dispersed trees in pastures in Monte Verde, Costa Rica finding 190 tree species (mean density of 25 trees/ha ±3.5 se) of which 57% were primary forest species, 39% were secondary species, and 4% were domesticated species. In the tropical dry forest of Costa Rica, Esquivel *et al.* (2003) found a total of 88 species belonging to 39 families in 5896 surveyed trees in pastures (average density of 8.6 trees/ha). Esquivel *et al.* (2003) reported that dispersed trees in pastures can be found as isolated trees (1 tree) or as clustered trees (two or more trees; see also Section 4. 3). Guevara *et al.* (1998) reported 98 tree species in pastures in Veracruz, México (mean density of 5.2 trees/ha ±0.7 se), of which 78% were primary forest tree species, 11% were late secondary succession species, and the other 11% were pioneer species. The reported 98 tree species represent 33% of the encountered tree flora in the nearest protected area (Guevara *et al.* 1998).

Dispersed trees in pastures provide habitat and resources for plant and animal species (Hietz-Seifert *et al.* 1996; Majer & Delabie 1999; Law *et al.* 2000; Saab & Petit 1992; Cárdenas *et al.* 2003). Trees in pastures can provide habitat and fruits, as well as nesting and perching sites for plants, insects, birds, bats, and other animals within the open landscape. For example, Hietz-Seifert *et al.* (1996) reported 58 epiphyte and hemiepiphytic species on 38 isolated trees on pastures. The numbers of epiphytic species per tree in pastures were within the range found in undisturbed forest sites. Isolated trees also support a high richness of arboreal ant species (Majer & Delabie 1999). In the Atlantic rain forest region of Bahia, Brazil, Majer & Delabie (1999) under isolated trees found 77 ant species, of which 43% were also found in forest trees. In the case of ant species, the conservation potential of isolated trees is greater if the trees are large, support a high epiphyte load, and are native to the area (Majer & Delabie 1999). In Australia, Law *et al.* (2000) reported that arboreal marsupials, owls, bats and birds use isolated trees as habitat or perching sites, although hollow-dependent nocturnal fauna prefer very large tree diameters (diameter greater than 182cm).

SAAB & PETIT (1992) argue that retention of some shrubs and overstory trees enhance the conservation of winter bird populations in Central America. They recorded 39 bird species in abandoned pastures that contained high isolated shrubs (from 0.5 – 3 m tall) while in active pastures (which have shrubs <0.5 m) they found 15 bird species. Almost one quarter of the bird species in both pasture sites were long distance migrants (SAAB & PETIT 1992). CÁRDENAS *et al.* (2003) investigated bird abundance and richness in five vegetation systems in Cañas, Costa Rica. They found that plots with a high density of trees (16-25% of canopy cover per hectare) and secondary regeneration plots harbored 45 bird species; this represented 50% more species than those found in remnant forest, 15% more than the species found in riparian buffers, and 61% more species than those found in pastures with low tree densities (1-15% of canopy cover per hectare). Although, the number of forest-dependent species was higher in remnant forests than in pastures with high tree density, pastures with trees can help conserve a great proportion of native avifauna in the dry tropics, particularly if they have high tree densities (CARDENAS *et al.* 2003).

Birds may visit dispersed trees because they provide nesting sites, calling perches, or because they shelter them from predators (CARRIERE *et al.* 2002). However, the characteristics that make isolated trees better habitat vary among species and places. SLOCUM & HORVITZ (2000), in a study in Costa Rica, found that birds prefer trees that produce fleshy fruits (such as fig trees) to species with dry fruits. In addition, they found that tree architecture and distance to forest edges are not significant variables for attracting birds and bats. TOH *et al.* (1999), however, argue that the provision of fruits appears to be less important than the structure and suitability of trees as bird perches. TOH *et al.* (1999) conclude that, for the Australian case, clustered trees are better perch sites than isolated trees.

Dispersed trees in pastures help conserve plant diversity by serving as foci for seedling recruitment and regeneration (CARRIERE *et al.* 2002; GUEVARA *et al.* 1992; GALINDO-GONZÁLEZ *et al.* 2000; SLOCUM & HORVITZ 2000; VIEIRA *et al.* 1994). This topic is perhaps the one that has received the most attention in the literature of dispersed trees for biodiversity conservation. Trees in pastures act as perch trees for birds, bats and other seed dispersal animals that enhance the seed rain beneath their crowns and thus accelerate forest regeneration (CARRIERE *et al.* 2002; GALINDO-GONZÁLEZ *et al.* 2000; SLOCUM & HORVITS 2000; GUEVARA & LABORDE 1993). In addition, tree canopy provides favorable environmental conditions, such as lower temperatures and better soil nutrients and moisture, for the establishment of forest species (RHOADES *et al.* 1998; VIEIRA *et al*. 1994).

GUEVARA *et al.* (1992) found significantly more plant species beneath tree canopies than in open pastures in Veracruz, México. In addition, the abundance of tree species was significantly higher under tree canopy (278 individuals) than in open pastures (48). In Brazil, VIEIRA *et al.* (1994) found a greater seedling density under isolated shrubs of *Cordia multispicata* (0.32 seedling/m^2) than in pastures of *Panicum maximum* (0.01/m^2).

VIEIRA *et al.* (1994) argue that the high density of woody seedlings beneath *C. multispicata* may be the result of elevated seed rain (estimated in 154 ±6 seeds/m^2 versus 9±1.5 seeds/m^2 in pastures), which in turn is due to the presence of seed dispersal animals such as bird and bats. GALINDO-GONZÁLEZ *et al.* (2000), in their study in México, found that seed rain under isolated trees was dominated by zoochorous species (88.6%) and CARRIERE *et al.* (2002), in a similar study in Cameroon, found that the animal dispersed species accounted for 94.5% of the total.

Dispersed trees act as nursery places for seedlings. For example, VIEIRA *et al.* (1994) found that soil conditions beneath tree canopy have significantly higher levels of nitrogen, calcium, magnesium, and potassium. RHOADES *et al.* (1998) report that air temperature in open pastures was 6ºC higher than in the shade of pasture trees, which in turn was 2.7ºC higher than in mature forest. Light passing through isolated trees varied between 9% and 18% of the light intensity in open pastures (RHOADES *et al.* 1998). In addition, soil nitrogen availability was higher beneath the canopies of dispersed trees than in open pastures, although there is a significant positive effect of nitrogen-fixing trees (RHOADES *et al.* 1998).

Dispersed trees in pastures function as stepping stones that facilitate animal movement within the agricultural landscape (SCHROTH *et al.* 2004, FISCHER & LINDENMAYER 2002; GUEVARA *et al.* 1998). In addition of the three topics discussed above, some specific evidence of the role of dispersed tree as landscape connectors is provided in FISCHER & LINDENMAYER (2002) and GUEVARA *et al.* (1998).

FISCHER & LINDENMAYER (2002) test the hypothesis of landscape connectivity by two different ways. Firstly, they analyzed the arrival and departure direction of birds relative to surrounding vegetation cover. The authors investigated whether birds use isolated trees as stepping stones while traveling from and to more densely vegetated parts of the environment. They found that foliage-foraging birds follow this pattern more than nectarivorous and open-country species. Secondly, FISCHER & LINDENMAYER (2002) addressed landscape connectivity by analyzing the departure direction of birds relative to their arrival direction. The hypothesis in this case was that a relative departure angle of 180° indicated that birds 'stopped over' to continue on their way in the opposite direction of arrival. They found that the 'stopped over' effect was more evident in trees located in long distances from woodland patches. "A possible explanation for this may be that birds were attempting to avoid open areas where they were more exposed to predators, and/or where food resources were scarce" (FISCHER & LINDENMAYER 2002:845). This pattern was less pronounced for open-country species.

GUEVARA *et al.* (1998) propose that isolated trees in pastures, together with other forest remnants as riparian corridors and live fences compose a physically discontinuous but functional canopy in the landscape. GUEVARA *et al.* (1998) summarize their discussion as follows (40):

> When flying through pastures frugivorous birds closely follow riparian corridors and the scattered IRT [isolated remnant trees in pastures], showing a marked preference for the remnants of the TRF [tropical rain forest] canopy. Traditionally, the definition of a corridor is based on human perceptions which, from a bird's eye-view, may be meaningless. Our observations of flight patterns in Los Tuxtlas pastures indicate that birds perceive and routinely take advantage of a network of connected TRF [tropical rain forest] remnants in which IRTs [isolated remnant trees] are the nodes.

Dispersed trees, combined with other conservation instruments, may reduce pressure to deforest additional land for agriculture (SCHROTH *et al.* 2004; ANGELSEN & KAIMOWITZ 2004; KAIMOWITZ & ANGELSEN 2001). Silvopastoral systems can have two indirect effects on avoiding deforestation of primary forest. Firstly, silvopastoral systems can provide wood resources to farmers and then, farmers do not need to harvest forest trees (KAIMOWITZ & ANGELSEN 2001). Second, silvopastoral systems can increase farmer income through intensification of production requiring less land to produce the same output (and then having few incentives to deforest and produce extensive-land outputs) (ANGELSEN & KAIMOWITZ 2004). However, these desirable positive effects are conditioned to the labor, capital, or market constraints which, under certain conditions, may induce silvopastoral systems to have the opposite effect. For example, in a situation where the labor and capital markets are unconstrained, a technology that increases farm incomes can be an incentive to clear-out more forest (ANGELSEN & KAIMOWITZ 2004). Silvopastoral systems can prevent deforestation when they are combined with more direct forest-conserving measures, such as the declaration of protected areas or by providing farmers with net benefits from forest conservation, such as payment for environmental services (SCHROTH *et al.* 2004).

In summary, dispersed trees are potential instruments for conserving biodiversity outside protected areas. It is worth mentioning, however, that silvopastoral systems, and agroforestry in general, cannot be seen as a substitute but only as a complement to areas of natural habitat, which remain key to conservation efforts (SCHROTH *et al.* 2004).

2.1.3 Implications for this study

The five topics reviewed above have addressed the potential of dispersed trees in pastures for biodiversity conservation. As indicated in the literature, this research assumes that increasing the density of dispersed trees in pastures, which also implies an increase in canopy area, has a positive effect on biodiversity conservation and landscape connectivity. The policy objective of this research is therefore to increase the density of dispersed trees in pastures in order to promote biodiversity conservation through the combined effect of the provision of habitat, resources, and improved connectivity.

2.2 The farming system approach and policy analysis

The most widespread methodology for policy simulation, in a broad sense, consists of three parts (KOBRICH *et al.* 2003; MCCARL & SPREEN 2004; ESCOBAR & BERDEGUÉ 1990): 1) identification of typical farms (or ‘recommendation domains’), 2) construction of simulation models for such typical farms, and 3) simulation of policy through a sensitivity analysis. There were then two key questions at the beginning of the research: what does a typical farm mean? How can a typical farm be identified?

The identification of typical farms is a critical part of the research (KOBRICH *et al.* 2003). The farming systems approach (FSA) offers the theoretical framework for identifying typical farms. This section reviews the concepts and applications of the farming systems approach that were used in this research.

2.2.1 Historical development of the FSA

Systems theory has been the basis for the construction of analytical models in agriculture (DIXON *et al*. 2001, ISON *et al*. 1997, TRIPP *et al*. 1990, RUTHENBERG 1980), and has been conceptually coined as the farming system approach (FSA). The FSA evolved from a crop-oriented approach, where the crop (or crops) was studied in isolation from its social and economic environments, to a situation where such external elements are included as endogenous variables in farming production systems (DIXON *et al*. 2001, NORMAN 2003).

In a historical perspective, the FSA started by considering the crop(s) itself as the objective of development and efforts were centered on the generation of new cultivation techniques for these crops. However, researchers soon realized that this vision was too narrow; therefore, they included the relationships among several crops into the analysis thus creating the so-called farming systems with a whole farm focus (DIXON *et al*. 2001, NORMAN 2003). During this phase, people (farmers) became the development objective instead of the crop itself. In late 1980s, environmental concerns forced researchers and practitioners to look at sustainable systems where temporal variability and externalities should be included to assure the natural resource base is available for future generations (DIXON *et al*. 2001, TRIPP *et al*. 1990). Recently, vulnerability and uncertainty (both social and natural) as well as political and institutional factors (variables considered as exogenous in previous years) have been considered to be important factors in determining the farmer capabilities to solve their problems and assure their survival (DIXON *et al*. 2001, NORMAN 2003). This last phase has been called the sustainable livelihoods approach (ELLIS 2000).

NORMAN (2003:3) summarizes the evolution of the farming system approach over the last 30 years as “an expansion of the variables considered endogenously determined and thus subject to analysis”. Therefore, although the FSA has considerably evolved, the conceptual mainstream based on systems theory has been unchanged. In order to explain the conceptual framework of the FSA, I review concepts of systems theory in the following paragraphs.

2.2.2 Definition of systems and the farming system approach

System theory has been applied in many different disciplines (ISON *et al.* 1997). I define a *system* following BERTALANFFY'S (1995) work: a *system* is a process where inputs interact to produce outputs. Every system has the following elements: (1) structure, (2) processes, (3) inputs, (4) outputs, and (5) supra-system elements. Figure 1 shows a general structure of a system.

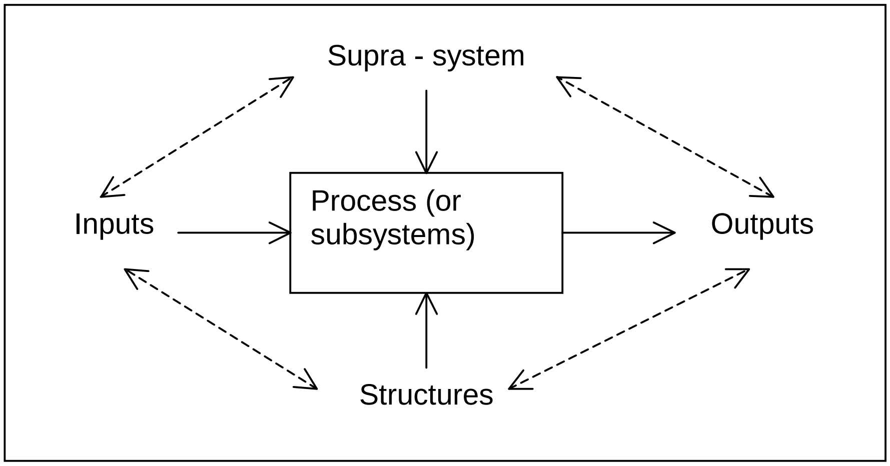

Figure 2.1. Schematic representation of a system. *Inputs* are processed in order to produce *outputs*. The *process* is defined by its *structure* and influenced by the *supra-system*. *Feedback* (dashed lines) flows from every element of the system (Source: Adapted from MONTERROSO & GUTIÉRREZ, 1997).

The system's *structure* is the organizational arrangement (individual or group of farms) that determines the production of the system. The system's structure defines the process, i.e. how inputs are transformed into outputs. The *process* is the action of transforming inputs into defined outputs. In Guanacaste, for example, livestock and capital resources are transformed to produce beef cattle. Beef, however, can be produced with a number of technical combinations, e.g. high use of external inputs or intensive use of natural resources. *Inputs* are raw materials or energy required to operate the system. The farmer's assets and resources (i.e. human, natural, financial, social, and physical resources) are examples of agricultural inputs. The *outputs* are products or results intended to solve farmer objectives, such as food security or reduction of social vulnerability. Non-desirable results such as pollution and environmental degradation should be considered outputs as well. The institutional environment that influences the process's performance is the so-called *supra-system;* in other words these are the rules that define the use and transaction of land, labor and other resources (BRUSH & TURNER 1987). The organizations that guarantee the accomplishment of such rules are also elements of the supra-system elements. *Feedback* is an important element in the model. It makes the system dynamic; information or energy can flow to, and from, any element of the system.

Every system is intended to reach previously defined objectives (BRUSH & TURNER 1987). In tropical agriculture, such objectives can be the improvement of food security, enhancement of well-being, or reduction of social vulnerability. In economics, it is frequently assumed that systems have a single objective. Some common single-objectives are profit or utility maximization, risk minimization, and labor minimization, among others (ELLIS 1988).

The use of systems theory to address agricultural problems is called the farming system approach. Both a farming system and the farming system approach have been defined in several ways depending upon the interest and discipline of authors (DIXON *et al.* 2001). In this document I use the concepts of BRUSH & TURNER 1987 (1987:13):

> A *farming system* is any level of unit(s) engaged in agricultural production as it is wedded in a social, political, economic, and environmental context.
>
> A farming systems approach describes the unit(s) in its context and/or explores some characteristics of the unit(s) in terms of all or parts of the context.

The scope of the FSA, however, is restricted to the description of the natural and social phenomena rather than to its explanation:

> It needs to be emphasized that the systems approach is *descriptive* rather than *explanatory*. It helps identify *what* processes exist and *how* sets of interrelated components function together. *Why* systems work the way they do is an explanatory task best performed by theoretical constructs that have traditionally emerged from economics, geography, or anthropology (BRUSH & TURNER 1987:27).

In the case presented in this research, the farming system approach will be used to describe the cattle production systems in Guanacaste (Chapter 4) while natural resource economic theory will be used to make predictions about the performance of the system (Chapters 3, 5 and 6).

2.2.3 Applied farming system approach

Given that every farmer (production unit) has its own resource endowment, BRUSH & TURNER'S (1987) definition would imply the analysis of every single farm for policy analysis. However, this task would be impossible and impractical to undertake. Therefore, the aggregation of farmers into more or less homogeneous groups is preferred. Such groups constitute the so-called recommendation domains, i.e. groups of producers that have the minimum variance among members but have the maximum variance among groups (ESCOBAR & BERDEGUÉ 1990). The idea of recommendation domains implies creating a taxonomy of farmers; in other words, a typification of producers (ESCOBAR & BERDEGUÉ 1990). Once the typical farms have been identified, mathematical models (or other analytical techniques suggested by economic theory) can be applied to explain and simulate policies.

The heuristic dimension of farming systems can be put into practice with multivariate statistical methods since they allow the creation of groups with several sets of social, economic, and environmental variables (ESCOBAR & BERDEGUÉ 1990; KOBRICH *et al.* 2003; SOLANO *et al.* 2000). The practical methodology to form typical farms can be found in ESCOBAR & BERDEGUÉ (1990), KOBRICH *et al.* (2003) and SOLANO *et al.* (2000). Appendix A shows the methodology applied in this research while Chapter 4 presents the description of formed groups following the schematic representation of Figure 2.1.

CHAPTER 3

THEORY AND APPLICATIONS OF ECONOMICS FOR AGROFORESTRY

This chapter complements the theoretical framework that supports this study. Chapter two showed that dispersed trees in pastures are instruments to conserve biodiversity in tropical areas because they provide habitat, resources and/or improve connectivity at the landscape level. Therefore, the increase of tree canopy of dispersed trees in cattle farms can be set as a policy objective.

Under the systems approach, policy analysis requires a theoretical framework to simulate instruments. Economic theory, i.e. microeconomics and natural resource economic theory, offers such a theoretical framework. Then, before analyzing potential policies that can be used in the Cañas and Bagaces contexts, a theoretical review for policy analysis is addressed in this chapter. This chapter presents a review of economic theory for analysis of agroforestry policies and applied policy studies. The chapter is divided into three sections: 1) economic theory related to agroforestry, 2) considerations in applied agroforestry economics, and 3) Chapter summary.

3.1 Economic theory related to agroforestry

In order to discuss economic theory, some generalizations of the main uses of trees in agroforestry systems are required. Tree and forest resources on rural farms can have several productive objectives. In alley cropping, trees are used to provide mulch to increase agricultural outputs and substitute for inorganic fertilizers. In other cases, such as in taungya systems, the stock value of trees is more desirable. However, trees also compete with crops for scarce resources such as nutrients, light, and labor. Depending upon the *main* economic use of trees in agricultural farms, three cases can be synthesized as follows (some agroforestry systems may have one or more of the following characteristics):[1]

- Trees as (direct) production inputs. Trees can provide mulch, shade, and fodder; examples of agroforestry systems can be alley cropping and forage banks.

- Trees as outputs (mainly timber, firewood, and fruits). Trees can be used as outputs, mainly to produce timber. Agroforestry examples are taungya and dispersed trees in grasslands.

- Trees with multipurpose objectives can be considered in two distinct ways:

    - As having private benefits only. In this case, standing trees are used as inputs through the rotation cycle and then harvested as timber at the end of the cycle. Live fences with valuable timber trees, for example, provide shade (flow value) and timber (stock value).

    - As having both private profits (timber) and social benefits (i.e. positive externalities). In this case, standing trees produce externalities that benefit society (such as biodiversity conservation, soil improvement, and carbon sequestration) and provide private profits in the form of timber. Externalities can vary depending upon the social characteristics where the producer is located.

The economic theory of these three cases is discussed in the following paragraphs.

3.1.1 Trees as production inputs

There are two economic questions in this case: 1) how much of the resource is needed in order to obtain the maximum profit? and 2) what is the optimal combination of natural and purchased inputs? In the agroforestry literature, MERCER (1991), and HOEKSTRA (1983) analyzed the economic theory related to the use of trees as inputs, and microeconomic textbooks widely explain the theory. I reproduce the main solutions (based on CHAMBERS 1988; HOWITT & TAYLOR, 1993) since they will be useful in further discussions.

---

[1] The classification presented here is a simplification of agroforestry uses and benefits. I do not intend to present a new classification of agroforestry, but to exemplify the use of economic theory to address agroforestry problems.

Take a static deterministic model representing a firm that produces a single output, y, by using natural inputs, such as mulch or shade provided by trees, represented by the vector x_k. The production function is:

$$y = f(x_k) \tag{3.1}$$

The model assumes the usual production function properties of a positive, but nonincreasing marginal product from the input x_k. The output y has a known price p while the vector of natural resource inputs x_k has a vector of extraction cost (or maintenance cost) of v_k. The profit function is:

$$\pi = p \cdot f(x_k) - v_k x_k \tag{3.2}$$

The optimal use of the natural resource can be obtained by maximizing equation 3.2. Assuming 3.1 is a concave and a first-order differentiable function, the first order condition that maximizes 3.2 is:

$$\begin{aligned} &{}^{d\pi}\!/_{dx_k} = p \cdot f'(x_k) - v_k = 0 \\ &p \cdot f'(x_k) = v_k \end{aligned} \tag{3.3}$$

Equation 3.3 represents the condition that maximizes profits by using inputs x_k. The optimal use of natural inputs is achieved when the marginal value product (MVP) $p \cdot f'(x_k)$ equals the extraction cost (v_k) which in turn is the marginal cost.

On the other hand, the optimal combination of inputs is addressed by assuming a production function of the form:

$$y = f(x_k, x_j) \tag{3.4}$$

where y is a single output sold for price p; x_k is a vector of k variable inputs, such as labor and pesticides; x_j is a vector of j flows of inputs from natural resources, such as shade and mulch. Variable inputs x_k have a vector of factor prices v_k, while the resource input flows x_j have an associated cost of c_j. The firm's cost function c, can be defined as:

$$c = v_k x_k + c_j x_j \tag{3.5}$$

The problem is stated as finding the minimum cost subject to the production function y_0. Thus, the problem is:

$$\min \quad c = v_k x_k + c_j x_j \tag{3.6}$$

subject to: $$y_0 = f(x_k, x_j)$$

The model assumes the usual production function properties of positive, but nonincreasing marginal product from the inputs x. In addition, y_0 is a concave and first-order differentiable function. Forming the Lagrangian,

$$L = v_k x_k + c_j x_j - \lambda \left[y_0 - f(x_k, x_j) \right]$$

the first order conditions state that:

$$\partial L / \partial x_k = v_k - \lambda \left(\partial f(\cdot) / \partial x_k \right) = 0 \tag{3.7}$$

$$\partial L / \partial x_j = c_j - \lambda \left(\partial f(\cdot) / \partial x_j \right) = 0 \tag{3.8}$$

$$\partial L / \partial \lambda = y_0 - f(x_k, x_j) = 0 \tag{3.9}$$

Dividing equation 3.7 by 3.8 yields the condition that the input price ratio is equal to the rate of technical substitution (RTS):

$$v_k / c_j = \left(\partial f(\cdot) / \partial x_k \Big/ \partial f(\cdot) / \partial x_j \right) = RTS_{x_k, x_j} \tag{3.10}$$

This relationship has two consequences for natural resource allocation. First, if c_j does not reflect all costs, the resource will be overused. Second, changes in factor market prices, v_k, or changes in the ability to substitute inputs will change the use of natural resources. Technical change can modify resource cost, quality, or degree of substitutability (HOWITT & TAYLOR, 1993).

3.1.2 Trees as outputs

There are also two main economic questions related to the use of trees as outputs: 1) finding the optimal combination of the agroforestry or silvopastoral components, and 2) finding the optimal rotation cycle. Agroforestry economists, based on neoclassical production function theory, have addressed the land allocation problem since the 1980s (FILIUS 1982, ETHERINGTON & MATTHEWS 1983, HOEKSTRA 1983, MERCER 1991, BRIGHT

2004). On the other hand, the estimation of optimal rotational cycles has been addressed by forest economics (e.g. GREGORY 1987; KLEMPERER 1996) and will not be discussed in this document.

Land allocation is analyzed with a profit function that (for simplicity) assumes two outputs and one vector of natural inputs. The two production functions are:

$$y_1 = f_1(x_k)$$

$$y_2 = f_2(x_k)$$

Outputs y_1 and y_2 are produced with a natural input x_k. By assigning p_1 as the price of output y_1, and p_2 the price of y_2, the profit function is:

$$\pi = p_1 \cdot f_1(x_j) + p_2 \cdot f_2(x_j) \tag{3.11}$$

Assuming the same desirable characteristics for the production functions (i.e. concave and first-order differentiable functions), the problem is solved by maximizing 3.11. The first order condition states that:

$$d\pi \big/ x_k = p_1 \cdot f'(x_k) + p_2 \cdot f'(x_k) = 0 \tag{3.12}$$

Rearranging 3.12 yields,

$$p_1 \cdot f'(x_k) = -P_2 \cdot f'(x_k) = MVP(y_1) = MVP(y_2) \tag{3.13}$$

Equation 3.13 mentions that the optimal choice for the enterprise occurs when the marginal value product (MVP) per unit of a variable resource is equal in both enterprises (e.g. trees vs. agriculture or pasture). It says that a variable input should be transferred from one enterprise to another up to the point where the MVP of each unit of the input is equal for both enterprises. Agroforestry systems will vary between farmers and adoption will depend not only upon profitability, but also upon the initial farmer resource endowment.

3.1.3 Multipurpose trees

Multipurpose trees should be studied in an intertemporal framework. The main economic question is related to finding the optimal land allocation among trees, agriculture, and livestock. Agroforestry economists (FILIUS 1982, ETHERINGTON & MATTHEWS 1983, HOEKSTRA 1983) and forest economist (GREGORY 1987; KLEMPERER 1996) have analyzed the optimal land allocation problem through the use of the **joint production theory**, which is based on neoclassical economic theory.

Joint production occurs "whenever the same production facility is used to produce two or more products" (GREGORY 1987:362). The producer is faced with the problem of allocating resources (i.e. land) to produce outputs: say, for example, trees and cattle. If trees and cattle share the same unit of land, as in silvopastoral systems, the producer may be confronted with three production possibilities (FILIUS 1981), which are exemplified in Figure 3.1. Figure 3.1 shows on the horizontal axis the area devoted to trees and on the vertical axis the area with cattle. The origin, *0*, represents pure cattle production while point *F* represents pure forest production. The segment *ab* denotes a **complementary** relationship between trees and cattle; i.e. when the increase in the production of trees allows an increase in the production of cattle. Complementarity exists, for example, when the shade of trees increases the production of milk in dairy farms.

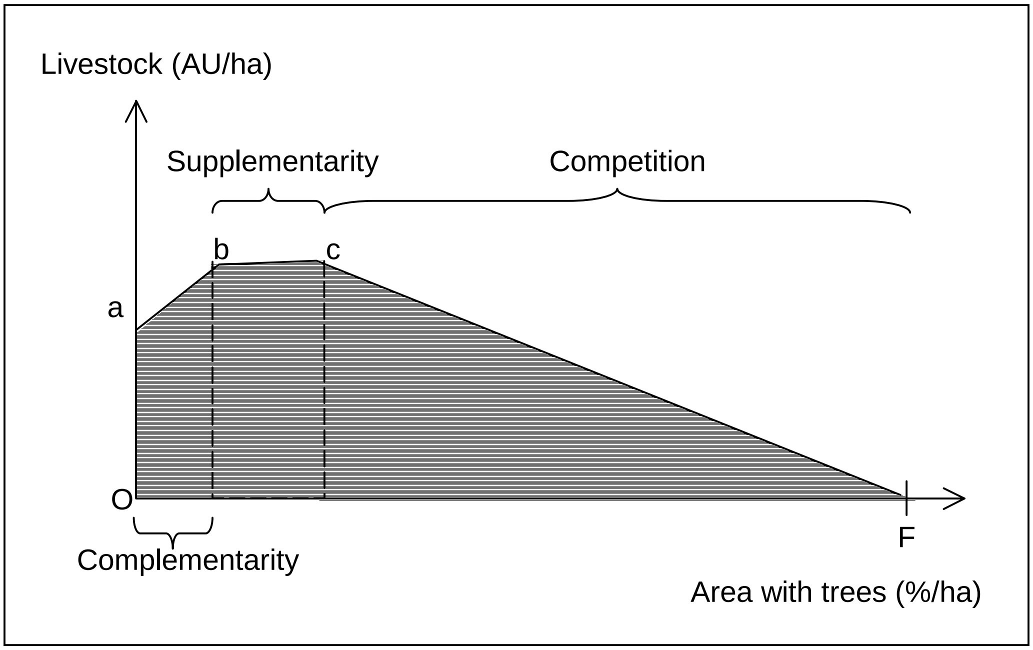

Figure 3.1. Example of production and economic relationships in agroforestry: complementarity (segment *ab*), supplementarity (segment *bc*) and competition (*cF*).

When the increase of one component does not affect the production of the other one, we have a **supplementarity** or **independent** relationship, which is exemplified in Figure 3.1 by the segment *bc*. Independent relationships can be found in agroforestry systems when the production of agricultural products does not compete for space with timber production.

In some cases, however, the increase in tree cover is only possible by decreasing the area devoted to cattle and *vice versa*. This is a **competition** relationship, which is exemplified in Figure 3.1 by segment *cF*.

The three relationships can occur over the whole range of production. Between the same crops we can find intervals of complementarity, supplementarity and competition. Also, within a certain interval there may be forces of complementarity, supplementarity and competition.

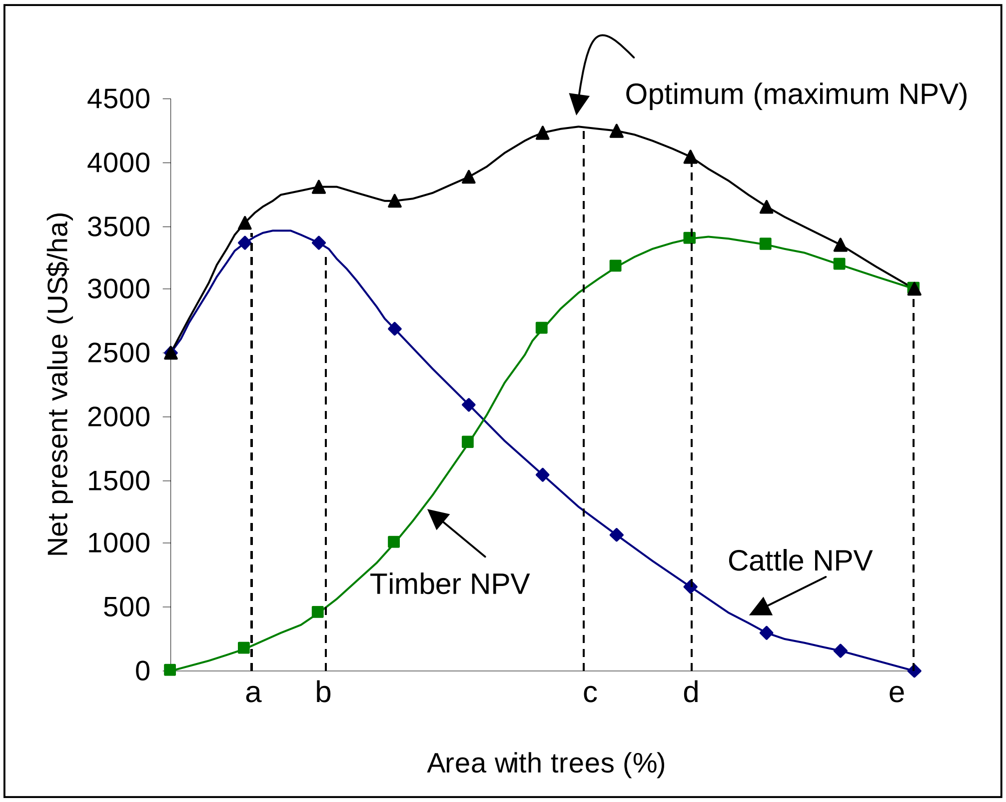

Figure 3.2. Hypothetical cattle and timber net present values (NPV in US$/ha). NPV are constant and perpetual, and they are annualized. The maximum profit is achieved with tree cover represented at point *c*. The segments *0a* and *de* represent a complementary relationship; segment *ab* represents an independent relationship, and segment *bd* represents a competition relationship.

A rational producer may not have problems in allocating land in the presence of complementarity and supplementarity relationships. For example, consider the hypothetical net present revenues for trees, cattle, and total depicted in Figure 3.2. If the producer has a pure cattle enterprise, the total NPV will be equal to $2,500. This producer may increase profits to $3,500 if the land devoted to trees is increased up to point *a*, since both cattle and tree revenues are increased; i.e. the producer faces a complementarity relationship. Moreover, the producer can increase profits if more land is devoted to trees up to point b, since cattle profits are kept constant and revenues of the tree component are increased (i.e. an independent relationship). In this case, total net profits are increased from $3,500 to $3,800.

However, if our hypothetical producer further increases tree cover, cattle profits will start decreasing but both tree revenues and total NPV will increase. The producer will keep increasing tree production as long as the added NPV of the tree component exceeds the loss in cattle NPV. The fundamental idea in joint production theory is that the total NPV will be maximized when the added tree NPV just equals the loss in the cattle NPV (KLEMPERER 1996). Figure 3.2 shows that the maximum total benefit in our example is achieved at point c; at this point, the producer obtains a total net profit of $4,250.

Joint production theory has been implemented in empirical studies by using mathematical programming (GREGORY 1987). Linear programming models have been developed to analyze multiple uses of forest, mainly by the US Forest Service. The approach has been to maximize timber yields, subject to constraints that include the production of non-timber products or services (GREGORY 1987).

However, since joint production is rooted in neoclassical economic theory, it fails to address the cases of market failure concerning the use of natural resources and agroforestry systems (HOWITT & TAYLOR 1993). These market failures involve externalities, uncertainties, and intertemporal allocation. Natural resource economic theory has addressed these problems and will be developed in this document as the theoretical framework to analyze agroforestry externalities and policies. The review of natural resource economic theory is based on SAMUELSON (1976), HARTMAN, (1976), CONRAD AND CLARK (1987), HOWITT & TAYLOR (1993), ZILBERMAN *et al.* (1993), and CONRAD (1999).

3.1.4 A natural resource economic model

The objective of natural resource economics is to find sustainable resource management systems. Sustainability is achieved when the resource stock does not change over time and, therefore, there are constant yields. It also implies that extraction stock is equal to the resource growth rate. When all these elements hold, the system is at steady-state. At a steady state, the biophysical components and the economic variables stay constant over time. Natural resource economists study the conditions under which sustainable management of renewable resources results in steady-state outcomes (ZILBERMAN *et al.* 1993:99-101).

A natural resource economic model consists of two parts. First, there is an equation that represents stock changes over time and is called the resource equation of motion. In a discrete-time representation, the equation of motion is represented by changes in the resource stock in two periods:

$$X_{t+1} - X_t = F(X_t) - Y_t \tag{3.14}$$

where X_t is the stock of natural resource in time t, $F(X_t)$ is the stock growth function that depends on the stock of natural resource, and Y_t is the resource harvest in time t.

Second, there is an objective function that maximizes 'social net benefits' of the resource harvest. Social benefits are the gains that society obtains by having and harvesting the resource. Net benefits are given by the function $\pi_t = \pi(X_t, Y_t)$, where X_t and Y_t have been already defined. The discounted profit function from time $t=1, 2, \ldots T$ is denoted by:

$$\pi = \sum_{t=0}^{T} \delta^t \pi(X_t, Y_t) \tag{3.15}$$

where $\delta = 1/(1+r)$ is the discount factor for the given discount rate r. The economic objective will be to find the harvest schedule, Y_t, which will:

$$\left.\begin{aligned} &\max \pi = \sum_{t=0}^{T} \delta^t \pi(X_t, Y_t) + V(X_T) \cdot \delta^T \\ \text{subject to:}\quad &X_{t+1} - X_t = F(X_t) - Y_t \\ &X_0 = X(0) \end{aligned}\right\} \tag{3.16}$$

where $V(X_T)\delta^T$ is the terminal value at time T. The objective is to maximize π, the present value of net profits, subject to the equation describing resource dynamics and the initial resource condition X_0.

Model 3.16 is a so-called bioeconomic model because it incorporates a biophysical component (equation of motion) and an economic component (profit maximization). This definition of bioeconomic model will be used elsewhere in the document.

3.1.4.1 Optimal management of tree resources

The optimal use of tree resources is obtained by solving 3.16. It is done by defining the present-value Hamiltonian:

$$H(X_t, Y_t, \lambda_{t+1}) = \pi(X_t, Y_t) + \delta\lambda_{t+1}[F(X_t) - Y_t] \qquad (3.17)$$

where λ represents the *costate* variable or shadow price associated with the resource stock. The first order conditions for maximization of 3.17 are (CONRAD & CLARK 1987):

$$\partial H / \partial Y_t = \partial\pi(\cdot) / \partial Y_t - \delta\lambda_{t+1} \qquad (3.18)$$

$$\delta\lambda_{t+1} - \lambda_t = -\partial H(\cdot) / \partial X_t = -\left(\partial\pi(\cdot) / \partial X_t + \delta\lambda_{t+1} F'(X_t)\right) \qquad (3.19)$$

$$X_{t+1} - X_t = \partial H(\cdot) / \partial(\delta\lambda_{t+1}) = F(X_t) - Y_t \qquad (3.20)$$

$$\lambda_T = V'(\cdot) \qquad (3.21)$$

$$X_0 = X(0) \qquad (3.22)$$

Equation 3.18 accounts for two types of costs. The first term on the right hand side (RHS) of 3.18 is the marginal net benefit of an additional unit of the resource harvested in period t. It is consistent with previous analyses (compare with equation 3.3). In the dynamic context, however, there is a second term to be accounted for in determining the optimal Y_t. The second term on the RHS of 3.18 reflects the influence of harvest on the stock of the resource available for future use. If an increase in Y_t reduces the amount of variable X_{t+1}, then this second term reflects an inter-temporal cost, often referred to as the user cost. Then the second cost reflects the marginal losses that might be incurred over the remaining future if the rate of resource extraction were to be increased.

Equation 3.19 is a difference equation which must hold through time and relates the change in the Lagrange multiplier to terms involving partials of X_t. Equation 3.19 states that the marginal value of an additional unit of the resource in period t equals the current period marginal net benefit, $\partial\pi(\cdot)/\partial X_t$, plus the marginal benefit that an unharvested unit will convey in the next period, $\delta\lambda_{t+1}[1+F'(X_t)]$.

Equation 3.20 is a re-arrangement of the difference equation for the state variable in equations 3.14 and 3.16. Finally, equations 3.21 and 3.22 are the boundary conditions defining the terminal value of the multiplier sequence (λ_T) and the initial condition on the state variable.

Equations 3.18 to 3.22 form a system of (3T+1) equations in (3T+1) unknowns: Y_t for t=0,1…T-1; X_t for t=0,1,…T; and λ_t for t=1,…T. It may be possible to solve the system simultaneously for Y_t, X_t, and λ_t but in practice this may not be feasible with a complex model. The structure of a particular problem may suggest more efficient solution algorithms than treating this as a fully simultaneous system. If Y_t, X_t, and λ_t are restricted to be non-negative, a solution may be obtained via a nonlinear programming algorithm with the assistance of the Kuhn-Tucker conditions (CONRAD & CLARK 1987).

In an infinite-horizon problem, i.e. $T \to \infty$, equations 3.18—3.20 become an infinitely large system of equations in an infinite number of unknowns. Under certain conditions such problems will converge to a period where Y_t, X_t, and λ_t are unchanging. In this infinitely long latter period the variables are said to have reached a steady state because $X_{t+1} = X_t = X^*$, $Y_{t+1} = Y_t = Y^*$, and $\lambda_{t+1} = \lambda_t = \lambda^*$. The triple [$X^*$, Y^*, and λ^*] is called a steady-state optimum.

In order to solve for the steady-state, we can dispense with all the time subscripts in equations 3.18—3.20, which become three equations in three unknowns, X^*, Y^*, and λ^*, and may be written as:

$$\delta\lambda = {\partial \pi(\cdot)}/{\partial Y} \tag{3.23}$$

$$\delta\lambda - \lambda = -\left({\partial \pi(\cdot)}/{\partial X} + \delta\lambda F'(X) \right) \tag{3.24}$$

$$Y = F(X) \tag{3.25}$$

Equation 3.24 can be re-arranged by using the definition $\delta = 1/(1+r)$ and by grouping $\delta\lambda$ to yield:

$$\delta\lambda\left[1 + F'(X) - (1+r)\right] = -{\partial \pi(\cdot)}/{\partial X} \tag{3.26}$$

Equation 3.26 can be further re-arranged to yield:

$$-\delta\lambda\left[r - F'(X)\right] = -{\partial \pi(\cdot)}/{\partial X} \tag{3.27}$$

Multiplying both sides by –1, substituting 3.23 into 3.27, and isolating r on the RHS yields:

$$F'(X) + \frac{\partial\pi(\cdot)/\partial X}{\partial\pi(\cdot)/\partial Y} = r \tag{3.28}$$

Equation 3.28 has been called the *fundamental equation of renewable resources*. Along with 3.25 it will define the optimal steady state for X and Y. On the left hand side (LHS) of equation 3.28, the term F'(X) can be interpreted as the marginal net growth rate. The second term is called the marginal stock effect and measures the marginal value of the stock relative to the marginal value of harvest. The two terms on the LHS sum to what might be interpreted as the resource's internal rate of return. Equation 3.28 thus requires that the optimal steady-state values of X and Y cause the resource's internal rate of return to equal the rate of discount, r, which presumably equals the rate of return on investments elsewhere in the economy. Finally, equation 3.25 can be interpreted intuitively. At the bioeconomic optimum, harvest must equal net growth.

In order to exemplify above conclusions, consider Figure 3.1. The curve Y=F(X) denotes all the Y and X combinations where resource stock is in steady state. The YY curves denote alternative loci of points where the price and output are at a steady state. The renewable resource systems attain steady states at points where YY and Y=F(X) intersect.

The curve YY^1 in Figure 3.1 presents a situation where the marginal stock effect is greater in magnitude than the discount rate r in equation 3.28. This would occur if less stock significantly increases costs. In such a case the steady state resource stock, X_1, is greater than the stock associated with maximum sustainable yield X_m. The curve YY^2 represents a situation where the discount-rate effect is stronger than the marginal stock effect. The steady state in resource stock in the case is X_2, which is smaller than X_m. Finally, at YY^3 the bioeconomic optimum would imply that depletion of the resource is optimal. In this case the discount rate is relatively large, and the optimal policy will not lead to a steady state.

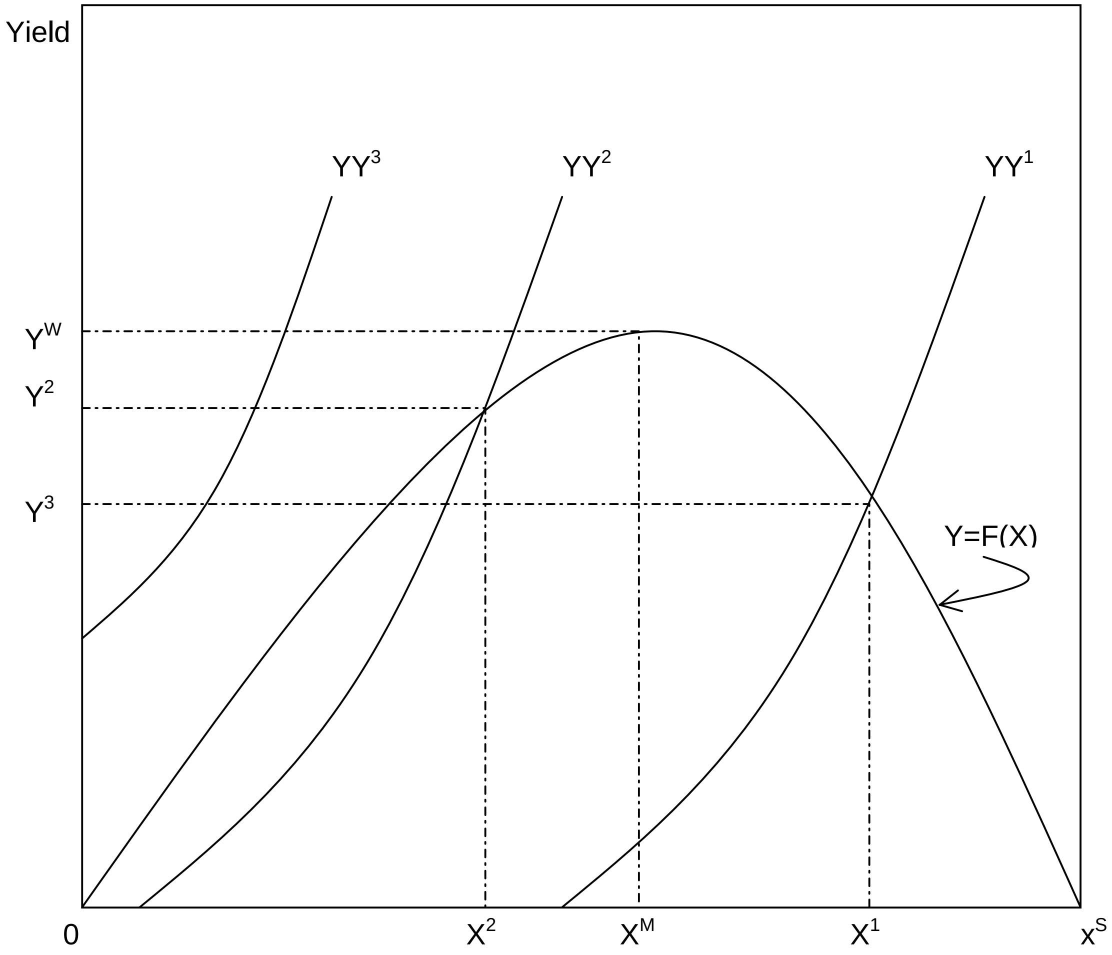

Figure 3.3. Three possible scenarios of optimal dynamic management of renewable resources. The vertical axis shows the resource yield (Y) and the horizontal axis shows the resource stock (S^X). The function Y=F(X) represents the different yields depending upon the stock level. The curves YY^n show three scenarios of dynamic management. The curve YY^1 has the greatest stock level (S^1) and a yield of Y^1; the curve YY^2 has a lower optimal stock level. The curve YY^3 is the case when the resource depletion is optimal. The meaning of the YY curve is explained in the text. (Source: ZILBERMAN et al. 1993).

3.1.4.2 The case of external economies

Now consider an extension of model 3.16 to account for external economies produced by renewable resources such as biological corridors, soil conservation, and carbon sequestration. The environmental service is given by the function $R(X_t)$; the marginal benefit from the resource stock is assumed positive but decreasing, $Rx>0$ and $Rxx \leq 0$. For example, trees dispersed in grassland produce goods (e.g. timber) and environmental services (e.g. biodiversity conservation by providing resources and connecting landscape). Adding $R(X_t)$ to equation 3.16 yields:

$$\left.\begin{aligned} &\max \pi = \sum_{t=0}^{T} \delta^{t} \cdot \left[\pi(X_t, Y_t) + R(X_t)\right] + V(X_T) \cdot \delta^{T} \\ \text{subject to:} \quad &X_{t+1} - X_t = F(X_t) - Y_t \\ &X_0 = X(0) \end{aligned}\right\} \tag{3.29}$$

The present-value Hamiltonian is given by:

$$H(X_t, Y_t, \lambda_{t+1}) = \pi(X_t, Y_t) + R(X_t) + \delta\lambda_{t+1}\left[F(X_t) - Y_t\right] \tag{3.30}$$

And the first order conditions for maximization of 3.29 are:

$$\partial H \big/ \partial Y_t = \partial \pi(\cdot) \big/ \partial Y_t - \delta\lambda_{t+1} \tag{3.31}$$

$$\delta\lambda_{t+1} - \lambda_t = -\partial H(\cdot) \big/ \partial X_t = -\left(\partial \pi(\cdot) \big/ \partial X_t + R'(X_t) + \delta\lambda_{t+1} F'(X_t)\right) \tag{3.32}$$

$$X_{t+1} - X_t = \partial H(\cdot) \big/ \partial\left(\delta\lambda_{t+1}\right) = F(X_t) - Y_t \tag{3.33}$$

$$\lambda_T = V'(\cdot) \tag{3.34}$$

$$X_0 = X(0) \tag{3.35}$$

Equations 3.31 – 3.35 are exactly the same as equations 3.18 – 3.22 with the only exception that the equation of motion of the shadow price must account for a new term, Rx. This term was defined previously as the external marginal benefit from the resource, and it was assumed positive.

In the case of the infinite-horizon problem, when $T \to \infty$, the triple (X^*, Y^*, and λ^*) is solved similarly as before to yield:

$$\delta\lambda = \partial \pi(\cdot) \big/ \partial Y \tag{3.36}$$

$$Y = F(X) \tag{3.37}$$

$$F'(X) + \frac{\partial \pi(\cdot) \big/ \partial X + R'(X)}{\partial \pi(\cdot) \big/ \partial Y} = r \tag{3.38}$$

The fundamental equation of renewable resources, equation 3.38, now has a term that increases the magnitude of the second term on the LHS of 3.38. Since it was assumed to be positive, the marginal stock effect becomes stronger and shifts the YY curve to the right, for example, from YY^3 to YY^2 in Figure 3.1. The net effect of incorporating an external economy is increasing the optimal stock of the natural resource, and therefore the likelihood of exhaustion of the resource is reduced.

The reader can realize that the incorporation of the external economy does not necessarily imply conserving a full stock of the resource –as it would be expected from a conservationist point of view. A non-harvest outcome can result in certain conditions (such as protected areas), but in other cases some level of harvesting may be socially optimum.

3.1.4.3 Policy considerations

The model 3.29 and its solutions assume the externality is fully recognized by the market. This can be the case when private farms receive payments for the environmental service they are providing (e.g. an ecotourism farm) or when a centralized organization manages the resource. However, when the externality is not internalized in the market, a lower stock than the social optimum will be preferred by private firms. In this case, policy intervention is required. The question is then: what are the available instruments to correct for externalities?

In order to exemplify, consider the case of biodiversity conservation in Guanacaste. The problem in this case is that farmers remove more forest and trees than is desirable for biodiversity conservation. Markets do not internalize the external economy provided by trees (i.e. the provision of resources, habitats and landscape connectivity). Farmers only receive profits from selling timber.

Suppose there are N farmers of the renewable resource stock (i.e. dispersed trees), with extraction (effort) cost functions $c_i(E_i)$, $i=1,\dots N$, and with identical production functions:

$$h_i = \phi(X, E_i) \qquad (3.39)$$

If the price of the harvested resource is p, each exploiter attempts to maximize his short-term net revenues:

$$\max_{Ei\geq 0} = \left\{ p \cdot \phi(X, E_i) - c_i(E_i) \right\} \qquad (3.40)$$

Thus the exploiter merely equates (short-term) marginal revenues and marginal cost (compare with equation 3.3):

$$c'_i(E_i) = p\frac{\partial\phi}{\partial E_i}(X, E_i) \tag{3.41}$$

Because of the stock externality, however, this is not a social optimum. The social optimum would be:

$$\max\int_0^\infty e^{-\delta t}\sum_i\left[p\phi(X,E_i)-c_i(E_i)+R(X)\right]dt$$

subject to
$$\dot{X} = F(X)-\sum_i\phi(X,E_i) \tag{3.42}$$

where R(X) is the value of the externality in function of the renewable resource (in situ).

The corresponding current-value Hamiltonian is:

$$H=\sum_i\left[p\phi(X,E_i)-c_i(E_i)+R(X)\right]+\mu(t)\left[F(X)-\sum_i\phi(X,E_i)\right] \tag{3.43}$$

where μ is the shadow price. The necessary conditions include $\partial H/\partial E_i = 0$, or:

$$\partial H\Big/\partial E_i = p\,\partial\phi(\cdot)\Big/\partial E_i - c'_i(E_i) - \mu\,\partial\phi(\cdot)\Big/\partial E_i = 0$$

$$c'_i(E_i) = p\,\partial\phi(\cdot)\Big/\partial E_i - \mu\,\partial\phi(\cdot)\Big/\partial E_i$$

$$c'_i(E_i) = (p-\mu)\,\partial\phi(\cdot)\Big/\partial E_i \tag{3.44}$$

Since μ equals the marginal value of the resource stock X, it is positive in all cases. It therefore follows immediately from a comparison of equations 3.41 and 3.44 that the competitive resource exploiters always extract more timber, relative to the social optimum. If the price received by the individual is reduced by the amount of the shadow price, then the individual will exert the optimal level of effort. In other words, a tax on resource harvest equal to the shadow price causes competitive resource exploitation to coincide with the optimum.

The value of the externality is recognized in the shadow price. For example, a second necessary condition requires $-\partial H/\partial X = \dot{\mu}$. As CONRAD & CLARK (1987:27) argue, the shadow price equals the marginal value of the state variable at time t, which in this case accounts for $\partial\phi(\cdot)/\partial X$ and $R'(X)$.

The discussion so far has shown that a tax can be used to correct the failure raised by the presence of externalities. However, a subsidy can also be used and have the same positive result. The resource shadow price μ is the optimal annual amount that farmers should be paid in order to avoid tree cutting.

3.2 Empirical considerations and mathematical programming

The theoretical review gave insights into the economics of renewable resources applicable to agroforestry. The optimal resource stock, optimal harvest, and policy implications in the case of externalities were reviewed. However the solution of optimal control models is not trivial. An analytical solution is only possible with very simple models and a direct numerical solution is plagued with difficulties (CONRAD & CLARK 1987, CACHO 2000). In practice, most applied optimal control problems are solved as either nonlinear programming or dynamic programming models (STANDIFORD & HOWITT 1992). These techniques can handle a variety of difficult problems and are not restricted to continuous and differentiable functions, but they have important limitations (CACHO 2000).

In order to construct the empirical framework, this section discusses numerical solutions focusing on dynamic programming and nonlinear programming. The section starts with definitions of optimization problems and linear programming models (LP) which are the bases for understanding NLP and DP. It then describes the main characteristics of NLP and DP stressing the main characteristics and limitations of DP and NLP in solving bioeconomic models. The literature review is based on CHIANG (1987), KENEDY (1986), and DI PILLO & PALAGI (2002).

3.2.1 Optimization problems

An optimization problem may be formulated in a general framework with an objective function to:

$$\text{Optimize } f(x) \tag{3.45}$$

subjected to constraints:

$$g(x) = 0 \tag{3.46}$$

and bound constraints on the decision variables:

$$\underline{x} < x < \overline{x} \tag{3.47}$$

where *x* is a vector of *n* decision variables, *g(x)* are constraints, $\underline{x}$ is the lower bound and $\overline{x}$ is the upper bound. Optimization problems have two essential parts: 1) an objective function that describes the performance criteria of the system (it can either maximize or minimize), and 2) constraints that describe the system of the process that is being designed or analyzed.

Important definitions in optimization problems are feasible solutions, feasible regions, and optimal solutions. A feasible solution is a set of values for the decision variable that simultaneously satisfies the constraints. A feasible region is the region of feasible solutions defined by the constraints. An optimal solution is a set of values for the decision variables that satisfy the constraints and provides an optimal value for the objective function.

3.2.2 Linear programming

Mathematical programming can be done through linear models, nonlinear models, and dynamic models. The LP model's main characteristic is that both the objective function and constraints are linear functions of the decision variables. LP has the general form:

$$\max(or \min) x_0 = \sum_{j=1}^{n} c_j x_j \tag{3.48}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j = b_i, \text{ for } i = 1, 2, \ldots m \tag{3.49}$$

$$x_j \geq 0, \text{ for } j=1,2,\ldots n \tag{3.50}$$

where c_j is the objective function coefficient, a_{ij} are the technological coefficients, and b_i are the right hand side coefficients.

3.2.3 Nonlinear programming

A nonlinear programming (NLP) model can have nonlinear functions in the objective or constraint functions. A general NLP problem with the nonlinear objective will:

$$\text{Minimize } f(\mathbf{x}) \qquad (3.51)$$

subject to:

$$g_i(\mathbf{x}) = 0 \quad i = 1, \ldots, m \qquad (3.52)$$

$$\underline{x_i} \leq x_i \leq \overline{x_i} \quad j = 1, 2, \ldots, n \qquad (3.53)$$

in which equation 3.53 is a bound constraint for the j-th decision variable.

The solution of NLP models is based on the Kuhn-Tucker conditions. These conditions must be satisfied at any constrained optimum, local or global, of any LP and NLP problems.

The Kuhn-Tucker conditions are almost satisfied if the constraints are linear (i.e. only the objective function is nonlinear). It is an important limitation in solving bioeconomic models since the biophysical component is almost always nonlinear. However, the Arrow-Enthoven Theorem (CHIANG 1987) gives a test to estimate whether the nonlinear restrictions qualify for a solution.

Nonlinear programming is the most common way of solving optimal control models. In general terms, this technique consists of defining the state and control variables in each time period as activities, and specifying the equations of motion as non-linear constraints linking variables across time periods (STANDIFORD & HOWITT 1992). With this technique, the number of decision variables in the NLP model is determined by the number of control and state variables multiplied by the number of time periods in the planning horizon, not counting other auxiliary activities and constraints that may be required by the particular problem. The most common software tool used in published reports of this type is GAMS/MINOS (BROOKE *et al.* 1998). It is generally much simpler to implement a NLP than a DP model, but with complex non-linear models the finding of a global maximum can fail (CACHO 2000).

3.2.4 Dynamic programming

Dynamic Programming (DP) is a convenient and powerful alternative to solve optimal control problems numerically. The main characteristic is that DP decomposes an N-decision problem into a sequence of N separate, but interrelated, single-decision subproblems. Using decomposition, a problem is solved more efficiently, resulting in significant computational savings when compared with a direct solution.

The algorithms to solve DP problems are the discrete differential dynamic programming and the differential dynamic programming. The greatest strength of dynamic programming may be in solving discrete problems, particularly where the underlying functions are not smooth and “nice”. The dynamic programming approach permits very efficient computer algorithms to be developed for such problems. But there are some concerns about the *curse of dimensionality*, which is related to the rapid growth of computer time and the core memory requirement associated with multiple state variables. Then, for multiple state variables, the NLP model may be preferred.

In this research, an NLP model was preferred because of the ease of using algebraic language (GAMS, BROOKE *et al.* 1998) and computational solvers (MINOS, MURTAG *et al.* 2003). In addition, the variables and functions, which conform the main empirical model, can be run in a NLP model. Since DP requires more computational training, NLP had an advantage in our case.

3.3 Chapter summary

This chapter first presented the economics of renewable natural resources as the theoretical framework to analyze agroforestry policies. The review started by analyzing the neoclassical production function theory that is the base of the joint production theory. However, the neoclassical production theory fails to address market failure (such as externalities, uncertainties, and intertemporal allocation) which are relevant in natural resources and agroforestry systems. Natural resource economic theory gave insights about the steady state and policy interventions to correct for externalities. For positive externalities, a subsidy should be set equal to the resource shadow price.

Although the optimal control theory helped to analyze the general framework, direct numerical solutions (i.e. simultaneous solution for unknown variables) may not be feasible with a complex model. In practice, most applied optimal control problems are solved as either nonlinear programming or dynamic programming models. Therefore, this chapter developed general characteristics of mathematical programming models focusing on NLP and DP as the empirical framework. In this research, NLP model was preferred because of the easy in using algebraic language such as GAMS (BROOKE *et al.* 1998) and solvers such as MINOS (MURTAG *et al.* 2003).

PART II

THE EMPIRICAL STUDY

CHAPTER 4

CATTLE RANCHING SYSTEMS IN GUANCASTE, COSTA RICA

This chapter introduces the empirical analysis by describing the main biophysical and socioeconomic characteristics of the study area in Cañas and Bagaces, Guanacaste, Costa Rica. The description is based on a farming systems approach (FSA) (BRUSH & TURNER 1987; NORMAN 2003), which means that the characteristics and general environment of the farms, as well as the interactions among them, are described. In order to summarize the social characteristics, the farms where grouped into farming systems depending upon the identification of homogeneous elements among them.

The identification of farming systems (or farm typology) was done with cluster analysis with production data from the National Livestock Census (MAG *et al.* 2001) and adjusted with survey information. The typology based on a cluster analysis guarantees that the formed groups have the maximum variability among groups and the minimum variance within groups (KAUFMAN & ROUSSEEUW 1990, ESCOBAR & BERDEGUÉ 1990). These are desirable characteristics in farm types in order to have clear recommendation 'domains' (TRIPP *et al*. 1990, KÖBRICH *et al*. 2003, SOLANO *et al*. 2000, ESCOBAR & BERDEGUÉ 1990).

Appendix A presents the methodology that was used to identify farming systems in the study area. This chapter presents the description of such typology. The chapter follows with section 4.1 that starts from a general perspective by describing the biophysical and macroeconomic characteristics that have influenced cattle farming in the study area. Section 4.2 presents the characteristics of three cattle systems: 1) small farm-size with low use of purchased inputs (SFS-LIU system), 2) medium farm-size with high use of purchased inputs (MFS-HIU system), and 3) large farm-size with high use of purchased inputs (LFS-HIU system). Section 4.3 describes the silvopastoral systems and the use of tree resources on cattle farms while Section 4.4 presents general characteristics of protected areas and biological corridors in the region. Section 4.5 concludes with a summary of main characteristics of cattle ranching in the area.

4.1 Agroecological and macroeconomic characteristics of Cañas and Bagaces

4.1.1 Study area

The study area is located in the **tropical dry forest** (bs-T) (Holdridge *et al.* 1971) of Cañas and Bagaces, Guanacaste, Costa Rica (Figure 4.1). This area has an extension of 570 km^2, representing 54% of the total dry forest of the country. Elevation ranges between 40 to 250 meters above sea level (Itcr 2000). The tropical dry forest is characterized by a six-month dry season and less than 1500 mm of precipitation. The landscape is generally flat (61% of land with less than 30% slope), and the mean annual temperature is 27°C (Restrepo 2002). Historically, it has been one of the hubs of cattle ranching in the country.

Figure 4.1. The tropical dry forest in Cañas and Bagaces, Guanacaste, Costa Rica.

The **universe of producers** was composed of 204 ranchers, who jointly own 35,190 hectares and 13,431 animal units (Mag *et al.* 2001) (Table 4.1). Calving-and-fattening is the predominant production system (76% of ranchers), while fattening-only (13%), dual purpose (9%), and dairy (2%) systems are relatively less important. Producers with a calving-and-fattening system sell young calves or heifers at weaning (less than 150 kg or 9 months of age), whereas producers with a fattening-only system buy calves or steers to feed (150 kg) and sell for slaughtering (450 - 500 kg live weight). Fattening-only is preferred by medium-size farms, with an average of 300 hectares and more than 100 animal units. Since calving-and-fattening is the predominant production system, this research was focused on this production system only.

Table 4.1. Cattle production systems in Cañas and Bagaces counties in 2000.

	Meat				
	Calving & Fattening	Only fattening	Dual Purpose	Dairy	Total
Number of Producers	156	28	18	2	204
% of total producers	76%	14%	9%	1%	100%
Total area (ha)	28,902	8,095	969	222	38,188
mean ha/farm (s.e.)	185 (30)	289 (105)	54 (20)	111 (97)	187 (27)
Total AU*	8,585	2,037	528	91	11,240
mean AU/farm (s.e.)	55 (7)	73 (17)	29 (7)	45 (29)	55 (6)

* One animal unit (AU) = 400 kg. Source: Census of Livestock, MAG *et al.* (2001).

The macro environment (i.e. the biophysical and macroeconomic characteristics) influences all of the cattle farms. The description of the macro-environment is divided into four parts: 1) agroecological characteristics, 2) agricultural policies, 3) forest policies, and 4) macroeconomic policies.

4.1.2 Agroecological characteristics

The predominant types of soils in the area are entisols and inceptisols (86%), which are mainly used for cattle ranching. The remaining 14%, divided among mollisols, vertisols, and alfisols are used for irrigated crops (ITCR 2000). The soils can be subdivided into flat, poorly drained; almost flat, well drained; undulating; and dissected (WIJFFELS 1996). Entisols in the area (63%) are eroded and thin soils with excessive drainage (WIJFFELS 1996). Entisols and inceptisols are not very fertile because of the low to moderate organic matter content. Regarding land use capacity, 58% of the land is classified for permanent crops (such as pastures), 27% is mainly for forest-like activities, and 15% is recommended for agricultural crops.

Shortages of rainfall during the dry season cause farmers to face seasonal forage availability. Seasonal forage availability and low fertility soils are the main agroecological characteristics in the study area. In addition, soil and pasture degradation are environmental concerns in cattle ranching. The first impact of soil degradation is a loss of productivity in pastures and consequently a reduction in cattle productivity (SZOTT *et al.* 2000; MAAS 1995).

4.1.3 Agricultural policies

In addition to agroecological characteristics, both agricultural and macro-policies have influenced cattle farming in the area. Cattle expansion in Costa Rica shares stylized features common to the rest of Central America (KAIMOWITZ 1996; MAAS 1995; SZOTT *et al*. 2000). First, a colonization policy allowed the expansion of the agricultural frontier. Then, ranchers introduced pasture and transformed the deforested landscape into pastures. Third, agricultural policies accompanied the process through subsidized credits while international markets helped with high meat prices (Figure 4.2) motivated by the expansion of the US meat demand. The recent decline of the cattle industry may be explained by the phasing out these two effects. Indeed, at the international level, low prices (Figure 4.2) were prompted by a weaker US demand for meat and contributed to lower cattle ranching profitability (MONTENEGRO & ABARCA 1998; KAIMOWITZ 1996). At the national level, a reduction, and in many cases, elimination, of agricultural policies also contributed to the cattle decline. In addition, environmental degradation contributed to the reduction of competitiveness in cattle ranching (MAAS 1995).

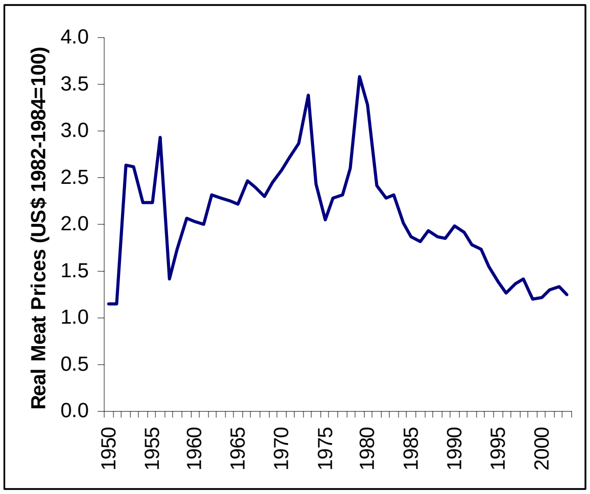

Figure 4.2. Costa Rica: Real export meat prices/kg 1950 to 2003 (constant US dollars, 1982-1984=100). The figure shows an increment of prices from 1950 to 1980 and then a steady decrease from 1980 to 2003 (Source: export prices: MIDEPLAN 2004; US consumer price index: USDL 2004).

The expansion and decline of meat policies marked two phases in cattle ranching (Figure 4.3). The first phase is represented by an increment in pastureland during the 1950–1984 period, favored by agricultural policies and high meat prices. In Central American countries, the expansion of export-oriented agricultural products such as meat resulted in deforestation (Nicholson *et al.* 1995; Kaimowitz 1996). During this period (1950-1984), the number of cattle and area dedicated to pastures grew 166% and 160%, respectively. The second phase witnessed a decrease of pastureland and an increase in forestland in the mid 1980's. During the 1984-2000 period, the number of head of cattle and pasture area decreased 45% and 10%, respectively (Dgec 1985, Mag *et al.* 2001.). Agricultural policy changes (e.g. less credit subsidies) and low meat prices have been addressed as the main causes of the reduction of pasture and livestock numbers (Kaimowitz 1996). Due to seasonal water constraints and poor soil characteristics, the shift to more productive agricultural crops is not easy in the region. The reduction of pasture area has resulted in the abandonment of land and increase of secondary forest (Arroyo-Mora *et al.* 2005; Flores & Monterroso 2002).

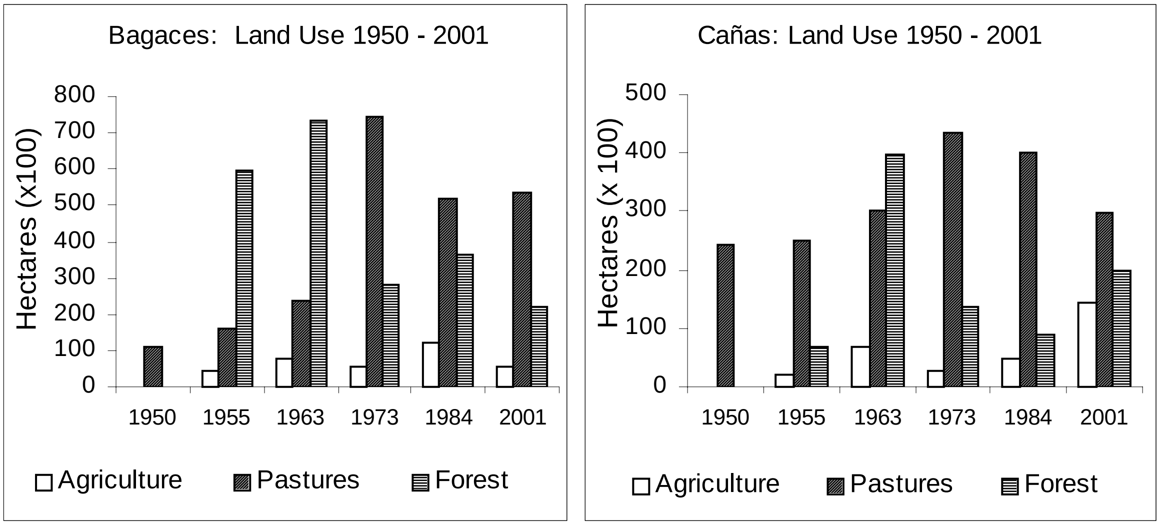

Figure 4.3. Bagaces (left) and Cañas (right): evolution of agricultural land use, as reported in the agricultural censuses from 1950 to 2001 (Source: Dgec 1953, 1959, 1965, 1973, 1985; Mag *et al*. 2001).

Agricultural land has increased mainly due to irrigation projects promoted in the area (Project Arenal-Tempisque), which started in the late 1970s. The agricultural crops cultivated on irrigated lands are rice and sugar cane, and to a lesser degree tomato, green pepper, watermelon, and beans. Fish farming, such as tilapia, is increasing in the area

(PROAMBIENTE 2000). The irrigated area is economically important in the region since it represents 95% of the irrigated area in Guanacaste. Four percent of Bagaces and 20% of Cañas is irrigated by the Project Arenal-Tempisque, accounting for a total of 19,794 hectares (SENARA 2002). The study area is mainly located outside the irrigation area.

4.1.4 Forest policies

Forest policy has also played a direct and indirect role in forming the current cattle landscape of the dry tropical forest. The effects of forest policy can be categorized into three aspects: 1) forest policy has been biased against forest management (KAIMOWITZ 1996); 2) the low incentives to manage natural forest have promoted the use of trees dispersed in pastures as a main source of timber in Costa Rica (MINAE 2004, CAMPOS *et al*. 2001); and 3) pastures are better ways to demonstrate property rights (KAIMOWITZ 1996). The last point has been studied widely in the literature (e.g. HANNA AND MUNASINGHE 1995) and no further explanation is needed.

Similar to other Central American countries, Costa Rica's forest policy has reduced the value of forestland and forest products instead of promoting sustainable forest management. Examples of such biases against forests are the "use of log export bans, low public expenditure on forestry, restriction on cutting timber, and cumbersome requirements for forestry management plans" (KAIMOWITZ 1996:60). It is worth mentioning, however, that Costa Rica has made enormous efforts to maintain a subsidy for forest management and conservation in the form of payments for environmental services. The incentives are now directed to priority areas located in biological corridors and buffer zones of protected areas (CBM 2002; FONAFIFO 2004).

Biased forest policies have promoted the extraction of trees dispersed in pastures due to less restrictive regulations for harvesting timber from agricultural lands (MINAE 2004; CAMPOS *et al*. 2001). CAMPOS *et al*. (2001) mention that 53% of the total timber consumed in Costa Rica comes from trees in grasslands, 33% from plantations, and 14% from primary forest. Weak institutions, with the inability to apply forest regulations, have also caused a rapid conversion of primary and secondary forest to agroforestry mainly in the Atlantic Zone of Costa Rica (CAMPOS *et al.* 2001; MINAE 2004).

4.1.5 Macroeconomic policies

Overvalued exchange rates in Costa Rica during the 1980s discouraged exports, which contributed in part to the reduction of cattle competitiveness and decline (KAIMOWITZ 1996). After structural adjustments in the late 1980s, exchange rates are no longer biased against export products and more 'neutral' macroprices can be expected in the whole economy.

Consumers in Central America have traditionally chosen to speculate with land prices, as land does not depreciate like other assets in the economy. For example, we found in the survey that the average real price of land rose 15% annually during the period 1989 to 1999 while the real (passive) interest rate (six month certificate of deposit in national banks) rose 8% per year for the period 1995 to 1999. During the 1999 to 2003 period, the rates were 8% and 5% for land prices and passive interest rates, respectively (CMCA 2004). This means that land as an asset was a slightly better option than bank deposits, considering that it is a low risk investment. Many interviewed landowners who live in the capital city allow natural regeneration on their land and do not invest in cattle management since their economic objective is to sell the land after a few years of possession. Landowners who pursue this economic objective generally have less than 100 hectares and were grouped as small farmers (see next section).

4.2 The cattle systems in Cañas and Bagaces

Although the macro-environment elements affect all farmers, different types of farmers react in different ways. The following paragraphs will analyze some of these reactions, focusing on general production characteristics of cattle farming systems. This research focused on cattle farmers, since this is the predominant production system in the area. The methodology for obtaining the cattle systems presented in this section is shown in Appendix A. Depending upon the initial farmer resource endowment and use of purchased inputs, three cattle systems were identified: 1) small farm-size with low use of purchased inputs (SFS-LIU system), 2) medium farm-size with high use of purchased inputs (MFS-HIU system), and 3) large farm-size with high use of purchased inputs (LFS-HIU system).

Table 4.2. Farm typology of cattle farms in Cañas and Bagaces and indicators of their structure, technology, social and forest characteristics.

	SFS-LIU*			MFS-HIU*	LFS-HIU*
	Calving	Dual purpose	Fattening only		
Ranks: Pasture Land (ha)	*1 to 150*	*1 to 250*	*1 to 400*	*151 to 500*	*+ 800*
Structural indicators					
-Total number of producers	111	18	26	18	12
-Total land (ha)	8,328	969	4,885	6,437	16,659
-Total land (percentage)	22%	3%	13%	17%	45%
-Mean farm area/farm (ha) (s.e.)	76 (8.7)	54 (19.5)	188 (33.5)	358 (31.0)	1,388 (249.9)
-Mean pasture /farm (ha) (s.e.)	42 (3.7)	43 (16.1)	155 (24.0)	286 (26.4)	800 (101.8)
-Mean animal units[#] /farm (s.e.)	24 (2.0)	29 (6.8)	67 (16.5)	114 (17.8)	292 (32.0)
Technological indicators					
-Stocking rate (AU/pasture) (s.e.)	0.7 (.05)	1.5 (0.4)	0.7 (.24)	0.4 (.07)	0.4 (.05)
-Purchased-inputs indicator[§]	3.6	4.11	4.5	4.7	6.3
-Main inputs reported:	Minerals, parasite control, vitamins and vaccines.	Minerals, parasite control, vitamins and vaccines	Minerals, parasite control, vitamins and vaccines	Minerals, parasite control, vitamins, vaccines, antibiotics and grass fertilization	Minerals, parasite control, vitamins, vaccines, antibiotics and grass fertilization
Social factors					
-Idle farms (% of total)	53%	71%	25%	0%	0%
-Owners with cattle as main income source (%)	32%	43%	33%	0%	29%
-Producers with agriculture	26%	57%	25%	17%	28%
Forest resources					
-% of farm with pasture	74%	82%	89%	83%	70%
-% of farm with plantations	1%	2%	0%	15%	15%
-% of farm w/natural regeneration	23%	10%	24%	4%	17%

*/ SFS-LIU: small farm-size with low use of purchased inputs; MFS-HIU: medium farm-size with high use of purchased inputs; and 3) LFS-HIU: large farm-size with high use of purchased inputs. [#]/ One animal unit equals a mature female of 400kg. [§]/ The purchased-inputs indicator was constructed with the average number of purchased inputs that farmers use of a total of 7 inputs. The MFS-HIU system was considered to be a high input use system because they fertilize pastures, which implies a higher amount of money spent on input purchases.

Source: Elaborated based on MAG *et al.* (2001) and Survey information by author (2001).

The main qualitative characteristics of the cattle systems are shown in Figures 4.3 to 4.5. These figures show the system's structure, inputs, outputs, processes, and supra-system elements (see Section 2.2 for explanation of concepts related to agricultural systems). The quantitative characteristics of the cattle systems are presented in Table 4.2. This table summarizes the structural, technological, and social characteristics of the three cattle systems. The description of each system is presented below.

4.2.1 Small farm-size with a low use of purchased inputs (SFS-LIU system)

The main characteristics of the SFS-LIU system are presented in Figure 4.4 and in Table 4.2. Five aspects define this system: 1) the process consists of calving-only, dual purpose, and fattening-only production systems; 2) the pasture area is small to medium (mean 92 ha, min 1, max 400 ha); 3) farmers use little, if any, feeding supplements or purchased inputs; 4) on average, 25% of the farm is under natural regeneration (ranks between 0% and 80% of the farm); and 5) 51% of the farms are in an idle state. I define 'Idle farm' as a farm whose owner was not producing any agricultural or livestock product at the time of the interview. Idle land, i.e. abandon pastures, allows for natural regeneration (ARROYO-MORA 2005).

The proportion of idle farms is higher for the SFS-LIU system (51% of farms) than for the high-input-use systems (0% for each system). In addition, the proportion of the farm with natural regeneration (abandoned pastures) is also greater for this group (25%) than for the high-input-use systems: 3% and 14% for the MFS-HIU and LFS-HIU systems, respectively.

Regarding the farm structure, two farm management units are found in the SFS-LIU system. Some producers (mainly the owners whose economic activity is related to urban areas) allow the farm manager to make decisions regarding input use and scheduling of field tasks, but the owner maintains the financial control. Other producers, who depend on agriculture to generate income, prefer to manage the farm by themselves. During the interview it was apparent that many small producers (we could not quantitatively estimate the proportion) depend on activities developed in the irrigation area rather than on livestock revenues, but they keep livestock as a risk reduction strategy.

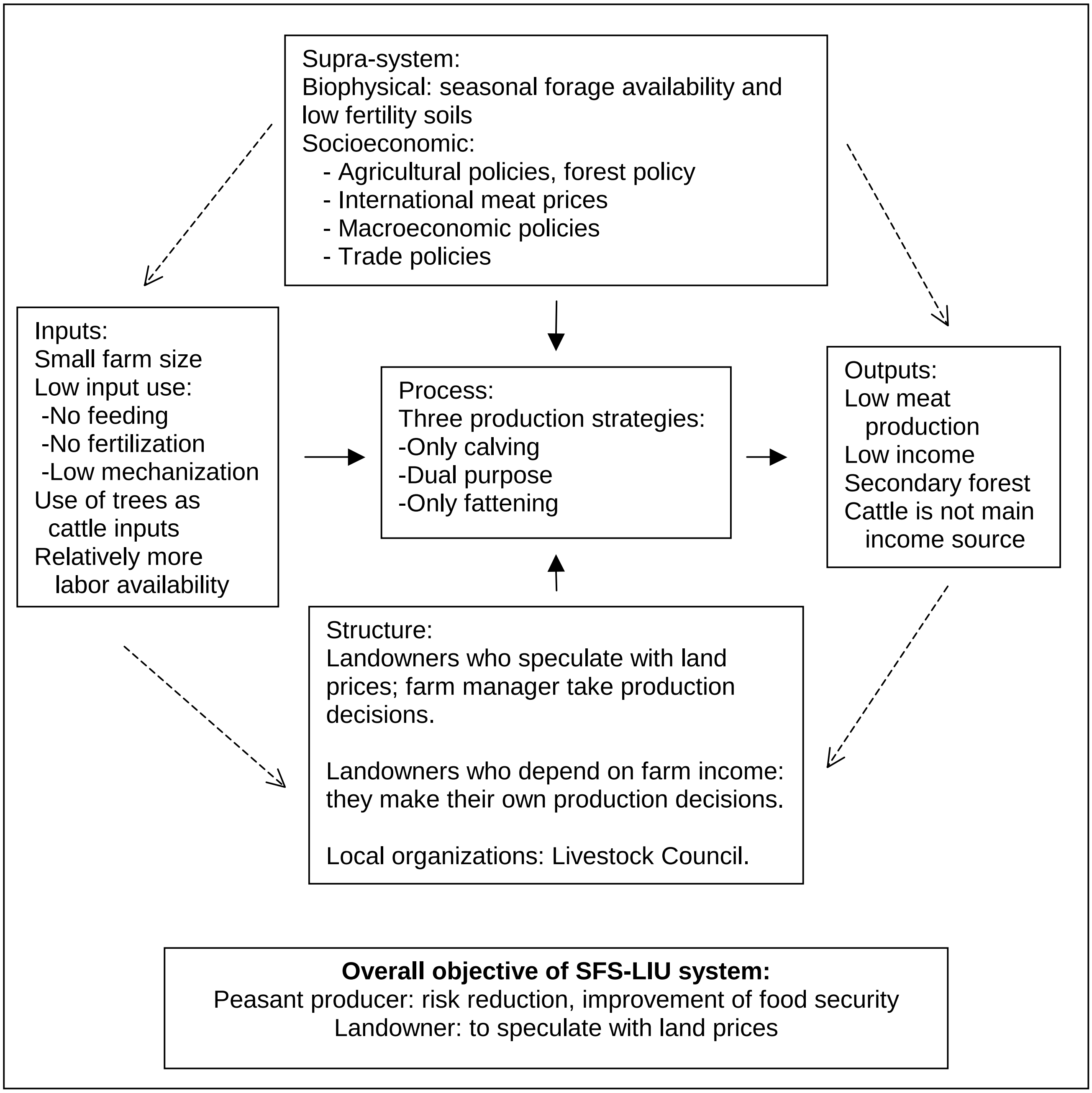

Figure 4.4. Qualitative characteristics and elements of the small farm-size with a low use of purchased inputs (SFS-LIU) system identified in Cañas and Bagaces, Costa Rica. [Source: Based on interviews with farmers (Flores and Monterroso 2002)].

An important element of the system's structure is the Cámara de Ganaderos de Cañas (*Cañas Livestock Council*), a private organization that governs the Cañas livestock auction. It enables producers to sell their animals in a weekly market although no other benefits (such as technical assistance) are provided to members.

The outputs generated by the SFS-LIU system are modest meat production. This means that owners who live in urban areas try to cover at least the farm management costs, which in many cases is equal to a one-year wage of one worker. Owners who depend on the agricultural sector keep cattle as a risk reduction strategy (e.g. they sacrifice animals when they need cash), since their income is mainly generated with other agricultural activities. RAMOS (2003) also found this strategy (along with sharecropping) in a study of sustainable livelihoods in the study area.

Finally, governmental organizations that may have a technical impact in both counties have seen their roles diminished due to governmental re-organization. For example, only 6% of farmers received technical assistance from the MAG (Ministry of Agriculture and Livestock) animal-health service and none of them from the MAG extension service during 2000 (MAG *et al.* 2001). In addition, the Ministry of Energy and Natural Resources concentrates its efforts on protected areas (such as national parks), paying little attention to the farmers in the surrounding areas. Irrigated areas receive more technical assistance from the Public Irrigation System Office (SENARA) but these areas are mainly dedicated to rice and sugar cane and therefore are beyond the scope of this research.

4.2.2 Medium farm-size with a high use of purchased inputs (MFS-HIU system)

Figure 4.5 shows qualitative characteristics of the MFS-HIU system while Table 4.2 presents quantitative data. The MFS-HIU have six main characteristics: 1) the process is defined by a calving production pattern, 2) the average farm area is 360 hectares (ranging from 180 to 500 hectares) which represents a medium size farm in the area, 3) the MFS-HIU system makes greater use of purchased inputs than the SFS-LIU system, 4) no idle farms were found in this system, 5) this system presents the smallest farm areas with natural regeneration (mean of 3% of the farm), and 6) forest plantations are more common for these producers. Some farmers reported as much as 250 hectares of forest plantations. This type of producer aims to increase their financial profits and therefore takes more risks than the SFS-LIU producers. The structure of the system is also characterized by owners whose main income is not generated by cattle. The farm is managed either by the farm manager (as in the SFS-LIU system) or by the owner himself (as in the LFS-HIU system). These producers are also part of the Cañas Livestock Council.

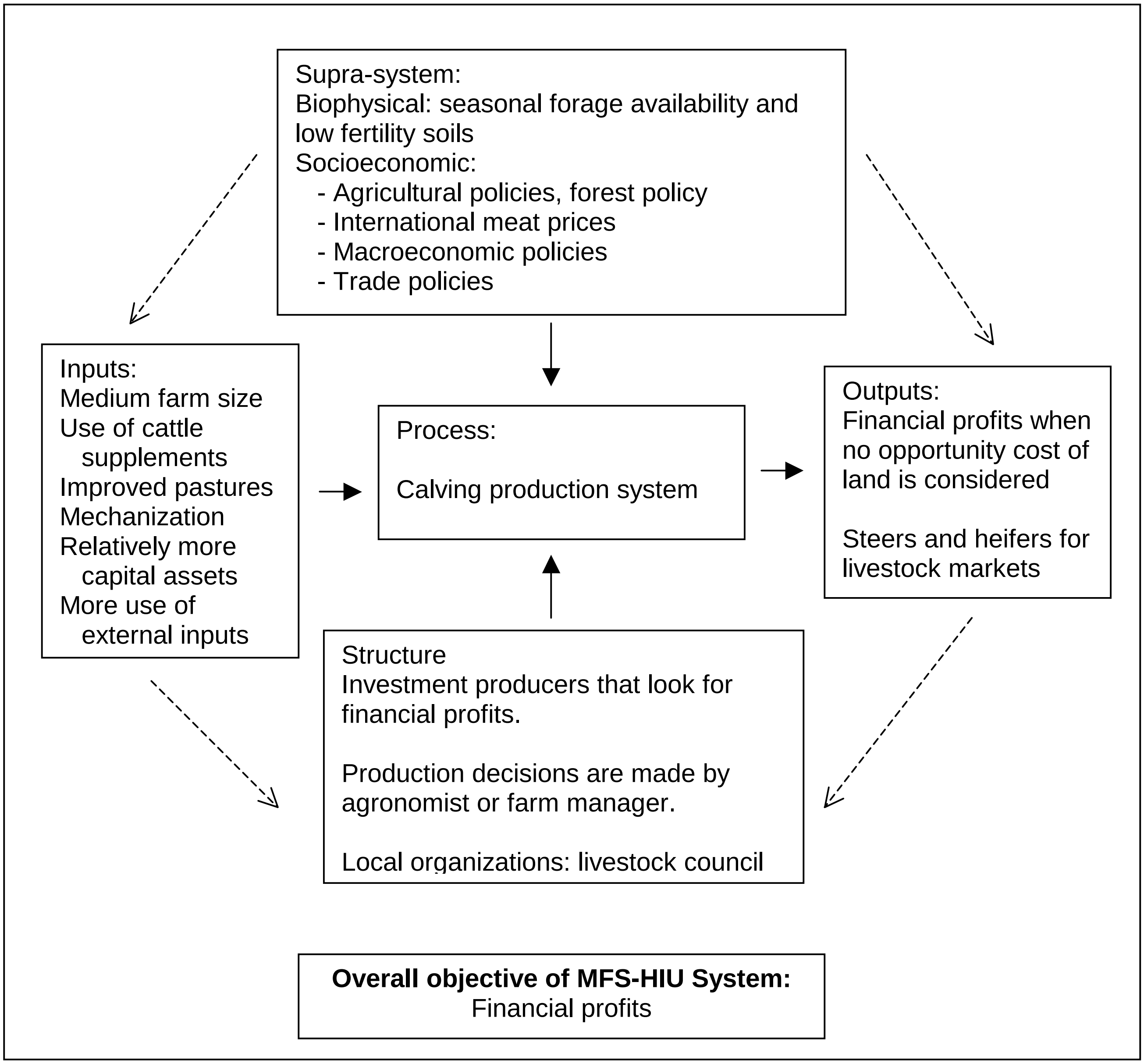

Figure 4.5. Qualitative characteristics and elements of the medium farm-size with a high use of purchased inputs (MFS-HIU) system identified in Cañas and Bagaces, Costa Rica. [Source: Based on interviews with farmers (FLORES AND MONTERROSO 2002)].

4.2.3 Large farm-size with a high use of purchased inputs (LFS-HIU system)

This system is characterized by five elements (Figure 4.6 and Table 4.2): 1) these farms contain both calving and fattening production systems in a single enterprise, 2) the average farm size is 1,400 hectares (ranges from 800 to 3,000 hectares), 3) producers employ purchased inputs, mainly cattle supplements during dry season (e.g. *Brachiaria decubems* hay), 4) the farm is managed by a cattle specialist or by the owner himself, and

5) forest plantations are important production options. The dynamics of these farmers are centered on the search for financial profits although some ranchers also consider livestock and land as prestige assets beyond their economic worth (KAIMOWITZ 1996).

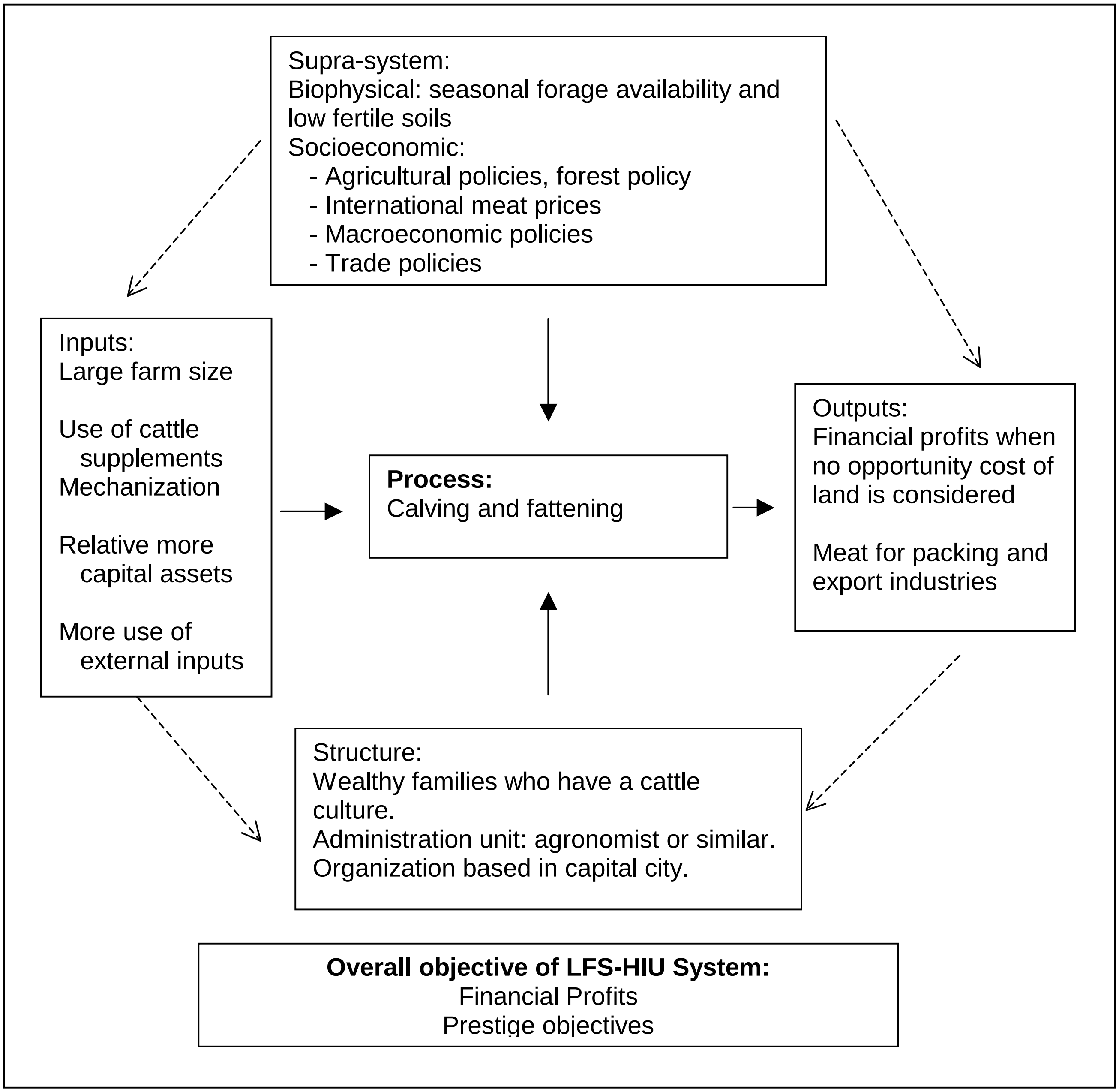

Figure 4.6. Qualitative characteristics and elements of the large farm-size with a high use of purchased inputs (LFS-HIU) system identified in Cañas and Bagaces, Costa Rica. [Source: Based on interviews with farmers (FLORES AND MONTERROSO 2002)].

4.3 Tree and forest resources

Farmers have similar tree arrangements on their farms regardless of the farm type (Table 4.3). For example, the same silvopastoral systems are found on cattle farms: dispersed trees in pastures, secondary regeneration, live fences, and riparian trees. The widespread occurrence of trees in cattle ranching could be explained by the fact that ranchers already know about the benefits that trees provide to livestock, i.e. there is a culture that favors the use of trees for cattle production (MUÑOZ 2003).

Table 4.3. Most common arrangements of trees in cattle farms of Cañas and Bagaces (percent of producers that reported having one or more system).

	SFS-LIU*				MFS-HIU*	LFS-HIU*
	Calving	D/P	Fattening	Total		
Producers (n)	111	18	26	155	18	12
Dispersed trees	97%	86%	75%	91%	100%	100%
Grazing in secondary forest	79%	57%	67%	74%	67%	71%
Riparian trees	82%	29%	67%	72%	67%	100%
Live fences	26%	14%	42%	28%	33%	14%
Trees on farm boundaries	18%	29%	0%	15%	33%	0%
Windbreaks	6%	0%	0%	4%	0%	14%
Plantations	18%	29%	0%	15%	17%	29%

*/ SFS-LIU: Small farm-size and low input use system; MFS-HIU: Medium farm-size and high input use system; LFS-HIU: Large farm-size and high input use system.
Source: FLORES & MONTERROSO (2002).

Farmers from the three cattle systems reported that they use trees for timber (35% of farmers reported this use), fodder (29%), shade for animals (19%), live fences (9%), firewood (7%), and other uses (1%). The tree species used in silvopastoral systems are also homogenous among cattle farms (Table 4.4). For example, farmers prefer *Cordia alliodora* and *Pachira quinata* for timber; *Guazuma ulmifolia* is mainly used to feed animals during the dry season; *Enterolobium cyclocarpum* is preferred for providing shade for cattle; *Bursera simaruba* and *Gliricidia sepium* are species for live fences; *Gliricidia sepium* is also the preferred timber species for fence posts; and *Tectona grandis*, *Gmelina arborea* and *Pachira quinata* are species used in forest plantations. VILLANUEVA *et al.* (2003) found similar tree species presented as dispersed trees and live fences in a study developed in Cañas.

Table 4.4. Main uses of trees and timber species as reported by 70 interviewed producers in Cañas and Bagaces (percentage of producers that reported the species)

Timber		**Fodder**	
Cordia alliodora	18%	*Guazuma ulmifolia*	57%
Pachira quinata	17%	*Acrocomia aculeata*	7%
Tectona grandis	13%	*Enterolobium cyclocarpum*	6%
Cedrela odorata	7%	*Gliricidia sepium*	5%
Hymenaea courbaril	7%	*Spondias purpurea*	4%
Total species mentioned	19	Total species mentioned	18
Shade for Cattle		**Firewood**	
Enterolobium cyclocarpum	21%	*Calycophillum candidissima*	17%
Cordia alliodora	8%	*Byrsonima crassifolia*	17%
Pachira quinata	8%	*Gliricidia sepium*	12%
Sideroxylum capri	8%	*Lysiloma divaricatum*	12%
Samanea saman	4%	*Andira inermis*	6%
Total species mentioned	26	Total species mentioned	11
Live Fences		**Fence post**	
Bursera simaruba	22%	*Gliricidia sepium*	55%
Gliricidia sepium	23%	*Guazuma ulmifolia*	4%
Spondias purpurea	19%	*Lysiloma divaricatum*	4%
Total species mentioned	9	*Myrospermum frutensis*	2%
		Acacia centralis	2%
Plantation		Total species mentioned	15
Tectona grandis			
Pachira quinata			
Gmelina arborea			

Source: Flores & Monterroso (2002).

There are two main differences in the tree cover among cattle systems. Firstly, although forest plantations are found in all of the systems, medium- and large-farms have (proportionally and absolutely) greater areas of forest plantations. This suggests that plantations are a productive option for commercial farms while for small-scale farms they are not feasible (small-scale farmers have less than 10 hectares of plantations). Secondly, the proportion of the farm under secondary forest is greater for small farms (Table 4.2). Some small farms have more than 80% of their land under natural regeneration while medium and large farms present less than 8% and 50%, respectively. Ramos (2003) found that natural regeneration in Bagaces and Cañas is a sign of production failure because it shows the rancher has abandoned the farm.

4.3.1 Dispersed trees in pastures[2]

ESQUIVEL *et al.* (In prep.) inventoried trees dispersed in grassland on farms located in Cañas. A total of 5,896 dispersed trees in pasture were inventoried in 16 cattle farms covering 1,073 hectares. A total of 3,376 trees (57%) were classified as timber trees. Simple statistics of timber trees are presented in Table 4.5.

Table 4.5. Simple statistics of timber trees inventoried in 16 cattle farms in Cañas, Guanacaste

Variable	**N**	**Mean**	**Std Dev**	**Min**	**Max**
DBH (cm)	3,371	43.80	23.47	4.80	221.5
Total tree height (m)	3,273	12.13	4.77	1.00	47.00
Commercial height (m)	3,265	3.10	1.49	1.00	16.15
Volume (m^3)	3,259	0.47	0.08	0.01	12.88

Source: ESQUIVEL *et al.* (In prep.)

Sixty percent of the total species are represented by six species, namely[3]: *Tabebuia rosea* 12.8% (medium value timber tree)*, Guazuma ulmifolia* 12.6% (shade, forage, and firewood), *Cordia alliodora* 12% (high value timber tree)*, Acrocomia aculeata* 10.7% (forage), *Byrsonima crassifolia* 7.4% (fruit and low value timber tree)*,* and *Tabebuia ochracea* 4.5% (low value timber tree, posts). With the exception of *A. aculeata*, all these species are for timber purposes. These data agree with the responses of interviewed farmers who mentioned that the main use of trees is for timber purposes.

Thirty-four timber species were identified. The most common timber tree species were *Tabebuia rosea* (22% of timber species), *Cordial alliodora* (21%), *Byrsonima crassifolia* (13%), *Tabebuia ochracea* (8%), and *Pachira quinata* (5%). Using basal area as a reference, *Cordia alliodora* is the most abundant tree. Table 4.6 shows the frequencies of the most abundant tree species and the timber species with high basal area.

The distribution of dispersed trees is twofold (with no differences between farm types in ESQUIVEL *et al.* (in prep.) study): individual trees or clusters of trees. The distribution pattern depends on management activities such as weed control and stocking rate, the objectives of producers (e.g. timber, shade, or fodder), and soil characteristics (RESTREPO,

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[2] This section is based on Esquivel's Ph.D. dissertation on dispersed trees in Cañas. I acknowledge his kindly permission to use his data.

[3] Percentages are based on ESQUIVEL *et al.* (In prep.); uses correspond to FLORES & MONTERROSO (2001).

2002). Taking into account these facts, however, ESQUIVEL'S *et al.* (In prep.) conclusion summarizes the distributional pattern as: "tree species with large tree crowns are maintained at low densities to provide shade and shelter to cattle but not interfere with pasture productivity, whereas tree species with small tree crowns are found more abundantly dispersed in pastures of cattle farms" (pp. 20).

Table 4.6. Frequencies of the most abundant timber tree species at the 16 inventoried farms in Cañas, Costa Rica.

Most abundant tree species	Total Number	%	Highest basal area	Total basal area (m^2)	%
Tabebuia rosea	756	22	*Cordia alliodora*	100.7	15
Cordia alliodora	707	21	*Pachira quinata*	92.7	14
Byrsonima crassifolia	434	13	*Tabebuia rosea*	91.0	14
Tabebuia ochracea	265	8	*Andira inermis*	50.6	8
Pachira quinata	183	5	*Byrsonima crassifolia*	48.1	7
Andira inermis	169	5	*Enterolobium cyclocarpum*	48.0	7
Acosmium panamensis	140	4	*Samanea samman*	35.0	5
Maclura tinctorea	98	3	*Tabebuia ochracea*	27.6	4
Hymenea courbaril	82	2	*Acosmium panamensis*	24.9	4
Samanea samman	77	2	*Hymenea courbaril*	22.3	3
Other	465	14	*Cedrela odorata*	20.4	3
			Other	92.2	14
Total 16 farms	3376	100	Total basal area 16 farms	653.5	100
Mean density (tree/ha)	8.6 (se 0.66)		Mean basal area (m^2/ha)	1.61 (se 0.12)	
Mean timber tree density tree/ha	4.5 (se 0.42)		Mean basal area of timber trees (m^2/ha)	0.86 (se 0.08)	

Source: ESQUIVEL's tree inventory.

ESQUIVEL'S data do not allow for comparisons of tree densities among the cattle systems presented in this study because he did not survey farms of the LFS-HIU system. ESQUIVEL *et al.* (In prep.) in a sampling of 16 farms, with a mean farm area of 67 hectares, found no significant differences between farms in the number of trees per hectare and total tree crown cover. However, information from one farm of the LFS-HIU system suggests that large-scale farms tend to have fewer trees per hectare. Table 4.7 reproduces ESQUIVEL'S data in addition to data from an LFS-HIU farm (the information is not statistically comparable). These data show that larger farms have 2 trees per hectare while very small farms have more than 13 trees per hectare. Some evidence that supports the idea that large farmers tend to have less trees was given during the interview, when farmers of the LFS-HIU system explained that too many trees in pasture interfere with mechanization activities such as grass-mowing. Farmers from the SFS-LIU system mow the grass manually, which makes the selection of trees easier.

Table 4.7. Density of trees (number/ha) in four cattle systems in Cañas, Costa Rica.

	SFS-LIU			LFS-HIU
Mean farm size (ha)	Micro[#] (28 ha)	Very Small[#] (73 ha)	Small[#] (163 ha)	Very Large[§] (1,900 ha)
Mean tree density with dbh > 10 cm (n ha^{-1})	13.4 (2.45)	7.8 (1.03)	6.5 (0.65)	2.0
Mean basal area per system (m^2/ha)	2.51 (0.31)	1.68 (0.12)	1.26 (0.15)	0.71

Source: [#] Esquivel inventory. [§] La Pacífica (1998), Plan de Aprovechamiento Forestal (unpublished document). Data for SFS-LIU comes from a tree inventory of more than 5,500 trees; data from La Pacifica comes from an inventory of 108 trees in 60 ha.

4.4 Protected areas and biological corridors

4.4.1 Protected areas and biodiversity conservation

Costa Rica is divided for administrative reasons into 11 conservation areas called the national system of conservation areas (*Sistema Nacional de Areas de Consevación, SINAC*). The study area is located in the Tempisque Conservation Area, which consists of about 35,000 hectares of terrestrial and wetland habitat which is still being legally defined and administered (MATA & ECHEVERRIA 2004). Twelve protected areas surround the study area (Figure 4.7), but the most important are: 1) Palo Verde National Park, 2) Lomas Barbudal Biological Reserve, 3) Rincón de la Vieja Volcano, 4) Miravalles Volcano, and 5) Tenorio Volcano.

Palo Verde is an 18,418-hectare park of seasonally dry forest on limestone outcrops and extensive wetland vegetation bordering the Tempisque River that flows into the Gulf of Nicoya. Lomas Barbudal, with foothills of volcanic origin, has an extension of 2,646 ha and is covered by savannas, deciduous and riparian forests, oak forests (*Quercus oleides*) and extremely dry sites. Both Palo Verde and Lomas Barbudal are considered some of the sites with the greatest ecological diversity in Costa Rica, encompassing more than 13 different habitats, including dry deciduous forest, regenerating dry deciduous forest of various ages, riparian and spring forests, savanna, mesic forest, mangrove forest, and wetlands (QUESADA & STONER 2004). The Palo Verde – Lomas Barbudal Protected Area, along with the Santa Rosa National Park (Costa Rica) and the Chamela-Cuixmala

Biosphere Reserve in Jalisco, Mexico, are considered the only protected sites of tropical dry forest in Mesoamerica that are large enough to possible sustain dry-forest ecosystems (QUESADA & STONER 2004).

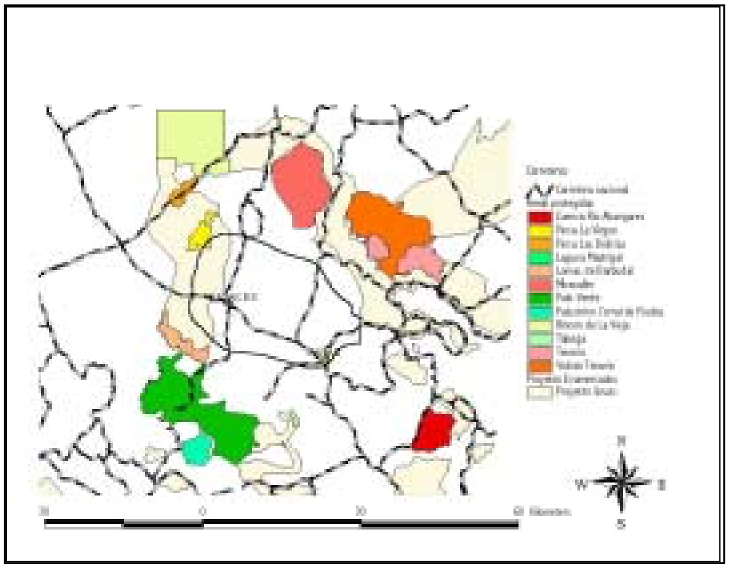

Figure 4.7. Protected areas and proposed biological corridors around the study area in the dry forest of Costa Rica (Source: Based on ITCR, 2000).

The Rincón de la Vieja Volcano, with an extent of 14,161 ha, is composed of lower montane rainforest, premontane wetforest –rainforest transition, secondary regeneration, natural pasture areas, and riparian forest. Miravalles and Tenorio volcanoes have an extension of more than 20,000 hectares. The main life zones are lower montane rainforest, premontane rainforest, and premontane wetforest rainforest transition. The volcanoes have a great diversity of flora and fauna.

Regarding biodiversity conservation, MATA & ECHEVERRÍA (2004) mention that Guanacaste still has rich flora and fauna, since the life zones of the area have an ample diversity of plants and animals. However, they argue that in the dry forest it is still necessary to increase the number of protected areas and to connect them with appropriate corridors.

Landscape fragmentation and deforestation has been identified as a problem in biodiversity conservation in the tropical dry forest of Guanacaste (MATA & ECHEVERRÍA 2004; HAMRICK & APSIT 2004; STONER & TIMM 2004; QUESADA & STONER 2004). Recent evidence (ARROYO-MORA *et al.* 2005) indicates that the Guanacaste region has had a very fragmented landscape during the 1960 to 2000 period. From 1960 to 1980, the fragmentation was due to forest shrinkage and division, caused by land-use changes from forest to pastures. Although the 1985 to 2000 period witnessed a secondary forest growth, the landscape remains fragmented because regeneration is mainly located in marginal agricultural land, where limiting factors such as soil, slopes and soil fertility constrain cattle ranching (ARROYO-MORA *et al.* 2005).

4.4.2 Biological corridors

Central America has proposed a regional strategy for biological corridors, named the Mesoamerican Biological Corridor (CBM 2002). From this initiative, there are seven proposed biological corridors that are important for the study area (Figure 4.7). They are summarized in Table 4.8, where general characteristics are highlighted. From the list, only Barbudal and La Mula are *strictu sensu* corridors, i.e. the protected areas are connected with forest cover. The other proposed corridors are a guide for policy-making and land use planning since the landscape is fragmented. For example, in the largest proposed corridor, Las Morocochas (with an extension of 168,200 ha), the main land use is extensive cattle ranching. In general, in the study area the most important land uses are pastures with trees (54% of the total area), forested areas (38%), and agricultural areas without trees (8%) (FLORES *in prep.*).

4.5 Chapter summary

In Cañas and Bagaces counties, forested areas have given way to pastures for cattle ranching. Agricultural policies and macroeconomic factors favored the increase of cattle production in the region. In recent years, both the reduction of meat prices and ending of agricultural subsidies caused a reduction of cattle ranching in the area.

The three systems described (i.e. SFS-LIU, MFS-HIU, and LFS-HIU) use their productive resources in different ways, intensifying the use of the most abundant (or relatively least costly) resource in the production process. The small farms (SFS-LIU) strategy is based on low external input use, implying an intensification of pasture and natural resources. Given the relatively large part of the farm with secondary regeneration and the number of farms that are in an ‘idle’ state, this system groups the farmers that have been affected the most by

Table 4.8. Main characteristics and situation of proposed biological corridors in Cañas and Bagaces counties, Costa Rica.

Corridor Name	Involved protected areas	Corridor area (ha)	Type of corridor	Main land uses	Land tenure	Threats
Las Morocochas	Lomas de Barbudal – Rincón de la Vieja	168,200	Fragmented landscape	Mainly extensive cattle ranching	Small- to large-scale private owners	Deforestation of riparian forest; social pressure due to cattle activities and timber extraction; hunting activities; forest fires
Barbudal	Palo Verde – Lomas Barbudal	400	Connected with forest	Forest	Protected area (legally constituted)	Social pressure due to cattle and rice activities; water pollution from agricultural activities; forest fires; hunting activities
La Mula	Palo Verde – Lomas Barbudal	450	Connected with forest	Mainly forest; cattle in small areas	Protected area (legally constituted), but tenure conflicts with 22 peasants who live inside the corridor	Social pressure due to conflicts of land tenure and cattle activities; agricultural pollution from rice; forest fires; hunting activities
Monte Verde – Golfo de Nicoya	Monteverde	62,000	Fragmented landscape	Dairy and meat cattle; coffee; maize; forest	96% small- to medium-scale private owners; 4% IDA	Mining activities
Rincón – Miravalles	Rincón de la Vieja Volcano – Miravalles	239	Fragmented landscape	18% forest	Small- to medium-scale private owners	N.A.
Miravalles – Tenorio	Miravalles – Tenorio Volcano	1,304	Fragmented landscape	63% forest 37% pasture with trees	61% private owners; 39% IDA	Volcanic hazards
Tenorio – Arenal	Tenorio volcano – Arenal Volcano	6,749	Fragmented landscape	32% forest 9% secondary regeneration 47% pastures with trees 6% agriculture	96% private owners; 4% IDA	Hunting activities

Source: Elaborated with information from ROJAS & CHAVARRÍA (2005).

the changes in meat prices and agricultural policies. Most of the producers in this system do not depend on cattle earnings.

Medium-size farms, MFS-HIU, intensify the use of land (pasture), supplements (external inputs), and mechanization (to reduce labor costs). This group is close to an ‘investment’ rancher (KAIMOWITZ 1996) because they view cattle ranching as an attractive sector for investments. Large-size farms, LFS-HIU, use land, external inputs, and mechanization in a similar fashion to the MFS-HIU system, but they have economies of scale by combining calving and fattening in one production unit. This system is linked to export markets rather than local meat markets.

Trees are important resources for cattle ranching. Trees and forest are mainly used for timber, fodder, shade for animals, live fences, and firewood. Although the uses of trees are common among cattle systems, there are clear differences among systems. The SFS-LIU system has relatively more secondary regeneration while the MFS-HIU and LFS-HIU systems have more forest plantations. Dispersed trees in pastures have similar uses and locations within the plot among cattle systems although large farms tend to have lower densities of dispersed trees than small farms.

The study area is located near an important protected area (Palo Verde – Lomas de Barbudal), which is one of the three main protected areas of tropical dry forest in Mesoamerica. Landscape deforestation, fragmentation and agriculture, however, threaten the possibility of biodiversity conservation in the region.

CHAPTER 5

THE EMPIRICAL BIOECONOMIC MODEL AND DATA COLLECTION

This chapter shows the characteristics of the empirical model for analyzing agroforestry policies that can increase tree cover in cattle farms, and in doing so, contribute to biodiversity conservation in the dry areas of Guanacaste.

Policy simulation, as a deductive analysis, started from the discussion of the theoretical framework based on natural resource economic theory (Chapter 4). Economic theory suggested the main variables that should be considered in empirical studies as well as the model structure and solutions. This chapter links economic theory with the cattle systems that were introduced in Chapter 2. This chapter uses the economic theory to construct an empirical bioeconomic model and takes the farm typology to estimate the model's coefficients. By changing coefficients, the main farming types are simulated. The main objective of this chapter is to describe the empirical bioeconomic model and present the estimation of its coefficients.

This chapter is divided into four sections. The first section presents the characteristics and assumptions of the simulated cattle farms. These cattle farms represent 'typical' farms of the typology presented in chapter two. The second section, entitled 'the empirical bioeconomic model', shows the structure of the nonlinear programming model that was built for policy analysis. This section also presents the model validation and the policy simulation procedures. The third section, 'data collection and coefficient estimation', presents the methodology and results of the estimation of coefficients for the empirical model. The last section presents a summary of the chapter.

5.1 Characteristics and assumptions of simulated farms

The model is a discrete time, bioeconomic model that simulates policies for a 20-year time period. It models three cattle systems, i.e. the cattle typology presented in Chapter 4. The model simulates at the regional level, taking a group as if it were a single farm (SCHIPPER *et al.* 2000). The model simulates the impact of policy instruments on tree canopy (from dispersed trees in pasture) and cattle production, at the hectare level.

The main characteristics of the simulated farms are (the mathematical structure of the model and its coefficients are presented in sections 5.2 and 5.3, respectively):

- The cattle enterprise is a calving-only system. No other agricultural products were considered. Two kind of pasture relevant to the area were modeled, *Hyparrhenia rufa* and *Brachiaria brizantha*. Cattle are assumed to be Brahman.
- The tree component is composed of dispersed trees in pastures. No other silvopastoral systems or tree arrangements were considered. It was assumed that trees were distributed as individual trees where no competition among trees is possible. Trees are a product of natural regeneration only; trees are assumed to have medium growth rates similar to *Cordia alliodora.*
- The simulated farms produce two outputs only, i.e. calves and timber.
- The silvopastoral system was simulated with two interactions:
    - Tree-pasture interaction, which implies a reduction of pasture production due to shade of tree canopy. A linear relationship was assumed, in the sense that 1m^2 of canopy reduces the production of 1m^2 of pastures (it implies that an increase of 1m^2 of pastures needs cutting of trees to reduce canopy). This assumption might overestimate pasture loss with low tree densities and underestimate it with high densities (ESQUIVEL *et al.* in preparation).
    - Cattle-tree interaction, which implies a reduction (or increase) in the number of trees that naturally regenerate when cattle stocking rates are increased (or reduced). It was assumed that high stocking rates linearly decrease the number of regenerated trees. This relationship might be nonlinear, but silvopastoral literature does not report evidence for different assumptions.

The model has two main assumptions. First, it assumes that prices are exogenously determined. This means that a change in the quantity produced in the region does not change the regional price. In the discussion section, the influence of this assumption over the results is analyzed. Second, the model does not consider other biophysical interactions among trees, pasture or cattle. Taking into account actual uses and management of tree resources in cattle farms, the relevant biophysical interactions that were omitted are 1) positive benefits provided by trees to cattle in the form of fodder and shade, and 2) negative impacts of cattle stocking rates on tree growth rates through trampling and browsing. These assumptions and limitations of the model are commented on in the discussion section.

5.2 The bioeconomic model structure

The 'cattle component' of the model is based on UPTON (1989) and STANDIFORD & HOWITT (1992) who simulate herd growth and steady-states based on variables such as the herd size of previous years, the rate of births, the mortality rate, and net animal offtake. The 'tree component' consists of a diameter class growth model that represents a typical situation of disperse trees in the area. This section is divided into three parts. First, the model structure, i.e. objective function and constraints, is presented. Then, the section presents the validation procedure, i.e. the tests that were done to check that the model could be useful for policy analysis. Finally, the section presents the methodology for the policy analysis.

5.2.1 Model structure

5.2.1.1 The objective function

Appendix B defines the variables, coefficients, and indexes used in this section while Appendix C shows the GAMS (BROOKE *et al.* 1998) program where a detailed explanation of the model structure can be found.

The **objective function** is to maximize discounted net revenues from livestock revenue and timber harvesting (Equation 5.1).

$$\max \sum_{t=0}^{T} DF_t \cdot \left(LR_t - LC_t + WR_t \right) \tag{5.1}$$

Where DF_t is the discount factor $1 \big/ \left(1+i\right)^t$, i is the discount rate, LR_t is livestock revenue, LC_t is livestock cost, WR_t is timber revenue, and t is year ($t=1,\ldots,20$). The livestock enterprise is assumed to be a calving-only system, the predominant production system in Cañas and Bagaces. Livestock revenue (LR_t) (Eq. 5.2) in time t is composed of the sale of feeder calves (SS_t), feeder heifers (HS_t), and mature cows (REP_t). Sales of steers are calculated by multiplying the number of steers sold (SS_t), their future price (dollar per kg, ps_t), and the average steer weight (in kilograms, ws). The value of sold heifers and cull cows is estimated in a similar fashion.

$$LR_t = \left(SS_t \cdot ps_t \cdot ws\right) + \left(HS_t \cdot ph_t \cdot wh\right) + \left(REP_{t-10} \cdot pREP_t \cdot wc\right) \qquad (5.2)$$

The number of steers sold (SS_t) (Eq. 5.3) is a function of the herd's calving rate (cr) and herd size (HRD_t), where HRD_t is a **state variable** for the model:

$$SS_t = HRD_t \cdot (cr/2) \qquad (5.3)$$

The number of heifer calves sold (Eq. 5.4) is the difference between the number of heifer calves born and the number used as replacement heifers REP_t. The number of replacement heifers added to the herd is a **control variable** for the model:

$$\begin{aligned} HS_t &= \left(HRD_t \cdot \left(cr/2\right)\right) - REP_t \\ HRD_t \cdot \left(cr/2\right) &= REP_t + HS_t \end{aligned} \qquad (5.4)$$

The cost of the livestock enterprise (LC_t) includes the variable cost and the feed cost (Eq. 5.5). Variable costs consist of the herd in time t multiplied by the variable cost per cow (vc_t). The variable cost consists of cattle management inputs (e.g. vaccines and labor) as well as nutritional supplements (e.g. vitamins and salts) to assure a complete supplementation of nutritional needs. The model does not consider the use of trees as fodder —an assumption that will be analyzed in the discussion section. The feed cost is related to the purchase of hay to feed animals that cannot be pastured due to the lack of grass. Feed costs are divided into two seasons, dry and rainy seasons (index j). The **control variable** $FED_{t,j}$ is estimated in the course of optimization; $pfed_{t,j}$ is the price of hay in season j:

$$LC_t = HRD_t \cdot vc_t + \sum_{j=0}^{1} pfed_{t,j} \cdot FED_{t,j} \qquad (5.5)$$

Timber revenue at time t (WR_t) (Eq. 5.6) is equal to total volume harvested at time t ($CUT_{t,dbh}\cdot vol_{dbh}$) times the future stumpage price (pwd_t) adjusted with an extraction cost factor (wdc). The quantity of tree harvest ($CUT_{t,dbh}$) is a control variable in the system:

$$WR_t = CUT_{t,dbh} \cdot vol_{dbh} \cdot \left(pwd_t - wdc \right) \tag{5.6}$$

5.2.1.2 Cattle equation of motion

The equation of motion for cattle (Eq. 5.7) considers only cows and is based on UPTON (1989) and STANDIFOR & HOWITT (1992). The cattle stock (HRD_t) in time t is a function of the stock of cattle in the previous time period $t–1$ plus the number of cows added as replacement heifers (which are 2-years-old, REP_{t-2}), minus the number of culled cows that are 10-years-old (REP_{t-10}). The age of cows represents the usual case in Cañas and Bagaces:

$$HRD_t = (1-mor)\cdot HRD_{t-1} + REP_{t-2} - REP_{t-10} \tag{5.7}$$

A forage equation (Eq. 5.8) is added to the model in order to account for the relationship between tree canopy and pasture and herd. The forage equation assumes two annual seasons (six months of rainy and dry seasons). It is assumed that the pasture that is not used during any of the two seasons is completely lost, which is an assumption that is close to the behavior of Jaragua grass (*Hyparrhenia rufa*) in the study area. Pasture availability ($FOR_{j,t}$) is given as the maximum stocking rate per hectare (A.U./ha). Thus, $FOR_{j,t}$ is a function of tree canopy (CC_t, in hectares) and the maximum animal units that one hectare of pasture can feed ($pasto_j$). The canopy variable (CC_t) is defined in Eq. 5.17. Equation 5.8 assumes that the area under the tree canopy produces no grass. This assumption of the model will be analyzed in the discussion section.

$$FOR_{j,t} = pasto_j \cdot \left(1 - CC_t\right) \tag{5.8}$$

The AU_t equation (Eq. 5.9) converts herd stock to animal units. This equation is needed to account for the maximum stocking rate allowed for the forage equation. The calculation takes into account calves (conversion factor 0.3), heifers (0.65), and bulls (estimated as 1 bull for every 20 cows). The conversion factors were taken from CORFOGA (2004).

$$AU_t = HRD_t + (HRD \cdot cr \cdot 0.3) + (REP_{t-1} \cdot 0.65) + 0.06 \tag{5.9}$$

In addition, a maximum animal units restriction (Eq. 5.10) was added to simulate the current technology in the area, i.e. mainly based on grazing. In this sense, the model restricts the animal units to the maximum stocking rate in the rainy season.

$$AU_t \leq pasto_{j=rain,t} \tag{5.10}$$

A forage availability constraint (Eq. 5.11) balances forage production ($FOR_{t,j}$) and quantity of supplemental feed ($FED_{t,j}$) against animal units that are fed every year (AU_t). Total animal units should be less or equal to the total feedstuff available in the farm:

$$FOR_{t,j} + FED_{t,j} - AU_t \geq 0 \tag{5.11}$$

5.2.1.3 Tree equation of motion

Timber growth was estimated by using a diameter class growth model (or stand table growth model). Diameter class models may be the most popular way to simulate tropical timber growth because of their facility to project in spreadsheets with few data and assumptions (VANCLAY 1994). The solution of diameter class models with nonlinear optimization has been used for several years in forest science (ADAMS & EK 1974), but they have not been common in agroforestry. Diameter class models have been used to estimate two separate but related forest problems: 1) the optimal diameter distribution, and 2) conversion strategy and conversion period length, i.e. the transition path from current distribution to the optimal distribution (HAIGHT *et al.* 1985). The diameter class model presented here considers the transition and equilibrium problems jointly.

The structure of a stand —that is, the distribution of trees by diameter classes— changes from year to year because of the growth, death, and cutting of trees (HUSCH *et al.*1982). Then, the future stand is predicted from the present structure using estimated diameter increments for each class. The basic structure of a stand growth model considers four concepts (ADAMS & EK 1974; HUSCH *et al.*1982; HOWARD & VALERIO 1992):

Upgrowth ($U_{t,dbh}$): the number of trees moving up from one class to the next class due to growth;

Ingrowth ($U_{t,dbh-1}$): the number of trees moving into a given class due to growth;

Mortality ($M_{t,dbh}$): the number of trees dying in each class per unit of time usually expressed as an annual percentage;

Cut ($CUT_{t,dbh}$): the number of trees removed due to commercial silvicultural activities.

The empirical diameter class growth model assumed five diametric classes: 1) trees in the diameter class from 5 to 10cm (midpoint 7.5cm), 2) trees in the diameter class from 10 to 20cm (midpoint 15), 3) trees in the diameter class from 20 to 30cm (midpoint 25), 4) trees in the diameter class from 30 to 40cm (midpoint 35), 5) trees in the diameter class from 40 to 50cm (midpoint 45), and 6) trees in the diameter class greater than 50cm (midpoint 55). SPITTLER (2001) reported that in the study area, the minimum commercial diameter for semi-hard wood with low commercial value is 25cm. In this model, trees can be harvested with diameters equal to or greater than 35cm.

Three equations govern the number of trees for each diameter class. The number of trees in the smallest diameter class, $DEN_{dbh=1}$, at the beginning of period t is estimated with equation 5.12:

$$DEN_{t,dbh=1} = DEN_{t-1,dbh=1} + NEWT_{t=\text{multiple of 5}} - M_{t,dbh=1} - U_{t,dbh=1} \tag{5.12}$$

where $DEN_{t-1,dbh=1}$ denotes the tree density of the 7.5 diameter class in the year $t—1$, $NEWT_t$ is ingrowth trees in the smallest diameter class, $M_{t,dbh}$ is mortality, and $U_{t,dbh}$ is upgrowth.

The number of ingrowth trees in the smallest diameter class ($NEWT_{t5}$), i.e. recruiting of trees, is a **control variable** whose value is found in the course of optimization. This variable represents the number of natural-regenerated trees that farmers allow to be established in pastures. The farmer cannot have more trees than the maximum ingrowth rate (assumed to be 80 trees when pasture is not grazed), but the farmer can decide to have less trees. The decision depends upon the profitability of having cattle or trees.

The model assumes that tree recruiting is done every five years to avoid interfering with pasture mowing (hence the subscript t of $NEWT$ in Eq. 5.12 is t=*‘multiple of 5’*). Annual recruiting, although a valid assumption for abandoned pastures, is not preferred by farmers because it makes more expensive pasture maintenance and management of trees. In other words, the model considers that in a silvopastoral system, recruiting is mainly a decision of the farmer; but recruiting cannot exceed the maximum number of trees that can naturally regenerate in the pasture.

The maximum ingrowth of trees ($NEWT_{t5}$) is mainly influenced by the cattle stocking-rate (AU_t). The influence of cattle over the regeneration of trees (Eq. 5.13) was estimated with the following assumptions: 1) the maximum ingrowth of trees is 80 trees/ha, 2) the cattle stocking rate affects the maximum number of regeneration trees with a negative linear relationship, 3) with a full stocking rate (2.3 AU/ha), no trees can be regenerated, and 4) the farmer can allow the entrance of fewer trees than the maximum allowed (hence the ‘less-than’ sign in Eq. 5.13). The maximum ingrowth rate (assumption 1) is consistent with recruiting reported by CAMARGO (1999) who estimated as much as 120 trees/ha of natural regeneration of *C. alliodora* in active pastures. MEZA *et al.* (2002) report 30 trees/plot in a permanent plot of secondary regeneration (25 years-old) in Guanacaste National Park. The linear assumption is made to simplify the equation and avoid the use of further assumptions.

$$\begin{aligned} NEWT_t &\leq 80 - 34.7826 \cdot AU_t \\ NEWT_t + 34.7826 \cdot AU_t &\leq 80 \end{aligned} \tag{5.13}$$

Mortality ($M_{t,dbh}$) was assumed to be a constant proportion for all diameter classes and independent of the cattle stocking rates. The mortality rate was set at 10% for each diameter class. This approach is consistent with the natural maintenance of a reverse ‘J’-shaped distribution of diameters in which there is a constant proportional reduction in the number of trees between adjacent classes (HOWARD & VALERIO 1992). CAMARGO (1999) found a tree mortality of 1.5% of *Cordia alliadora* trees in pastures, and tree damage of 13%. Then, the 10% mortality rate is consistent with values reported in the literature.

Upgrowth for each diameter class ($U_{t,dbh}$) was estimated using equation 5.14:

$$U_{t,dbh} = \left(\frac{\mathrm{G_{dbh}}}{\mathrm{W_{dbh}}} \right) \cdot \left[\left(1 - M_{t,dbh} \right) \cdot DEN_{t,dbh} \right] \tag{5.14}$$

where G_{dbh} is the average diameter increment (cm), W_{dbh} is the width of the diameter class (cm), $DEN_{t,dbh}$ is tree density, and $M_{t,dbh}$ is mortality. Upgrowth is computed after mortality is discounted. The average diameter increment G was estimated from a literature review as explained in section 5.2.5.

The number of trees for the noncommercial diameter classes (15cm and 25cm classes) at the beginning of period t was estimated by using equation 5.15:

$$DEN_{t,dbh} = DEN_{t-1,dbh} + U_{t,dbh-1} - M_{t,dbh} - U_{t,dbh}, \text{ for } dbh = 2, \dots n-1, \tag{5.15}$$

and the number of trees for commercial diameter classes (35cm, 45cm, and 55cm classes) at the beginning of period t was estimated as:

$$DEN_{t,dbh} = DEN_{t-1,dbh} + U_{t,dbh-1} - M_{t,dbh} - CUT_{t,dbh} \tag{5.16}$$

where upgrowth ($U_{t,dbh}$) and mortality ($M_{t,dbh}$) have already been defined. The ingrowth variable ($U_{t,dbh-1}$) represents the upgrowth value that is estimated in the inferior diameter class (dbh-1). The number of harvested trees ($CUT_{t,dbh}$) is a **control variable** for the model.

An additional constraint (Eq. 5.17) is added to ensure that more wood cannot be sold than available on the site:

$$DENS_{t,dbh} - HARVEST_t \geq 0 \tag{5.17}$$

One additional equation was needed to simulate canopy area as a function of tree density (Eq. 5.18). Equations 5.18 and 5.19 transform the state variable DEN_{dbh} (tree density) to canopy cover (CC) and basal area (BA), respectively, which are then used for policy analysis. Equation 5.18, which relates canopy (CC_t in hectares) as a function of basal area (BA_t) was statistically estimated with ESQUIVEL'S *et al.* (in prep.) data. Equation 5.18 presents the estimated parameters and section 5.3.5.4 shows the goodness of fit values:

$$CC_t = 0.00222 + 0.050175 \cdot BA_t \tag{5.18}$$

Basal area (BA_t) is the sum of basal areas at the diameter class midpoint ($basalarea_{dbh}$):

$$BA_t = \sum_{dbh} DEN_{t,dbh} \cdot basalarea_{dbh} \tag{5.19}$$

where $basalarea_{dbh}$ (in m^2) is estimated as:

$$basalarea_{dbh} = \pi \cdot \left(\frac{dbh \text{ at the midpoint}}{200} \right)^2 \tag{5.20}$$

The model assumes that ingrowth at the smallest diameter class and average diameter growth rates are from trees with characteristics similar to those of *Cordia alliodora*. The main assumption is that trees reach a diameter of 40 cm at the age of 30. This is a valid assumption for the model, since the biophysical characteristics of the study area restrict the growth of trees.

A common problem with diameter class models is that they allow some stems to move n classes in n projection intervals, and may thus overestimate yields (VANCLAY 1994). Possible solutions are using longer projection intervals, employing narrower classes, or smoothing the stand table (VANCLAY 1994). In this research, narrower classes and longer projection intervals were preferred. This is another reason why the model structure considered the entrance of trees at the 7.5cm class ($NEWT_t$) to be every five years.

5.2.1.4 Terminal conditions

Terminal conditions are employed to reduce the bias that can arise when an infinite-horizon problem is truncated to a finite-horizon problem (ROWSE 1995). For this reason, T was set at 60 years and HRD_t and DEN_t of the last 10 years were required to be identical (ROWSE 1995). Results are discussed only for the first 20 year-time period.

5.2.1.5 Initial conditions

Initial conditions for the stock of cattle and number of trees per diametric class are specified in Equation 5.21. The diameter distribution at year $t=0$ was estimated from tree inventories for Cañas County (section 5.2.5) (ESQUIVEL *et al.* In prep.), while initial cattle stock was estimated as the reported average per farm type (section 5.3.4).

$$\begin{aligned} HRD_0 &= \text{Given} \\ DEN_{dbh,0} &= \text{Given} \end{aligned} \tag{5.21}$$

Nonnegativity constraints were also imposed on all state and control variables.

In summary, the optimization problem has four control variables, namely number of cattle to hold as replacement (REP_t), supplemental feed purchased ($FED_{j,t}$), ingrowth trees in the 7.5cm class ($NEWT_t$), and harvested trees (CUT_t). The model also has two state variables: number of cows (HRD_t) and tree density per diameter class ($DEN_{t,dbh}$). The objective function (Eq. 5.1) is optimized subject to constraints 5.2 to 5.21, as well as nonnegativity constraints.

5.2.2 Model validation

Validation refers to “exercises determining whether the […] model behavior is close enough to real world behavior” (McCarl & Spreen 2004:18-1). The overall purpose is to test how well a model serves its intended objectives.

There are two validation approaches (McCarl & Spreen 2004): validation by construct and validation by results. Validation by construct asserts the model was built properly therefore it is valid. Validation by results refers to exercises where the model outputs are systematically compared against real world observations. I validated the model using both approaches.

Validation by construct relies on subjective judgments; nonetheless, it is the basis for validation by results. Validation by construct can be of several forms (McCarl & Spreen 2004). The approach I used was to verify that correct procedures were undertaken in model structure and data collection. It means that the model was consistent with economic theory and data was specified using reasonable scientific estimation or accounting procedures.

Validation by results involved comparison of model solutions with real world data. This validation was done by solving backwards in time and comparing the model solutions with herd data from past years. This validation was possible only for the ‘cattle submodel’ (i.e. the livestock component) because no data was available for the ‘forest submodel’. The backward-time experiment evaluated five periods, 1950, 1955, 1963, 1973, and 1984 (Table 5.1).

Table 5.1. Total herd, animal units and pasture area in Bagaces and Canas counties, for years 1950, 1955, 1963, 1973, 1984 and 2000.

	Total herd (Cows and heifers only)	**Animal units**	**Pastures** (Hectares)
1950	23,077	32,506	35,455
1955	26,023	39,521	40,730
1963	28,257	45,511	54,310
1973	64,668	80,099	118,296
1984	58,841	85,900	92,046
2000	40,115	46,684	83,784

Source: DGEC 1953, 1959, 1965, 1974, 1985; MAG *et al* 2001.

5.2.3 Policy and sensitivity analysis

The policy analysis was done by changing the values of specific parameters or equations and studying what might happen if such values change in a real world situation. Specifically, I was interested in simulating policies that may increase tree cover in cattle farms. Two kinds of policies were simulated: 1) policies that intervene in the tree component, and 2) policies that intervene in the cattle component. The first kind of policies offer subsidies to increase tree cover in the form of a payment for environmental services; the second kind taxes extensive cattle farmers to change the land use pattern of cattle farms.

The policy analysis consisted of finding the instrument that may motivate ranchers to increase tree cover to (previously defined) policy targets. Two policy targets were selected: 1) to increase by 50% the current canopy level of dispersed trees at year $t=10$ (policy target-I), and 2) to increase by 100% the canopy level at year $t=15$ (policy target-II). At the regional level, policy target-I implies increasing canopy cover (of dispersed trees) from an estimated initial level of 2,241 ha in year $t=0$ (2003) to 3,362 ha in year $t=10$, while policy target-II implies an increase to 4,482 ha in year $t=15$ (Table 5.14).

The analysis also simulated a scenario of free trade, with changes in meat and timber prices as the likely outcomes of an open market policy. Finally, a sensitivity analysis was performed to estimate changes in total profits and tree cover if small farms had different hay prices, calving rates and improved pastures.

5.2.3.1 Payment for environmental services (PES)

The PES consisted of simulating a direct payment to farmers for all standing trees in pastures of diameter classes greater than 30cm. Four different PES schemes were analyzed. The first scheme is a constant annual payment of standing trees in pastures of diameters greater than 30cm. In this case, for example, the farmer can receive from $0.20 to $1.50 per tree per year for 20 years. In the second scheme, the farmer is paid different amounts for different diameter classes for 20 years. For example, the farmer can receive more money for trees in the 35 cm diameter class, and a less amount or even no payment for larger classes. The third scheme simulates a target-oriented payment. In this scheme, the farmer is paid if s/he achieves a minimum tree cover (or tree density) per hectare. The farmer can receive annual payments during the 20 years of the program. These three schemes were simulated to analyze different payments and evaluate their administrative efficiency. The estimation of the lowest PES level was done in a trial-and-error procedure where several payments were tested. The results section only present the lowest payments that can reach the policy objective.

The last payment simulates the current PES for agroforestry that is used by the Costa Rican Fund for Forest Investment (FONAFIFO, Fondo Nacional de Financiamiento Forestal). The interest in this case was to compare the efficiency of the current PES program in achieving policy objectives.

The simulation of the PES required a modification of the model structure. To estimate a payment for standing trees (first two schemes), a new term was added to equation 5.6:

$$WR_t = \left(CUT_{t,dbh} \cdot vol_{dbh} \cdot pwd_t\right) + \left(DEN_{t,dbh} \cdot PES_{t,dbh}\right) \tag{5.22}$$

In Equation 5.22, PES_t is the payment scheme, i.e. annual payment or differentiated payment per diameter class. The variable $DEN_{t,dbh}$ is tree density in diameter classes greater than 30 cm.

The estimation of the target-oriented payment was done by adding a restriction of a minimum canopy level to the model. The restriction is represented in equation 5.23:

$$BA_t \geq \text{Policy target}_t \tag{5.23}$$

Where *policy target* was set at the 50% or 100% increased canopy level at year $t=10$ or $t=15$, respectively.

5.2.3.2 Tax policy

Economic theory reports the use of taxes as useful instruments to change the preferences of economic agents (PEARCE & TURNER 1990; section 3.1.4.3). This policy consisted of applying an annual tax per hectare to farms that have less basal area (on a per hectare basis) than the policy target. The desired effect of the tax is to penalize production of meat with low levels of trees in pastures and to promote the production of silvopastoral systems.

The empirical model was modified to account for the tax instrument, by adding a new equation:

$$tax_t = a - b \cdot BA_t \tag{5.24}$$

where tax is the tax level in US dollars (which varied from US$10 to US$50 per hectare/year), BA is basal area in year t, and a and b are parameters that change depending upon the initial level of the tax. The estimated tax was then added to the livestock cost function:

$$LC_t = HRD_t \cdot vc_t + \sum_{j=0}^{1} pfed_{t,j} \cdot FED_{t,j} + tax_t \tag{5.25}$$

Equation 5.24 should be a smooth equation to be considered in the model structure. Since it is linear, the amount of taxes that the farmer pays decreases while canopy area is increased.

5.2.3.3 Free trade policy (changes in output prices)

The main agricultural policies in Central America are free trade agreements. The main trade agreements in Central America are the *Dominican Republic, Central America, and the USA Free Trade Agreement* (RD-CAFTA), the Central American Market Integration (SICA, Sistema de Integración Centroamericana), as well as bilateral initiatives. The probable impacts of RD-CAFTA on the cattle sector in Costa Rica can be summarized in three aspects[4]: 1) meat export markets will not change since markets are already open; 2) local meat prices will gradually decrease because import tariffs for cheap meat will be reduced on a 10-years basis; and 3) input prices (of importable goods such as agrochemicals) will be slightly cheaper the first year of the agreement.

The timber industry will have a gradual reduction in importable tariffs and free access to the US markets on a 10-year schedule. Local prices will therefore depend on the development of local industry and its ability to increase efficiency and competitiveness in the US markets. In general, the Costa Rican forest sector is dynamic and higher timber prices can be expected. Therefore, the policy scenario consisted of simulating lower meat prices and higher timber prices. The different prices were estimated with the lower and higher bounds of the statistical forecast.

5.2.3.4 Sensitivity analysis

The sensitivity analysis simulated 1) a reduction of hay prices, 2) different calving rates, and 3) different pasture carrying capacities. The scenario with low hay prices evaluated three price levels: 10%, 20% and 30% reduction in hay prices. Emphasis was placed on finding the price level to promote higher cattle stocking rates through the use of feed supplements during the dry season.

The scenarios with different calving rates and pasture carrying capacities were applied to the SFS-LIU system only. These scenarios consisted of simulating the changes in net income and tree density of the SFS-LIU system if they had similar calving rates and pastures to the MFS-HIU system.

5.3 Data collection and coefficient estimation

Tables 5.2 and 5.3 summarize the coefficients of the empirical model and their estimated values (see also Appendix B). Table 5.2 shows the technical coefficients of the cattle system per farm type while Table 5.3 summarizes the technical coefficients of the timber growth model. The coefficients can be grouped depending upon the methodology for

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[4] The impacts were estimated by the author through interpretation of tariff schedules (COMEX 2004).

estimation, namely: 1) direct estimation (in-field work), 2) econometric estimation (time series econometric), 3) technical coefficients of pastures, 4) initial cattle values, and 5) timber and tree equations (i.e. timber growth function and canopy-pasture interactions). Each of these groups of coefficients is presented in the following sub-sections.

Table 5.2. Technical coefficients for the cattle component for three farming systems in Cañas and Bagaces counties (prices in constant US dollars 1982-1984=100)

Coefficient	**SFS-LIU***	**MFS-HIU***	**LFS-HIU***	**Source**
Prices for cattle classes	Forecasted time series	Forecasted time series	Forecasted time series	Time series econometrics
Timber stumpage prices	Forecasted time series	Forecasted time series	Forecasted time series	Time series econometrics
Weight of cattle:				Average at the Cañas council (Subasta Ganadera)
Steers	235 kg	235 kg	235 kg	
Heifers	195 kg	195 kg	195 kg	
Cows	400 kg	400 kg	400 kg	
Calving rate	60%	80%	80%	Monitoring
Cattle mortality rate	1%	1%	1%	Monitoring
Fixed cost per cow	$59 per cow	$65 per cow	$60 per cow	Monitoring
Supplement cost per animal unit	$44 per AU	$58 per AU	$44 per AU	Monitoring
Calf animal unit equivalent	0.33	0.33	0.33	CORFOGA 2004
Heifer animal unit equivalent	0.65	0.65	0.65	CORFOGA 2004
Pasture	*Hyparrhenia rufa*	*Brachiaria brizantha*	*Hyparrhenia rufa*	Monitoring
Maximum stocking rate:				Literature review
Dry season	1.0	1.1	1.0	
Rainy season	2.3	6.8	2.3	
Discount factor	9.7%	9.7%	3%	Monitoring
Initial cattle stock	0.7 cows/ha	0.7 cows/ha	0.7 cows/ha	MAG *et al.* 2001

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system.

Table 5.3. Technical coefficients for the timber component in Cañas and Bagaces counties

DBH class	Annual diameter increment (cm/year)	Commercial volume per tree (m^3/tree)	Maximum ingrowth at the 7.5cm class (trees)	Tree mortality (Percentage)	Initial tree density LFS-HIU system	Initial tree density SFS-LIU and MFS-HIU systems
7.5	1.35	n.a.	80	10%	0	0
15	1.50	n.a.	n.a.	10%	1.2	1.8
25	1.34	n.a.	n.a.	10%	1.7	2.5
35	1.11	0.28 m^3	n.a.	10%	2.1	3.1
45	0.79	0.45 m^3	n.a.	10%	1.9	2.9
55	0.35	0.66 m^3	n.a.	10%	1.3	1.9
Source	Adapted SOMARRIBA & BEER 1987	ESQUIVEL 2005	Adapted CAMARGO 1999	Adapted HOWARD & VALERIO 1999	Adapted ESQUIVEL 2005	Adapted ESQUIVEL 2005

n.a.: Not applicable

5.3.1 Direct (in-field) estimation of coefficients

5.3.1.1 Methodology

The data collection consisted of four parts: 1) farm typology and selection of farmers, 2) questionnaire design, 3) monthly visits to farmers, and 4) data processing and analysis.

The **Farm typology** was elaborated as described in Appendix A and no further explanation will be done in this chapter. The **selection of farmers** consisted of choosing ‘typical’ farms for each of the three farm types. The selected farmers were chosen based on willingness to collaborate with the study and willingness to monitor the weekly use of inputs and outputs of their cattle enterprise during one year. Preferably, the farm had easy access. A total of 23 farms were selected: the Fragment Project monitored 15 farms and the Cerbastan Project monitored 8 farms. The joint work allowed a reduction of cost and a wider monitoring of farmers. For the SFS-LIU system 17 farmers were monitored, 4 farmers for the MFS-HIU system, and 2 farmers for the LFS-HIU system.

The **questionnaire** focused on four topics, 1) cattle inventories, 2) cattle cashflows, 3) tree uses and forest resources, and 4) forest and timber cashflows. Appendix D shows a summary of the questionnaire used for data collection.

Table 5.4 Estimated variable cost per cow of a cow-calving production system in Cañas and Bagaces (real US$/cow)

Item	**Commercial Input**	**Recommended dosis**	**Dosis per year**	**Price (CR Colones per input unit)**	**SFS-LIU***	**MSF-HIU***	**LSF-HIU***
Common salt	Salt	50 g/day	18 kg/year	24	432	432	432
Minerals	Pecutrin	16 g/day	5.7 kg/year	300	1,710	1,710	1,710
Vitamins	B-12	3 cc/cow	4 doses/year	111	N.A.	1,332	1,332
Vaccines							
Carbon	Carbon	2 cc/cow	1 dose/year	80	N.A.	160	160
Triple	Triple	5 cc/cow	1 dose/year	32	N.A.	160	160
External antiparasitic	Bayticol	4 ml/cow	48 ml/year	25	1,200	1,200	1,200
Internal antiparasitic	Dectomax	8 ml/cow	32 ml/year	25	800	800	800
Antibiotics	N.A.	Average of surveyed farms		N.A.	100	100	100
Molasses	Melaza	2.5 kg/day	6 months/year	39	17,550	7,020[#]	17,550
Labor	N.A.	Average of surveyed farms		413	21,300	34,800	20,800
TOTAL CURRENT COLONES (2003)					43,092	47,714	44,244
Constant Colones (1995=100)					16,629	18,413	17,074
Current Dollars (2003) US$1 = C.399.73					108	119	111
Constant Dollars (1982-1984=100)					59	65	60

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system.

[#] MFS-HIU make lower use of molasses because they have improved pastures.

Source: Estimated by author from field work.

A **monthly visit** to collect data was undertaken between July 2002 and June 2003 (one group of farmers) and from January to December 2003 (second group). One-year data collection was needed for every farm to capture the variation of production during both seasons. Data collection consisted of face-to-face interviews with producers or, in some cases, with the farm managers. Collected data was captured in spreadsheets. Cashflow for each farm were constructed and then coefficients were estimated by simple statistics. The main results are presented for each coefficient.

5.3.1.2 Cow variable cost

Table 5.4 shows the information needed to estimate the coefficient ‘variable cost per cow’. This table presents the main cattle maintenance activities performed in the area. Since same maintenance is required per cow, there are no differences among cattle systems in this item. The differences are the cost of molasses and labor. MFS-HIU farmers use a different pasture (*Brachiaria brizantha*) which allows higher stocking rates and lower use of molasses. Labor corresponds to the average wage in the area per farm type. For instance, small farmers pay one worker permanently while medium and large farmers can contract temporal workers. Table 5.4 presents the information in current and constant currencies; however, the model was run with constant US dollars only.

5.3.1.3 Supplement costs

The feed supplement cost coefficient ($pfed_t$) was estimated in animal units (A.U.) and corresponds to the dry season only. Supplementation during the rainy season implied an intensive production system and therefore a different technology. For the cases of SFS-LIU and LFS-HIU, this coefficient was equivalent to the purchase of Transbala hay (*Digitaria decumbens* Sten.) to fulfill daily nutrient requirements of one animal unit that has no grass availability during the dry season (all other maintenance elements have been supplied in the variable cost equation). In the case of MFS-HIU, the cost considers Transbala hay and molasses because the cow variable cost does not account for molasses for this farming system. The estimated costs along with prices for policy analysis are shown in table 5.5.

Table 5.5. Estimation of supplement cost per cow, per six months for three farming systems in Cañas and Bagaces (real US$)

	Dry Season		Prices for Policy Analysis		
	Constant Colones	Real US dollars (1982-1984=100)	Scenario A: 10% reduction	Scenario B: 20% reduction	Scenario C: 30% reduction
SFS-LIU and LFS-HIU	32,400	44	39.6	35.2	30.8
MFS-HIM	42,930	58	52.2	46.4	40.6

Source: Estimated by the author.

5.3.1.4 Weight of cattle classes

Three different data sources were chosen to estimate the average weight of cattle: 1) the average weights of market transactions at the *Cañas Livestock Council* (Subasta Ganadera) (CNP 2004); 2) the average weight of animals sold in monitored farms; and 3) simulations with software PASTOR 4.0 (BOUMAN *et al.* 1998). PASTOR 4.0 is a program to simulate cattle performance to generate technical coefficients for mathematical programming models. The average weights used in the model were, steers: 235 kg/animal, heifers: 195 kg/animal, and cows: 400 kg/animal.

5.3.1.5 Calving and mortality rates

Calving and mortality rates were also estimated as the average of monitored farms. The calving rate for the SFS-LIU was estimated to be 60% while it was 80% for the MFS-HIU and LFS-HIU systems. The cow mortality rate for the three systems was estimated as 1%. In the policy analysis scenario, higher calving rates for the SFS-LIU system were analyzed, i.e. 70% and 80% calving rates. These calving rates could be achieved with current technology, by using better management practices such as division of plots, monitoring of daily weight gain and correct supplementation, among others.

5.3.1.6 Discount rates per farm type

The estimation of discount rates was undertaken following the criteria presented in NAVARRO (1999). Small-scale (SFS-LIU) and medium-scale (MFS-HIU) farmers were assumed to be net borrowers and therefore the active interest rate (in US dollars) was used as a discount rate. The average active interest rate (in US dollars) was 9.76% in 2003 (SECMCA 2004). For the case of large-scale farmers (LSF-HIU) a net-saver assumption was assumed and a passive interest rate was used as a discount rate. The average passive interest rate (i.e. the interest rate of savings) was 2.8% in 2003 (SECMCA 2004).

5.3.2 Time series econometrics

This section presents the methodology and main results for the estimations of future timber and cattle prices. The theoretical aspects in this section are based on JUDGE *et al.* (1998) and ENDERS (1995) where also a detailed exposition can be found.

5.3.2.1 Methodology

A price forecast was developed as a two step procedure. First, an estimation of correlation between local and export prices was undertaken. Second, econometric ARIMA (AutoRegressive, Integrated, Moving Average) models were estimated.

The correlation analysis was needed because no time series data is available for local prices. Therefore, the correlation between local and export prices was tested. If they were correlated, local prices could be forecasted with an estimation of export prices. The correlation test was developed with the PROC CORR command of SAS (SAS 1993).

Once the price correlation hypothesis was accepted, export and local prices were forecasted through ARIMA models. An ARIMA model assumes that the time series data has enough information to forecast into the future. ARIMA models also assume that both independent and dependent variables are stochastic. In addition, ARIMA models assume that the trend is stationary (if it is not, the researcher should make it stationary). An ARIMA (p,q) model takes the form (JUDGE *et al.* 1998):

$$\begin{aligned} y_t &= \theta_1 y_{t\text{-}1} + \theta_2 y_{t\text{-}2} + \ldots + \theta_p y_{t\text{-}p} \\ &\quad + e_t + \alpha_1 e_{t-1} + \ldots + \alpha_q e_{t-q} \end{aligned} \tag{5.26}$$

The practical problem is to find the model class (i.e. the values of p and q). The Box-Jenkins procedure (JUDGE *et al.* 1998) is a widely-used methodology to estimate such values. The estimation of the p and q classes and the estimation of the model consists of three steps: 1) the time series stationarity should be proved (e.g. unit root test); 2) estimation of partial and total autocorrelation tables should be developed in order to estimate the values of p and q; and 3) the ARIMA model is estimated through a nonlinear estimator (e.g. maximum likelihood). The econometric estimation was done with the PROC ARIMA command of SAS (SAS 1993).

Data for the cattle and meat industry was obtained from two sources: 1) MIDEPLAN (2004) provided export prices time series for the period 1950 – 2003; and 2) CNP (2004) provided information of cattle classes (i.e. steers, heifers and cows) for the period 1998 – 2003. Appendix D presents cattle and meat time series data.

Export prices of timber (1961 to 2003) were obtained from FAOSTAT (2004) (Appendix D); local prices were obtained from CCF (2004), GÓMEZ (1995), and HOWARD (1995). Data for the forest sector consisted of the aggregation of values for the Central American exports of sawnwood. It means that the prices were estimated with the relative prices obtained by dividing total value exports by total volume.

5.3.2.2 Results for the cattle price forecast

The correlation matrix showed a high correlation among local and export prices. Pearson correlation coefficients were among 0.7 and 0.96 showing that local prices are highly correlated with export prices. Therefore, a forecast of the local prices could be undertaken with the forecast of export prices.

The unit root test suggested that the time series was nonstationary. Another indicator of the need for first differencing came from the examination of the autocorrelation function. The slow decay of the aurocorrelation is the sign of the nonstationarity of the series.

A plot of the first differences showed no obvious evidence of a trend remaining in the series, and the autocorrelation plot was consistent with a stationary series. Examination of the autocorrelation and partial autocorrelation plots suggested that an autoregressive model might be appropriate. However, their order was not so evident. Since the autocorrelation plots suggested that lag 2 and 5 were important, six models were run with several combinations of them: ARIMA (1,1,0), ARIMA (2,1,5), ARIMA (0,1,5), ARIMA ([(2,5),1,0)], ARIMA [0,1,(2,5)], ARIMA (5,1,0). The selection of the best-fit model was done by comparing their *t* values, and using the AIC and SBC statistics. Table 5.6 shows the statistical results. The *t* values for the ARIMA (1,1,0) model are not significant, so this model can be discarded. The models that consider lags 2 and 5 have better AIC and SBC statistics, but models 4 and 6 are the best. Since the forecasts in both models were similar, I selected model 4 for further analysis.

Table 5.6. Statistics for five ARIMA models for forecasting meat prices.

Model Number	**ARIMA model**	***t* values (p value)**	**AIC***	**SBC#**
1	(1,1,0)	AR(1)= –0.87 (0.3870)	58.80533	60.75657
2	(2,1,5)	MA(5)= 3.46 (0.0011) AR(2)=7.74 (0.0875)	46.38887	50.29136
3	(0,1,5)	MA(5)=3.71 (0.0005)	47.42455	49.37579
4	[(2,5),1,0]	AR(2)=1.86 (0.0684) AR(5)= –3.56 (0.0008)	**45.75258**	49.65506
5	[0,1,(2,5)]	MA(2)=1.12 (0.2664) MA(5)= –3.28 (0.0019)	48.18927	52.09176
6	(5,1,0)	AR(5)= –3.69 (0.0005)	47.24175	**49.19299**

* AIC= Akaike's information criteria. # SBC= Schwarz's Bayesian criterion

An ARIMA model [(2,5),1,0)] was used to forecast meat export prices. The estimation of future local prices was done with the criteria:

$$\hat{P}_{i,t+n} = \hat{P}m_{t+n} \cdot gap_i \tag{5.27}$$

where $\hat{P}_{i,t+n}$ is the estimated future price of class i (i.e. steer, heifer, or cow) in the year $t+n$, $\hat{P}m$ is the export price estimation (which was done with the ARIMA model [(2,5),1,0)]), and gap_i is the average price difference between export price and local price. In other words, gap_i was estimated as:

$$gap_i = \frac{\sum \left({P_{i,t}}/{Pm_t} \right)}{T} \tag{5.28}$$

Table 5.7 shows the projected prices for the period 2003 to 2023 (20 year forecast). The lower bound prices were estimated with a damped exponential smoothing model.

Table 5.7. Local meat price forecast 2003–2033 (real US dollar 1982-1984=100).

Year	Export Prices (Chuck 85%)	Steer prices (US$/kg)	Lower bound steer prices (US$/KG)	Heifer price (US$/KG)	Lower bound heifer prices (US$/KG)	Cull cow prices (US$/KG)	Lower bound cull cow prices (US$/KG)
2003	1.25	0.59	0.69	0.50	0.57	0.42	0.49
2004	1.33	0.73	0.68	0.60	0.56	0.53	0.49
2005	1.34	0.74	0.67	0.61	0.56	0.53	0.48
2006	1.29	0.71	0.67	0.58	0.55	0.51	0.48
2007	1.27	0.70	0.66	0.58	0.54	0.50	0.47
2008	1.32	0.72	0.65	0.60	0.54	0.52	0.47
2009	1.29	0.71	0.64	0.58	0.53	0.51	0.46
2010	1.27	0.70	0.63	0.58	0.52	0.50	0.45
2011	1.30	0.72	0.62	0.59	0.51	0.51	0.45
2012	1.32	0.72	0.61	0.59	0.51	0.52	0.44
2013	1.29	0.71	0.61	0.58	0.50	0.51	0.44
2014	1.30	0.71	0.60	0.59	0.49	0.51	0.43
2015	1.31	0.72	0.59	0.59	0.49	0.52	0.42
2016	1.30	0.71	0.58	0.59	0.48	0.51	0.42
2017	1.29	0.71	0.57	0.58	0.47	0.51	0.41
2018	1.30	0.71	0.56	0.59	0.46	0.51	0.41
2019	1.30	0.71	0.55	0.59	0.46	0.51	0.40
2020	1.29	0.71	0.55	0.58	0.45	0.51	0.39
2021	1.30	0.71	0.54	0.59	0.44	0.51	0.39
2022	1.30	0.72	0.53	0.59	0.44	0.51	0.38
2023	1.30	0.71	0.52	0.59	0.43	0.51	0.37

Source: Estimated with the ARIMA model [(2,5),1,0)] and a damped exponential smoothing model.

5.3.2.3 Results for timber price forecast

The unit root test suggested that the forest time series was stationary. However, the hypothesis that none of the autocorrelations of the series up to 6 lags were significantly different from 0 was true (the white noise test). Since this was true for all the lags, there was no information in the series to model with an ARIMA model. This was confirmed by simple statistical models run in SAS (SAS 1993). Table 5.8 shows four models where the mean model obtained the best goodness of fit results. Therefore, to simulate future timber prices, the mean of several years was used.

Table 5.8. Statistics for four timber forecast models.

Model	**Root Mean Square Error**
Mean	63.35485
Log Mean	63.35838
Simple Exponential Smoothing	63.63869
Log Simple Exponential Smoothing	63.83113

The policy analysis considered the probable impact of free trade agreements in meat prices. For instance, the free trade agreement Central America-US (CAFTA) will eliminate US import tariffs on wood products in two time periods (Comex 2004). The first reduction will take place in the fifth year from the starting date (proposed as January 1, 2006), and will reduce import tariffs to 0% from the initial level of 5%. The second reduction will take place in year 10, and will reduce import tariffs to 0% from a base of 10% (Comex 2004). The policy analysis simulated an increase in stumpage prices of 10% in year 5 and a second increase of 10% in year 10. Table 5.9 shows the estimation of future timber prices in the study area as well as the higher bound of prices for policy analysis.

Table 5.9. Forecast 2004 – 2033 of stumpage prices in Costa Rica.

Observation Date	Stand Tree* (C/PMT)[#]	Stand Tree (C/m^3)	Exchange rate (C/US$)	Stand Tree (US $/m3)	CPI USA 1982-1984 = 100	Real Price (US $/M3)
jul-90	8.03	2,618	91.54	28.60	130.5	21.91
jul-91	10.61	3,458	122.53	28.22	136.6	20.66
aug-92	16.39	5,344	133.97	39.89	140.8	28.33
nov-93	18.07	5,890	142.01	41.48	146.0	28.41
nov-94	20.66	6,736	157.02	42.90	149.8	28.64
dec-02	55.00	17,930	378.39	47.38	181.6	26.09
jun-03	50.00	16,300	397.91	40.96	183.5	22.32
feb-04	70.00	22,820	423.94	53.83	183.3	29.37

Average price	25.72
Price for years 5 to 10 (10% price increase; policy analysis only)	28.29
Price for years 11 to 20 (10% price increase; policy analysis only)	31.12

* Average of semi-hard classified woods, which include: amarillón, ciprés, guanacaste, carey, botarrama, maría, guayaquil, ajo, cedro dulce, plomillo, ocora, roble sabana, titor, níspero, chiricano, tamarindo, camíbar, pilón, cenízaro, eucaliptos.

[#] $1m^3$ = 326 Costa Rican Metric Inch (Pulgada Metrica Tica PMT)

Sources: Prices 90-94: Gómez (1995), Howard (1995); Prices 2002-2004: Ccf (2004); Exchange rate: Bccr (2004); and US CPI: Usdl (2004).

5.3.3 Technical coefficient for pasture

The technical coefficient for pastures ($pasto_{j,t}$) was estimated with available information from the scientific literature for *Hyparrhenia rufa* and *Brachiaria brizantha* in the tropical dry forest of Guanacaste (Morales *et al.* 2003; Restrepo 2002; Quiros 1993; Chavarria 1990; Rivas 1990; Vargas & Fonseca 1989; Cerdas 1977; Vargas 1978).

The *pasto* coefficient was estimated by obtaining the maximum dry matter and crude protein that a hectare of grass produces in the area, and then expressing this values in terms of total animal units that can graze a hectare of grass. Based on fieldwork (FLORES & MONTERROSO 2002; section 4.2), it was assumed that SFS-LIU and LFS-HIU producers graze animals on Jaragua grass (*Hyparrhenia rufa*) while MFS-HIU producers graze animals on *Brachiaria brizantha*. The estimated values are presented in Table 5.10. The policy analysis simulated the use of *B. brizantha* for the SFS-LIU system, as a way of intensifying cattle production and increasing incomes.

Table 5.10. Estimated technical coefficients for *Hyparrhenia rufa* and *Brachiaria brizantha* to be used in the simulation model.

	Hyparrhenia rufa		*Brachiaria brizantha*	
	Dry Season	Rainy Season	Dry Season	Rainy Season
DM* production (kg / month)	302	681.5	327	2053
Maximum consumption per month of one A.U. (kg/month/cow)#	300	300	300	300
Maximum stocking rate per hectare (AU/ha)	1.0	2.3	1.1	6.8

* DM: Dry Matter in kg per month. # It is assumed that one animal unit consumes 2.5% per day of its live weight of dry matter. An animal unit equals a cow of 400kg. Source: Estimated based on RESTREPO (2002), QUIROS (1993) CHAVARRIA (1990) and RIVAS (1990).

5.3.4 Initial model values

This section presents the estimation of total area and initial livestock levels. Section 5.2.5 deals with initial timber stocks. The total study area was estimated with a GIS with available maps from Cañas and Bagaces (ITCR 2001) to be 570 km^2 (FLORES & MONTERROSO 2002). For each farm type, an estimation of pasture area was needed. The Costa Rican Livestock Census (MAG *et al.* 2001) provided the information to estimate both total farm area and pasture area per farm type (see Table 4.2). The model was run with pasture area data only.

In addition, initial herd size was also estimated with data from the Costa Rican Livestock Census (MAG *et al.* 2001). Initial herd size only considered the number of cows and heifers (more than 2 years old) that farmers reported in the Census. The estimated coefficients are presented in Table 5.11.

Table 5.11. Farm area, pasture area, and herd size for three farming systems in Bagaces and Cañas, Costa Rica.

	SFS-LIU	MFS-HIU	LFS-HIU	Total
Total farm area (ha)	14,292	6,437	16,659	37,388
Total pasture area (ha)	9,441	5,141	9,595	24,177
Initial herd size	1,996	1,320	2,312	5,628

Source: MAG *et al.* 2001

5.3.5 Coefficients for the tree growth model

Coefficients for the tree growth model were estimated based on ESQUIVEL'S *et al.* (In prep.) inventory data (see section 2.3 for more details about the tree inventory) as well as relevant scientific and expert knowledge. The required coefficients to be estimated were: 1) annual diameter increment, 2) average volume of commercial classes, 3) maximum ingrowth in the 7.5 cm class, and 4) initial diameter distribution. In addition, an equation that relates the basal area with canopy area was required (Eq. 5.18). The procedure to estimate these coefficients as well as the required equation is presented in this section.

5.3.5.1 Annual diameter increments

SOMARRIBA & BEER (1987) reported growth rates of *Cordia alliodora* for the Atlantic zone of Costa Rica. Contrary to the dry areas of Cañas and Bagaces, the Atlantic zone has good soils and is more humid. I estimated the diameter growth rates with SOMARRIBA & BEER'S (1987) equations and then adjusted these rates to be 33% lower than the values for the Atlantic zone. It implied that a tree requires 30 years, instead of 20 years, to reach a diameter of 40 cm. The annual diameter increment is (Table 5.3) 1.35 cm/year for the 7.5 cm class, 1.5 cm/year for the 15 cm class, 1.34 cm/year for the 25 cm class, 1.11 cm/year for the 35 cm class, and 0.79 cm/year for the 45 cm class.

SPITTLER (2001) mentioned that dry forest has slower growth rates than humid forest. MONGE *et al.* (2002) found average annual diameter increments of 0.3 cm (trees of diameter class smaller than 40 cm) in four permanent plots with 30 years of monitoring at Palo Verde National Park. CHAPMAN & CHAPMAN (1990) found annual diameter growth rates of 0.6 cm for non-timber tree species at Guanacaste National Park. MOREIRA-BEITA (2002) reports mean annual increments of 1.12 cm/ha/year in *Pseudosamanea guachapele*, 0.83 cm/ha/year in *Astronium graveolens*, 0.95 cm/ha/year in *Bombacopsis quinata*, in 13-year-old plantations in Cañas, Guanacaste. In secondary forest at

Guanacaste National Park, MEZA & MORA (2002) report current annual diameter increments between 0.18 and 0.27 cm/year.

5.3.5.2 Average volume of commercial classes

ESQUIVEL'S (2005) data allows the estimation of average volume per hectare. In the area, the commercial volume is estimated with a single formula for all tree species (Equation 5.29). Producers are paid based on that formula and the errors of using it are charged to producers. Since my approach is to maximize the profits farmers obtain by selling the trees, the estimation of volume with this formula was a valid assumption for the model. The formula used is:

$$m^3 = dbh^2 \cdot \frac{\pi}{4} \cdot f \cdot h \tag{5.29}$$

where m^3 is volume, dbh is diameter at breast height, f is a form factor equal to 0.7, and h is tree height.

Commercial classes have diameters greater than 30cm. The average volume of commercial trees was estimated with ESQUIVEL'S (2005) data. Table 5.12 presents the simple statistics of inventoried trees and shows that the average volume for the 35 cm and 45 cm classes is 0.23 m^3 per tree and 0.45 m^3 per tree, respectively.

Table 5.12. Simple statistics and average volume of *Cordia alliodora* for the 35cm, 45cm, 55cm and 65cm diameter classes

DBH class	**Number of observations**	**Average volume (m^3/tree)**	**Std Dev**	**Min**	**Max**
35	154	0.28	0.13	0.07	0.84
45	157	0.45	0.25	0.14	1.12
55	99	0.66	0.31	0.22	2.54
65	50	0.83	0.34	0.37	1.98

Source: Tree inventory in Cañas, Esquivel (2005).

5.3.5.3 Maximum ingrowth in the 7.5cm class

Ingrowth at the smallest diameter class is a control variable. It means that the model finds the optimal number of trees that farmers should allow to be established in pastures in order to increase profits. However, a maximum number of trees that naturally regenerate should be specified to the model, and it was set at 80 trees/ha. CAMARGO (1999) reported natural regeneration of *C. alliodora* between 60 to 120 trees per hectare in pastures in Esparza while MEZA *et al.* (2002) report 30 trees/ha in a permanent plot of secondary regeneration (25 years-old) in Guanacaste National Park.

5.3.5.4 Initial diameter distribution

The initial diameter distribution was estimated with the tree inventory data (ESQUIVEL *et al.* in prep.). Two parameters were used to estimate the initial diameter distribution. First, the observed diameter distribution of trees in cattle farms was used to obtain the tree density per diameter class. Then, the average density of trees in pastures provided the total tree density at year $t=0$.

The tree inventory (ESQUIVEL *et al.* in prep.) showed that the average density of dispersed trees (dbh>10cm) was 8.06 trees/ha (se 0.66); small farms have an average of 13 trees/ha and large farms have 7 trees/ha. In this research, the SFS-LIU and MFS-HIU systems were simulated with an initial tree density of 15 trees/ha and the LFS-HIU system was simulated with and initial density of 10 trees/ha (Table 5.13).

Figure 5.1 shows the diameter frequency of timber trees for the 16 inventoried farms. It can be seen that the average plot does not have the desired ‘inversed-J’ diameter distribution. This frequency was used to estimate the initial diameter distribution of the baseline scenario.

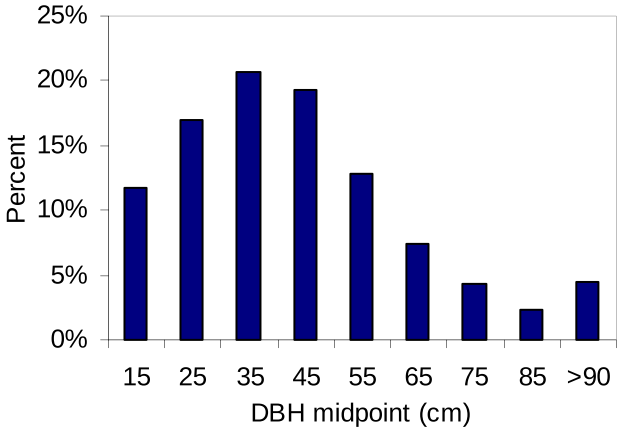

Figure 5.1. Distribution of diameters at breast height (in cm) of dispersed trees in pastures (n = 5,896 trees) of cattle farms in Cañas. (Source: ESQUIVEL 2005)

Table 5.13 summarizes the diameter distributions and tree density of the baseline scenario for the three cattle systems. The diameter distribution of the baseline scenario follows the same pattern shown in Figure 5.1. The other two scenarios, namely middle and high tree densities, were arbitrarily selected to test the performance of the model for finding the optimal density of dispersed trees. Only the baseline scenarios were considered for the policy scenarios.

Table 5.13. Estimated initial diameter structure of dispersed trees in pastures of three cattle systems, and densities for two policy analysis, Cañas and Bagaces.

DBH class	Baseline scenario		Middle density (84 trees/ha)	High density (160 trees/ha)
	Initial tree density for LFS-HIU system	Initial tree density for SFS-LIU and MFS-HIU systems		
7.5	0	0	35	60
15	1.2	1.8	25	50
25	1.7	2.5	22	40
35	2.1	3.1	2	10
45	1.9	2.9	1	1
55	1.3	1.9	0.5	0.5
65	0.7	1.1	-	-
75	0.4	0.6	-	-
85	0.2	0.4	-	-
>90	0.5	0.7	-	-
Total trees/ha	10	15	85.5	161.5

5.3.5.5 Canopy and basal area equation

The equation that relates canopy area as a function of basal area was estimated with data of the inventoried trees (ESQUIVEL 2005). Equation 5.30 reproduces the estimated parameters and goodness of fit values:

$$\begin{aligned} &CC_t = \left(22.2 + 501.75 \cdot BA_t\right)/10000 \\ &t \text{ values} \quad (0.89) \;\; (30.95) \\ &R^2 = 0.86 \qquad \text{Adj } R^2 = 0.8598 \end{aligned} \tag{5.30}$$

5.3.5.6 Initial tree cover at the regional level and policy targets

Table 5.13 and Equations 5.19, 5.20 and 5.30 were used to estimate initial tree cover at the regional level. The estimation consisted of calculating total tree density per farm type and then estimating the tree cover. The estimation is shown in Table 5.14.

Table 5.14. Estimated regional tree cover (total hectares) in 2003 in Cañas and Bagaces and two targeted canopy levels (hectares) for policy analysis.

	Units	SFS-LIU	MFS-HIU	LFS-HIU	Total
Initial tree density	N	15	15	10	
Initial basal area per stand	m^2/ha	2.70	2.70	1.80	
Initial canopy area per stand	m^2/ha	1,378	1,378	926	
Total pasture per cattle system	ha	9,441	5,141	9,600	24,177
Total tree cover in pastures per cattle system	ha	1,301	709	889	2,898
Policy target					
1: To increase current tree cover by 50%	ha	1,952	1,063	1,333	4,348
2: To increase current tree cover by100%	ha	2,602	1,417	1,777	5,797

Source: Estimated with tree inventory (ESQUIVEL 2005) and MAG *et al.* 2001.

5.4 Chapter summary

This chapter presented the model structure and the methodology to obtain the model coefficients. The empirical model represents a calving-only enterprise, the main production system in the area. The model has three control variables (replacement, supplemental feed purchase, ingrowth trees in the 7.5cm diameter class, and tree harvest). In addition, the model has two state variables, number of cows and tree density per diameter class. The objective function is a maximization of net revenues from cattle and timber sales.

The chapter presented the methodology to simulate silvopastoral policies in the area. Five specific policies were simulated: 1) implementation of a payment for environmental service (PES) program, 2) tax policy, 3) changes in output prices, 4) changes in input prices, and 5) technological improvements.

Then the chapter explained the estimation of the coefficients to run the model so that the reader can see that one of the most time-demanding processes in this kind of research is the estimation of technical coefficients and natural resource variables. The coefficients and initial value of variables were estimated following scientific procedures and using the most up-to-date information and methods.

CHAPTER 6

SILVOPASTORAL POLICIES AND BIODIVERSITY CONSERVATION IN THE TROPICAL DRY FOREST OF COSTA RICA

This chapter presents results and discussion of the policy simulation for increasing tree canopy in pastures as a means to enhance biodiversity conservation. The policy instruments were of two kinds (Table 6.1): 1) economic incentives focused on the tree component (i.e. direct payment for environmental services, PES), and 2) economic (dis-) incentives focused on the cattle component (i.e. taxes on cattle production with low tree cover). There are two ideas behind the selection of these policies. First, the PES assumes that taxpayers should compensate the cattle producer for the environmental services they provide. In the PES, the government acts as the intermediary between society and producer. In contrast to the PES, a tax policy assumes that cattle production without trees degrades the environment and therefore producers with low tree cover should pay for the environmental damage. This is a close idea to the ‘polluter pays principle’, which advocates that producers who pollute (or degrade) the environment should pay for it.

The question of who should pay for the environmental improvement (either tax payers or producers) is a *normative* issue that is debated within a society. In this research, I focus on the *positive* analysis (as the opposite of the *normative* analysis) about the efficiency and cost of the three policies to increase tree canopy in cattle farms.

In addition, since free trade agreements (e.g. DR-CAFTA) will impact the cattle industry, a free-trade scenario without policy interventions was also analyzed. This scenario simulates the impact of low meat prices and high timber prices on land use as the likely impact of open markets in the tropical dry forest of Guanacaste. Finally, a sensitivity analysis for input prices, calving rates, and pasture carrying capacity was undertaken. Tables 6.1 and 6.6 summarize the policies and scenarios evaluated in this chapter.

The analysis of policies and free trade considered the three farming systems introduced in Chapter Four: 1) small farm-size with low use of purchased inputs (SFS-LIU system),

2) medium farm-size with high use of purchased inputs (MFS-HIU system), and 3) large farm-size with high use of purchased inputs (LFS-HIU system).

Table 6.1. Description of policies and scenarios that were simulated for the case study in Cañas and Bagaces.

Policies to increase tree cover		**Free trade scenario**	**Sensitivity analysis**
Intervening in the tree component	**Intervening in the cattle component**		
Payment for environmental services (PES) with four payment schemes: a) payment per tree >30cm dbh b) payment per tree dependent on dbh class c) payment per changes in basal area d) FONAFIFO's PES (payment for planting trees)	Taxes on cattle management without trees: a) annual tax payment when tree basal area per ha is below a previously defined policy target	Simulation of a scenario with changes in output prices: a) reduction in meat prices b) increase in timber prices	Analysis of income and tree cover if key parameters were different than the estimated: a) low hay prices b) higher calving rates c) higher pasture carrying capacity

This chapter is divided into four sections. Section 6.1 presents the validation of the model and section 6.2 introduces the baseline scenario per farm type. Section 6.3 presents the implications of a PES policy in cattle farms while section 6.4 focuses on the tax instrument on extensive cattle ranching. Section 6.5 presents the case of free trade and section 6.6 presents a sensitivity analysis scenario. Finally, section 6.7 discusses the main results as well as analyzes the influence of initial assumptions over the empirical results.

6.1 Model validation

The validation exercise consisted of solving the 'cattle sub-model' backwards on time and comparing it with real herd data from past years (see section 5.1.3 for further details). Table 6.2 shows the results of the validation exercise by comparing the observed cattle stocking rates with the predicted values. The table shows that the model highly overestimates the stocking rate in 1973. This can be caused mainly by two factors. First, there were no observations for the 1974-1984 period when cattle stocking rates must have been at their highest level given the meat price peak during this period (see Figure 4.2). Second, the biophysical (e.g. pasture fertility), economic (e.g. risk aversion), or social (e.g.

farm organization) characteristics of the farms, which were assumed constant in the model, must have been different in the 1970s. For example, the increase of cattle production was dependent on clearing of new land, and therefore a livestock increase implied extra labor costs during the 1960–1970 period.

Table 6.2. Observed and predicted stocking rates (animal units/hectare) in Cañas and Bagaces, Guanacaste, during 1950, 1955, 1963, 1973, 1984 and 2000.

	Observed stocking rates (AU/ha)	**Predicted stocking rates (AU/ha)**	**Difference (%)**
2000	0.557	0.556	0%
1984	0.933	1.189	27%
1973	0.677	2.192	224%
1963	0.838	0.958	14%
1955	0.970	0.944	-3%
1950	0.917	0.700	-24%

Source: Observed data: DGEC 1953, 1959, 1965, 1973, 1985; MAG *et al.* 2001.

Nonetheless, the recent trend of herd size is captured well by the model. Figure 6.1 shows the estimated regional animal units and the observed trend for the last 20 years where it can be seen that the model adjusts the values around the observed trend. It can be concluded that in general terms, the model predicted the recent observed trend and therefore it can be used for policy analysis in the dry tropics of Guanacaste. However, caution should be taken to model large periods of time (e.g. more than 20 years) without reconsidering the model's main assumptions.

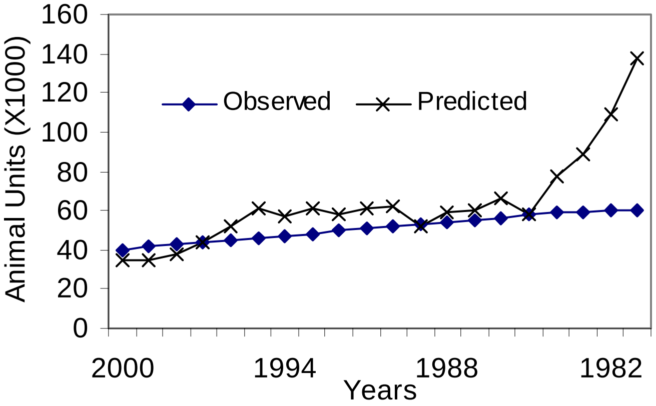

Figure 6.1. Observed herd size and predicted herd size from 1981 to 2000 in Cañas and Bagaces, Guanacaste, Costa Rica (Source: Table 5.1 and empirical model).

6.2 Baseline scenario

The baseline scenario is presented by describing: 1) simulated state variables (herd stock and tree density), 2) simulated decision variables (number of replacement cows, number of animal units fed with supplements, number of recruiting trees, and number of harvested trees); and 3) simulated net present profit (NPV) per farm system.

6.2.1 State and control variables for tree resources

Figure 6.2 shows two simulated dynamics of the basal area (state variable)[5] for the three cattle systems. Figure 6.2a shows the case when remnant trees (diameter greater than 60 cm) can be harvested. Since the model finds that the optimal tree harvest is at the 35 cm class, it is suggested that all trees of diameters greater than 30 cm should be harvested at the beginning of the period. Given that more than 70% of trees belong to diameter classes higher than 35 cm (see Table 5.13), the model suggests a reduction in basal area from 2.7 m^2/ha (for the SFS-LIU and MFS-HIU systems) and 1.8 m^2/ha (LFS-HIU system) to 0.1 m^2/ha in year $t=1$.

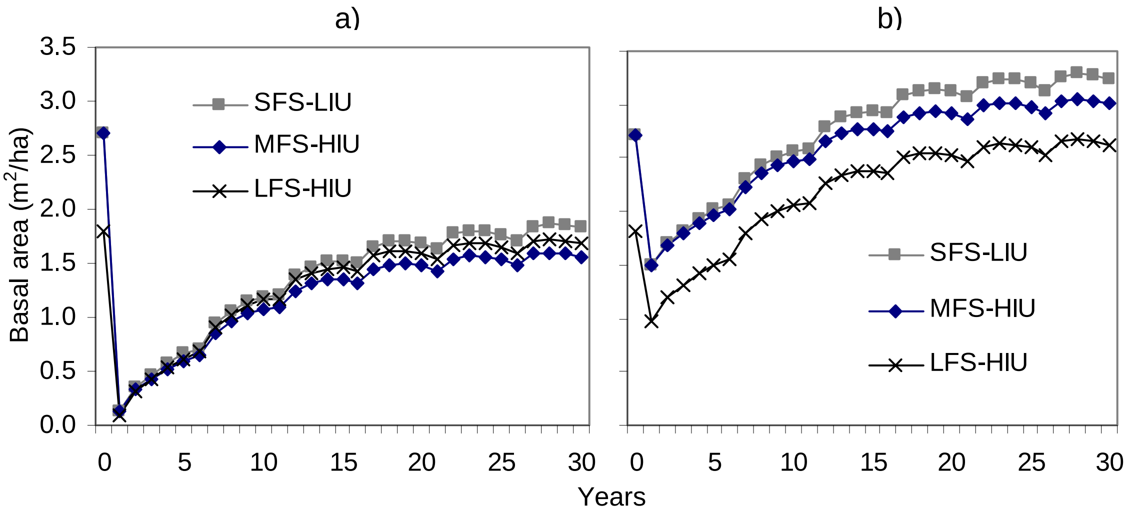

Figure 6.2. Simulated basal area (m^2/ha) for 20 years for three cattle systems in Cañas and Bagaces: a) when all trees greater than 30 cm can be harvested, and b) when only trees of the 35, 45 and 55 cm diameter classes are harvested, and trees greater than 60 cm are left standing in the field.

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[5] The model's state variable is tree density (DEN_{dbh}). However, basal area represents the aggregation of tree densities and becomes a better indicator for presenting results and conclusions.

The model did not capture some costs and benefits of trees from the diameter classes greater than 65 cm, which are remnant trees of original forest. Farmers, for example, do not harvest big trees because their management is difficult; for example, the cost of trucks to transport the wood is not justified for one or two trees per farm. In addition, remnant trees are valuable resources for biodiversity conservation (HARVEY & HABER 1999; HARVEY *et al.* 2004; Section 2.1). For example, HIETZ-SEIFERT *et al.* (1996) found that remnant trees have a greater number of epiphyte vegetation than cultivated *Cedrela odorata* and citrus trees in dispersed trees in pastures in Veracruz, México.

In order to capture the value of remnant trees for biodiversity conservation, a restriction of no harvest of trees greater than 60 cm was imposed on the model. Figure 6.2b shows such a scenario where trees belonging to diameter classes 35, 45 and 55 cm are sustainably managed, and trees greater than 60 cm are left standing in the field. This scenario shows a smaller reduction of basal area in year $t=1$ than Figure 6.2a and a greater optimal basal area due to the imposed restriction. The basal area of the LFS-HIU system is lower than the other two systems because the former system has a lower density of remnant trees. Given the great value of remnant trees for biodiversity conservation**, the policy analysis will be simulated with the baseline scenario presented in Figure 6.2b** (unless otherwise is stated), i.e. trees of the diameter classes 35, 45 and 55 cm can be harvested while remnant trees (diameter greater than 60 cm) are left standing in the field.

Four further points can be highlighted from Figure 6.2. First, since Figure 6.2a actually begins the analysis in year $t=1$ with a basal area of 0.1 m^2/ha, which can represent farms with a very low tree density. The model found that in farms without trees, the optimal basal area will be around 1.5 m^2/ha. I will refer to this case as the ‘scenario without initial remnant trees’.

Second, Figure 6.2b shows that there is a **steady-state** level that is approximately reached in year $t=20$ for the three cattle systems. It is worth remembering that the steady-state is reached when both the stock of the natural resource and the harvest level do not change over time (section 4.1.3 discussed the theory of steady-states). In Figure 6.2, the steady state of dispersed trees is reached in year $t=20$ because the basal area starts fluctuating around a fixed minimum and maximum level in year 20.

Third, there is a **transition path** from year $t=0$ to year $t=20$, when the basal area reaches the steady-state level. The transition path from the initial basal area (2.7 m^2/ha for the SFS-LIU and MFS-HIU systems at year $t=0$, and 1.8 m^2/ha for the LFS-HIU system) to the steady-state basal area shows first a reduction in year $t=1$ due to the harvest of commercial trees and then an increase up to the year where steady-state is reached ($t=20$). The transition path will be further analyzed in section 6.1.3.

Fourth, the optimal **basal area varies among cattle farms**. The model finds that the SFS-LIU system has the greatest basal area (an average of 3.2m^2/ha in the steady-state level in Figure 6.2b) while the MFS-HIU system has and average basal area of 3.0m^2/ha in the steady-state level. The LFS-HIU system has the lowest basal area with an average of 2.6 m^2/ha in the steady-state level. As explained above, the low density of remnant trees in the LFS-HIU system causes the optimal basal area to be at a lower level than the SFS-LIU and MFS-HIU systems. In the scenario without initial remnant trees (Figure 6.2a) the LFS-HIU system has a higher basal area than the MFS-HIU system.

The simulated **optimal tree cover** in Figure 6.2b averages 1,700 m^2/ha at the steady-state level for the SFS-LIU, 1,600 m^2/ha for the MFS-HIU system, and 1,300 m^2/ha for the LFS-HIU systems. However, in the 'scenario without remnant trees' (Figure 6.2a), the tree cover averages 900 m^2/ha for the three cattle systems, which is similar to the 700 m^2/ha (±54 s.e.) (ESQUIVEL *et al.* in prep.) average canopy area that farmers typically manage in their farms.

Table 6.3. Simulated ingrowth of trees (number/ha/5 years) and harvest of trees (volume and density/ha/year) during the steady state of the baseline scenario.

	Unit	SFS-LIU system	MFS-HIU system	LFS-HIU system
Recruiting in the 7.5 cm class	Number/ha/5 years	54	49	50
Volume harvested	m^3/ha/year	0.62	0.55	0.57
Harvest trees 35 cm dbh	Number/ha/year	1.94	1.71	1.79
Harvest trees 45 cm dbh	Number/ha/year	0.16	0.14	0.15
Harvest trees 55 cm dbh	Number/ha/year	0.01	0.01	0.01

Regarding **control variables of tree resources** (i.e. number of recruiting trees and harvested trees), the SFS-LIU system has the greatest number of recruiting trees in the 7.5 cm diameter class while the MFS-HIU has the lowest recruiting level (Table 6.3). The number of recruiting trees agrees with the level of basal area: the SFS-LIU system has the greater number of recruiting trees and the highest basal area. The LFS-HIU system actually has a greatest basal area under sustainable management than the MFS-HIU system (see for example Figure 6.2a); the difference is given by the basal area that is fixed due to remnant trees that are not harvested. The SFS-LIU system harvests the greatest annual volume per hectare, as well as the greatest number of trees in the three diameter classes. The harvest of trees also agrees with the level of the optimal basal area.

6.2.2 State and control variables for cattle resources

Figure 6.3 shows the simulated **optimal herd stock** for the three cattle systems under the scenario of non-harvesting of remnant trees. Figure 6.3 shows that the MFS-HIU system has a cattle stocking rate of 1 AU/ha, while the SFS-LIU system maximizes at 0.9 AU/ha during the whole period. The MFS-HIU system can attain higher stocking rates than the SFS-LIU system because of the use of improved pastures (*Brachiaria brizantha),* whose carrying capacity during the dry season is greater than the Jaragua grass (*Hyparrhenia rufa*). The optimal animal units of the LFS-HIU system present an instable system; on average, animal units are maximized at 0.93 AU/ha, but there are three peaks of 1.15 AU/ha. This instability is present during the tree transition path (almost the first 25 years). After this time, the system stabilizes at 0.92 AU/ha. The livestock census (MAG *et al.* 2000) reports an average stocking rate of 0.97 (± 0.32) AU/ha for the SFS-LIU system, 0.4 (± 0.07) AU/ha for the MFS-HIU system, and 0.4 (± 0.05) AU/ha for the LFS-HIU system.

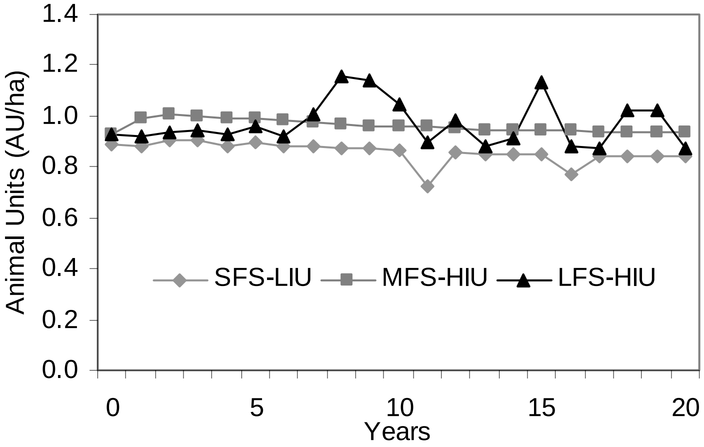

Figure 6.3. Simulated cattle stocking rates (AU/ha) for the SFS-LIU, MFS-HIU, and LFS-HIU systems, in Cañas and Bagaces, Guanacaste, 20 year projection (Source: Empirical model).

Figure 6.3 also shows a smooth decline in cattle stocking rates. For example, the MFS-HIU system has 1 AU/ha in year $t=2$ and 0.94 AU/ha in year $t=20$. It represents a 7% decrease in 20 years. For SFS-LIU and LFS-HIU systems, the same proportional reduction is found. This smooth decline in cattle stocking rates is caused by the increase of canopy cover, which reaches the steady-state approximately in year 20 (compare with Figure 6.2).

The maximum animal units that pastures can support during the dry season (i.e. pasture's carrying capacity) constrain the optimal cattle stocking rate. During the dry season, *H. rufa* can support 1 AU/ha (if supplements are provided) while *B. brizantha* can feed 1.1 AU/ha. During the rainy season, pastures could feed more than double the stock in the dry season.[6] Hence, pasture availability during the dry season is the main limiting factor in the intensification of herd size in the study area.

The **optimal cull-cow variable** (replacement) was found to be between 0.08 and 0.10 AU/ha/year. The replacement rate assures that the livestock is sustainable over time. The number of **animals fed with supplements** is null for both the SFS-LIU and MFS-HIU systems. The LFS-HIU system, however, uses supplements during the first 15 years, which correspond to the transition path period for reaching the optimal tree stocking rate. The simulation shows that supplementation is not economically optimal for the SFS-LIU and MFS-HIU systems, and for the LFS-HIU farmers it is profitable only during the transition path. These results agree with the low use of feeding supplements in the study area.

6.2.3 Optimal net present values

Table 6.4 shows the simulated net present benefits of dispersed trees in pastures for a future 20-year period. The NPV of tree harvest shows the profits from harvesting existing remnant trees (35, 45, and 55 diameter classes only) and the profits from year 1 to year 20, which represent the transition path and the steady-state. The table shows that the profit from harvesting initial tree stock (i.e. remnant trees) accounts for more than 63% of timber profits.

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[6] Pastures, however, should be grazed in both seasons, otherwise pasture maintenance costs may increases (pers. comm. interviews). In practice, producers have different strategies for using the extra pasture from the rainy season such as steer fattening during 6 months or renting their pastures (RAMOS 2003). The production of hay from Jaragua grass is not common in the area.

For a comparison, a scenario without trees, named 'cattle-only system', was also added to the table. The **silvopastoral system is more profitable** than the cattle-only system in the three farming systems even when compared with the scenario without the harvesting of remnant trees. Although the cattle profits of the silvopastoral systems (e.g. $212 for SFS-LIU) are less than in the cattle-only system ($223), profits of the tree component compensate for such a reduction.

Table 6.4. Simulated net present values (NPV) of dispersed trees in pastures vs. a cattle-only scenario for three farming systems in Cañas and Bagacas, Guanacaste (NPV/ha in constant US$ 1982-1984=100).

	SFS-LIU*	**MFS-HIU***	**LFS-HIU***
Silvopastoral System			
-NPV of the cattle component	212	366	613
-NPV of the tree component			
-Profits from remnant trees[#]	75	75	51
-Profits from year 1 to year 20	44	41	87
Total NPV SPS with remnant trees	*331*	*482*	*751*
Total NPV SPS without remnant trees	*256*	*407*	*701*
NPV Cattle-only system	223	392	660

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system. [#]/ Only remnant trees from the 35,45, and 55 cm diameter class. Discount factor for SFS-LIU and MFS-HIU: 9.7%; LFS-HIU: 3.25%.

Dispersed trees in pasture (as a silvopastoral system) can be more profitable than **managed secondary forest**. SPITTLER (2001) appraised the profitability of three different management regimes for secondary forest in Cañas, finding that 200 ha of secondary forest can yield a NPV of US$ 173 (real prices), in a rotation of 50 years. This represents less than 30% of the profits for the SFS-LIU system with silvopastoral production. These data explain why the regeneration of secondary forest is mainly occurring in marginal areas or land that is not suitable for cattle production.

The differences in areas devoted to trees among cattle systems are caused by the relative weight in profits of the timber and cattle components. Compare, for example, the case of the MFS-HIU system that has the same initial basal area to the SFS-LIU system but different cattle technology such as better calving rates and improved pastures. Table 6.4 shows that timber revenues contribute to 17% of the SFS-LIU's total net benefits (in the scenario without profits from remnant trees) and 10% for the MFS-HIU's profits. In addition, the net benefits of the cattle-only system are 4% and 7% lower than the silvopastoral system in the case of the MFS-HIU and LFS-HIU systems, but they are 13%

lower in the case of the SFS-LIU system. Hence, the contribution of timber to total income is relatively higher for the SFS-LIU system than for the MFS-HIU and LFS-HIU systems.

Given the high profits of the cattle component, the MFS-HIU system requires high timber revenues to compensate for any foregone profit from the cattle component if tree cover were increased. The high cattle profits for the MFS-HIU producers explain the low tree cover of these producers compared with the SFS-LIU system. It can be concluded that the **relative profitability of trees decreases as farms become more specialized** in cattle production.

The impact of specialization on the distribution of resources (in this case land) inside a silvopastoral system is an expected result. Economic theory suggests that farmers will allocate resources (i.e. land) depending upon the profitability of the products (see section 3.1.2 and Eqs. 3.11 to 3.13). The use of better cattle technology makes timber revenues relatively less attractive than cattle gains and then fewer incentives exist to have trees in the farm. VILLACIS *et al.* (2003), in a study in Rio Frio, Costa Rica, found that the more intensive cattle farms tend to have less tree cover in pastures as well as in the whole farm. Contrarily, the less intensive farms presented more tree cover in pastures and more areas devoted to forest. FLORES & MONTERROSO (2002) also found that the less intensive farms in Cañas and Bagaces have more natural regeneration areas (Sections 4.2 and 4.3).

6.2.4 Transition paths and diameter distributions

A closer look at the economics of dispersed trees is presented by analyzing the transition paths and the optimal tree diameter distribution. Figure 6.4 shows three different initial tree densities and their transition paths to the steady-state for the SFS-LIU system. The baseline scenario reproduces the curve shown in Figure 6.2a where all the remnant trees are harvested. The baseline represents a scenario of low basal area since it starts the systems with 0.1 m^2/ha in year $t=1$. The mid curve (in Xs) shows an initial diameter structure similar to the optimal structure (basal area of 2.15 m^2/ha). For this reason, the curve achieves the optimal basal area during the first years. The upper curve (in diamonds) depicts a situation of high initial basal area (4.4 m^2/ha). This scenario requires approximately 25 years to reach an optimal stand structure. The main point in Figure 6.4 is that **the model finds the transition path** to reach the tree density that assures the sustainable use of the resource. Policy analysis will focus on the steady state and not on the transition paths. The approach will be to analyze the impact of policies on the steady-state.

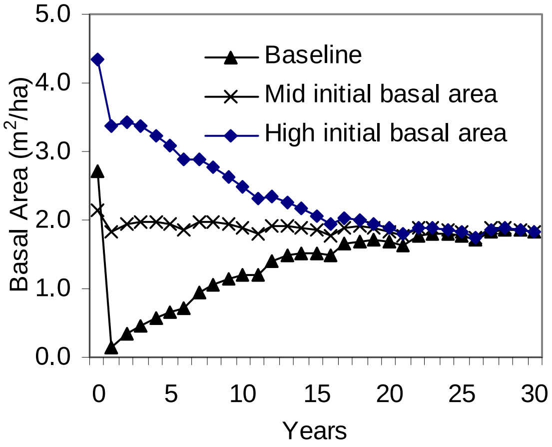
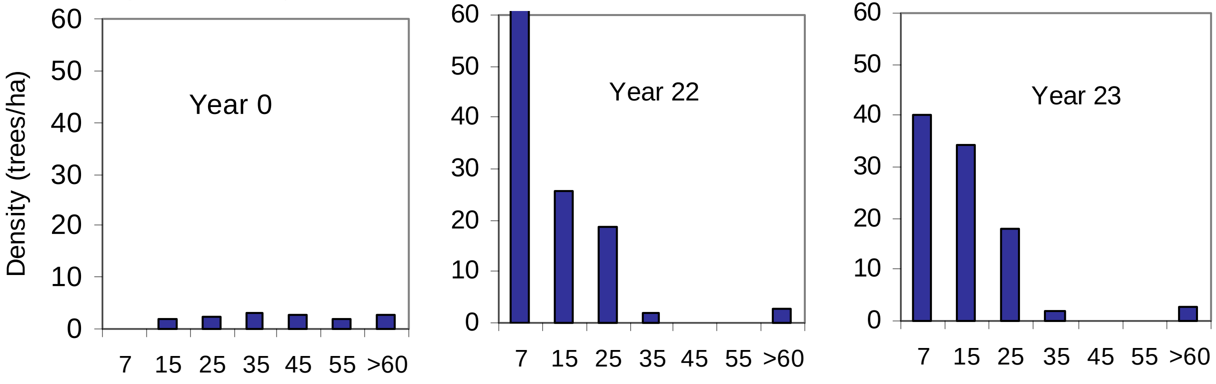


Figure 6.4. Simulation of three different initial basal areas (m^2/ha) and their transition paths to the steady-state for the SFS-LIU system (Source: empirical model).

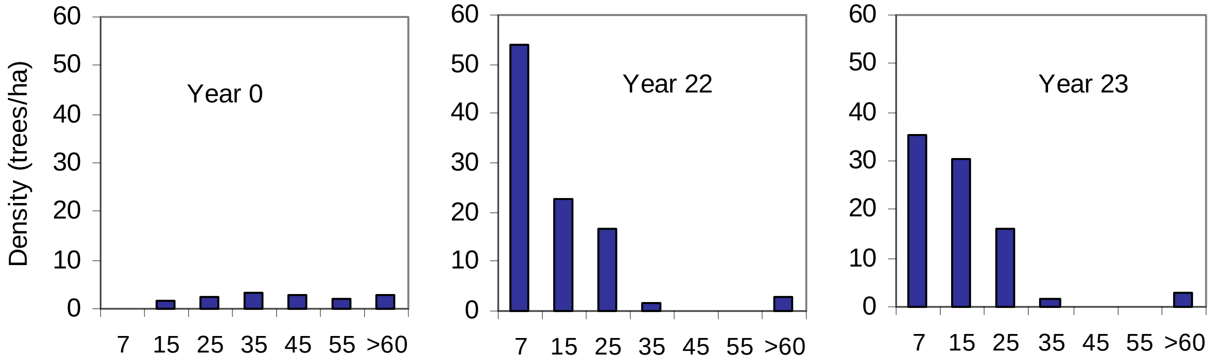
Figure 6.5 shows three groups of graphs with **stand diameter structure** for the three farming systems in the baseline scenario. In year *t=0*, the stand structure of the three farming systems differs highly from the optimal structure, which is shown for years 22 and 23 for the three cattle systems. In year *t=22*, recruiting trees are accounted for in the system. In the model structure, no new trees enter the system in the subsequent four years (in this case years 23 to 26, see section 5.2.1.3). The maximum dynamics occur in the 7.5 cm diameter class where the number of trees varies greatly. At steady-state, the diameter distributions present a downward-slopping curve (or ‘reversed-J’ structure) for the three farming systems. Trees in the 65 cm class are not harvested in the three systems. For the diameter structure presented in Figure 6.5, years 22 to 26 are the baseline scenario for tree density.

Given that a great proportion of young trees do not reach maturity (e.g. because of mortality and damage from cattle), a structure with a greater number of young trees is preferred. Figure 6.5 shows that current diameter structures do not present a ‘reversed-J’ shape, suggesting that disperse trees in the three cattle systems have an unsustainable pattern. HARVEY & HABER (1999) found the same situation for trees in cattle farms in Monte Verde, Costa Rica.

a) SFS-LIU system



b) MFS-HIU system



c) LFS-HIU system

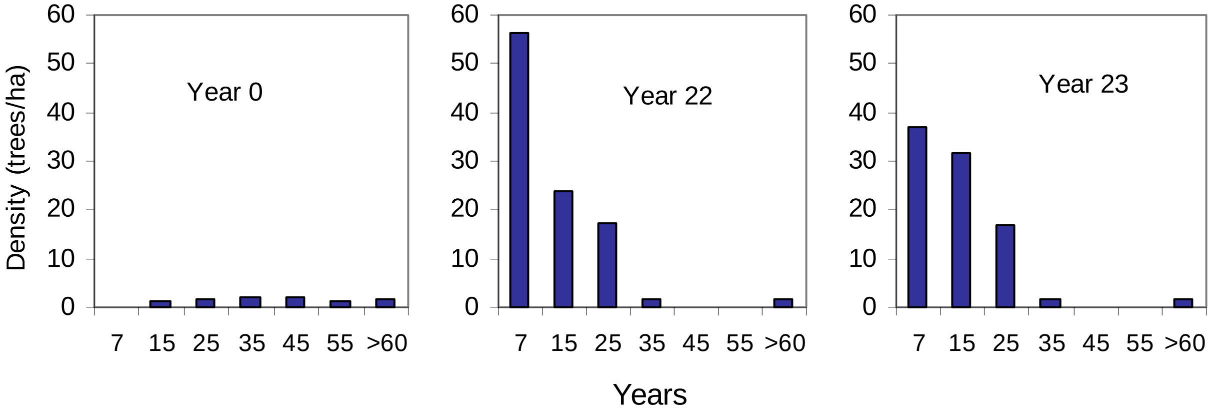


Figure 6.5. Simulated densities per diameter class (trees/ha) for selected years at the steady-state for three cattle system in the baseline scenario, Cañas and Bagaces, Guanacaste. (Source: empirical model).

The model developed in this research finds both the transition path and the optimal structure itself. However, technical assistance is needed to encourage farmers to move toward a sustainable structure. Therefore, an immediate policy action is to provide technical assistance to producers for improving the structure of tree resources on their cattle farms. Both the transition path and the optimal structure presented in this research can be used as an implementation guide.

6.2.5 Optimal combination of silvopastoral components

The baseline outlined in this section gives the optimal combination of components at the current technology. It means that an increase in tree cover from the optimal level, for example, is not possible without reducing the total (and cattle) net income.

6.3 Policy analysis I: Payment for environmental services

6.3.1 Policy targets and PES regimes

This section analyzes payments for environmental services as an instrument to increase tree canopy in the dry topics. The approach is to find the cheapest PES payment that can make ranchers increase existing tree cover by 50% from their current (2003) canopy level by year $t=10$ (policy target-I), and to increase the canopy level by 100% by year $t=15$ (policy target-II). Table 6.5 presents the baseline scenario (in terms of basal area), and the policy targets for the three cattle systems.

Table 6.5. Basal area (m^2/ha) for both the baseline scenario and the targeted levels for policy analysis, for three cattle systems in Cañas and Bagaces

	SFS-LIU system	MFS-HIU system	LFS-HIU system
Baseline	2.70	2.70	1.80
Basal area of remnant trees (not accounted for policy analysis)	1.35	1.35	0.89
Policy target-I (50% increase in basal area)	3.40	3.40	2.30
Policy target-II (100% increase in basal area)	4.10	4.10	2.70

Table 6.6. Characteristics of four PES schemes evaluated in the policy analysis

Payment for environmental service	**Periodicity**	**Duration**	**What does the PES modify?**	**What is paid for?**
Annual payment per tree greater than 30 cm dbh	Annual	20 years	Stand diameter structure	All standing trees with diameters greater than 30 cm
Annual payment per tree dependent on diameter class	Annual	20 years	Stand diameter structure	All standing trees with diameters greater than 30 cm are paid for, but payment is dependent on diameter class (35, 45 and 55 cm).
Compensation payment	Variable	20 years	Basal area	The payment compensates for changes in net farm income caused by the increase of tree basal area
FONAFIFO PES	Annual	1 year*	Stand diameter structure	Recruitment of trees in the 7.5 cm diameter class

*/ In practice, the FONAFIFO payment is disbursed over three years to assure trees have been established.

Four payment schemes were evaluated and summarized in Table 6.6. The PES mainly differs by the factor of intervention (e.g. stand diameter structure and basal area) and the payment mechanism (number of standing trees, basal area, or tree plantation). The next sections present the main results of the simulation.

6.3.2 Three innovative PES regimes for dispersed trees in pasture in Guanacaste

6.3.2.1 Annual payment per tree

This PES regime consists of a constant annual payment for all standing trees of diameter classes greater than 30 cm (which is the commercial size) during a 20-year time period. The estimation of the PES level was done in a trial-and-error procedure where several payments were tested (see section 5.2.3).

Figure 6.6 exemplifies the selection of the lowest payment for the three cattle systems. For example, for the SFS-LIU system (Figure 6.6a) a payment of \$0.90 per tree (greater than 30 cm dbh) is not enough for farmers to increase basal area to any of the policy targets. With \$1.02/tree, SFS-LIU farmers may increase basal area to 3.4m^2/ha in year 15; and with a payment of \$3.16/tree, farmers would reach policy target-I in year 9 and policy target-II in year 15. Figure 6.6b shows the case of the MFS-HIU system, where a payment of \$1.10/tree is not enough to reach either policy target; with a payment of \$1.12/tree, policy target-I is reached in year 10 and with a payment of $3.39/tree policy target-II is reached in year 16. Figure 6.6c shows the case of the LFS-HIU system: for this system only one payment is required to achieve both policies. With a payment of $0.73/tree, policy target-I is achieved in year 9 and policy target-II in year 12.

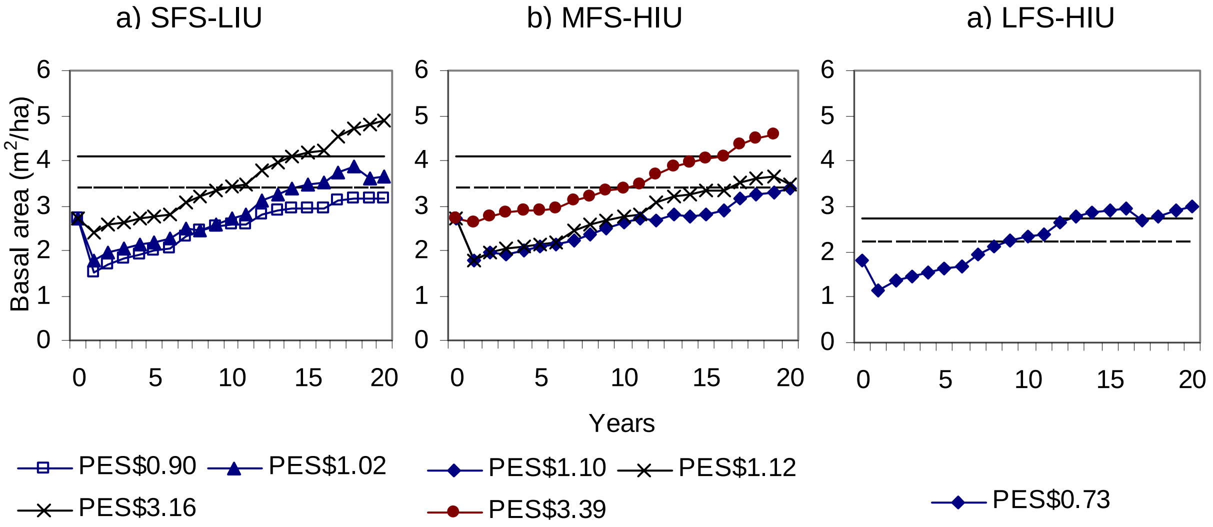


Figure 6.6. Simulation of the PES regime of (constant) annual payments per tree greater than 35 cm dbh (US$/tree), in three cattle systems in Cañas and Bagaces. In the three figures the horizontal lines are the targeted basal areas; the dashed line is the 50% policy target-I, and the solid line is the 100% policy target-II.

Table 6.7 shows the policy targets (i.e. increase by 50% and 100% initial basal area) and estimated minimum payments per cattle system that could motivate ranchers to increase tree canopy. The table shows, for example, that if policy target were to increase tree cover of pastures by 50%, the payment for SFS-LIU producers should be $1.02/tree, $1.12/tree for MFS-HIU producers, and $0.73/tree for LFS-HIU producers. The total cost of this policy would be US$2.1 million at real prices 1982-1984=100 ($3.9 million at 2003 prices). The cost of the policy rises to US$6.7 million (at real prices) with a policy target of 100% tree canopy increase.

Table 6.7. Simulated payments and costs for two policy targets under the PES scheme of annual payment for trees greater than 30 cm dbh, 20 year projection (NPV in constant US$).

	SFS-LIU*	**MFS-HIU***	**LFS-HIU***	**Total**
Target I: to increase canopy by 50% by year t=15				
PES (US$/tree for dbh classes 35, 45, and 55 cm)[#]	1.02	1.12	0.73	
Whole period payment per ha (US$/ha/20 years)	54	63	56	
Regional payment per farming system (US$ 1982-1984=100)	$764,061	$406,451	$936,002	$2,106,514
Target II: to increase canopy by 100% by year t=15				
PES (US$/tree for dbh classes 35, 45, and 55 cm)[#]	3.16	3.39	0.73	
Whole period payment per ha (US$/ha/20 years)	271	302	56	
Regional payment per farming system (US$ 1982-1984=100)	$3,844,434	$1,946,501	$936,002	$6,726,937

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system.

[#]/ The estimation of the minimum payment was done through a trial-and-error procedure.

The annual payments per tree shown in Figure 6.6 and Table 6.7 can be explained as the minimum payment the **producer is willing to accept in order to increase canopy** to the desired policy target. In practice, however, the policy could not discriminate among producers, but imposed a common payment on all cattle producers. Therefore, Table 6.7 can also be read as: 'if the payment were $0.73/tree, then only large farmers would increase tree cover and the SFS-LIU and MFS-HIU producers would leave canopy levels unchanged'. If the policy were $3.16/tree, then SFS-LIU producers would achieve policy target-II but MFS-HIU would achieve only policy target-I. With such a payment, the LFS-HIU system would receive an extra payment of $2.43/tree. This difference is referred to in economic theory as the *producer's surplus* (NICHOLSON 1997:308), which is the benefit the producer receives when producing a good or service. Section 6.3.3 further analyzes why LFS-HIU farmers tend to have the lowest willingness to accept to increase tree canopy in their farms.

6.3.2.2 Annual payment per tree per diameter class

This PES scheme offers a different payment to producers, depending upon the diameter class of the trees. Different amounts are offered for trees in each of the 35 cm, 45 cm and

55 cm diameter classes to reach the policy targets. The estimation of the PES is similar to the previous one; i.e. it used a trial-and-error procedure where several payments are tested until the desired basal area is reached. Table 6.8 shows the results of this simulation.

Table 6.8. Simulated payments and costs for two policy targets under the PES regime of payment per tree per diameter class, 20 year projection (NPV in constant US$)

	SFS-LIU*	MFS-HIU*	LFS-HIU*	Total
Policy target: To increase canopy by 50% by year $t=10$				
PES (US$/tree 35cm class)[#]	1.11	1.22	0.80	
PES (US$/tree 45cm class)[#]	0	0	0	
PES (US$/tree 55cm class)[#]	0	0	0	
Whole period payment (US$/ha/20 years)	35	33	44	
Regional payment per farming system (US$ 1982-1984=100)	$497,262	$212,168	$733,709	$1,443,139
Policy target: To increase canopy by 100% by year $t=15$				
PES (US$/tree 35cm class)[#]	1.11	1.22	0.79	
PES (US$/tree 45cm class)[#]	2.01	2.17	0.00	
PES (US$/tree 55cm class)[#]	3.16	3.40	0.00	
Whole period payment (US$/ha/20 years)	177	213	44	
Regional payment per farming system (US$ 1982-1984=100)	$2,509,932	$1,371,547	$733,709	$4,615,188

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system.

[#]/ The estimation of the minimum payment was done through a trial-and-error procedure.

With this PES regime, the payment per tree is different to the previous PES regime (i.e. constant payment per diameter class) but the same canopy level is obtained. For example, a payment of $1.11/tree is required for SFS-LIU system to reach policy target-I, $1.22/tree for the MFS-HIU system, and $0.80/tree for the LFS-HIU system. However, with such payments, there is considerable reduction in policy costs. Comparing Tables 6.7 with 6.8, the aggregated cost of policy target-I is 35% cheaper with this PES regime than with a constant PES for the SFS-LIU system, 48% cheaper for the MFS-HIU system, and 22% lower for the LFS-HIU system.

Why do both PES schemes differ? One of the main effects of the PES is to delay the harvest of trees. To achieve policy target-I (50% increase of basal area), for example, farmers do not harvest trees in the 35 cm diameter class. For the constant PES, the payment that is given to trees in the 45 and 55 cm classes is producer surplus. For the payment per diameter class, the payment is directed to the diameter class that is required to change the basal area of the plot. By doing so, a significant reduction in policy cost is achieved.

Although the annual payment per diameter class requires less financial resources than constant payment per tree, it may be difficult to implement in a real-world situation because of the difficulties in monitoring and measuring tree diameters. The main reason to present the results of this PES regime is because it gives insight about the economics of the PES regimes in silvopastoral systems. A further discussion of the economics of the PES schemes will be presented in section 6.3.3.

6.3.2.3 Compensation payment

This PES regime is estimated by looking at the changes in net profits (i.e. NPV/ha) caused by increases in canopy cover. To simulate this PES, a restriction of a minimum tree canopy is added to the empirical model (see section 5.2.3.1). Figure 6.7 exemplifies the estimation of this PES. The curve with diamonds shows the scenario where a restriction of a minimum basal area of 3.4 m^2/ha has been imposed in year 10 (policy target-I). The curve with squares represents a scenario of a minimum basal area of 4.1 m^2/ha starting in year 15. The restriction forces the basal area to be at the desired policy level.

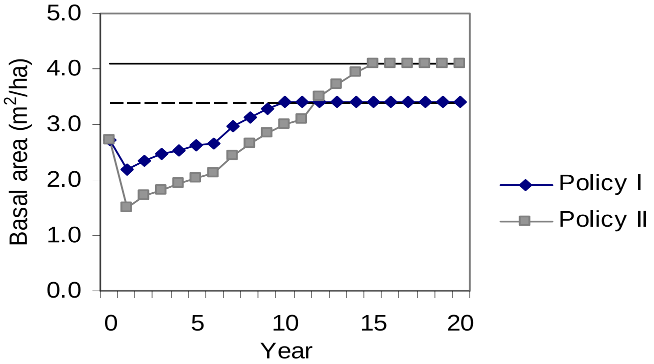


Figure 6.7. Simulation of basal area (m^2/ha) under the PES regime of compensation of net income changes, SFS-LIU system only. (Source: empirical model).

The estimation of this PES is shown in Table 6.9. The last column of Table 6.9, ‘net change in income’ is the minimum compensation farmers may accept in order to increase canopy level to the policy target. In other words, this PES regime estimates the opportunity cost of increasing tree cover, calculated in terms of changes in profits of the silvopastoral system.

Table 6.9 shows that this estimation yields the lowest PES rates for the three cattle systems (compare Tables 6.7, 6.8 and 6.9). The reason for such low rates is because in this estimation the farmer is allowed to adjust the density and harvest of trees. For example, the basal area required for the policy target is achieved with more trees of the smaller diameter classes, and trees of the 35 cm class can be harvested in selected years. The free adjustment of tree densities allows farmers to harvest some mature trees, which reduces the cost of the PES by avoiding the payment of extra costs for leaving older trees in the field.

Table 6.9. Simulation of PES by compensation of reduced net profits for three cattle systems in Cañas and Bagaces, 20 year projection (NPV/ha in real US$ 1982-1984=100)

	NPV from timber	NPV from cattle	Total NPV (US$/ha)	Net change in income = PES/ha (US$/ha)	Regional payment per cattle system (US$)
SFS-LIU system					
Without policy	44.26	211.73	255.98		
With policy target-I	41.32	203.01	244.33	11.66	165,362
With policy target-II	26.83	196.58	223.40	32.58	462,050
MFS-HIU system					
Without policy	40.98	366.27	407.25		
With policy target-I	37.93	343.09	381.01	26.25	168,975
With policy target-II	23.61	328.01	351.62	55.63	358,090
LFS-HIU system					
Without policy	87.57	613.26	700.83		
With policy target-I	85.22	612.15	697.37	3.46	57,640
With policy target-II	84.07	610.00	694.07	6.76	112,615
Total policy costs					
Policy target-I					391,974
Policy target-II					932,755

The estimation of the PES by net changes in income offers the following advantages over the payments per tree:

- The PES by compensation in net income changes is estimated with basal area as the main indicator, but the payment is structured by hectare. This gives more flexibility to the administration of the PES.

- The PES can be disbursed over several years. The most common scheme has been to pay the total amount during the first years of the contract.

- The PES can set different payments per basal area (per hectare). Taking as an example the estimated PES of the SFS-LIU system (Table 6.9), the PES can pay US \$11.66/ha to farms with an average basal area lower than 3.4 m^2/ha (policy target-I) and US \$32.58/ha to farms with average basal areas between 3.5 and 4.1 m^2/ha (policy target-II).

- Since the farmer can decide on the density and structure of the stands, the payment encourages the conservation of remnant trees with diameters greater than 50 cm.

- It is easier to estimate the basal area as an indicator of tree cover than counting the number of trees per diameter class.

6.3.3 The economics of the PES

The PES affects farmers in two ways. First, the PES changes the tree rotation cycle by delaying the harvest of trees and by modifying the densities of trees in the farm plot. Second, the increase of tree cover affects the area devoted to cattle. To exemplify these two effects, look at the PES of annual payment per tree (section 6.3.2.1).

The effect of the annual payment per tree (policy target-II, paying \$3.16/tree) on the density of commercial trees in the SFS-LIU system is depicted in Figure 6.8. This figure shows that the increase in canopy is achieved by leaving trees from the 35 and 45 cm diameter classes in the field. By approximately year 10, the system has achieved policy target-I and the PES scenario has 3 more trees/ha in the 35 cm diameter class than the baseline scenario. By year 15, the system achieves policy target-II and the PES scenario has 9 more trees/ha in the 35, 45 and 55 cm classes. These are expected results that agree with economic theory (see section 3.1.3). In the presence of PES, farmers delay the harvest of trees almost 10 years in order to reach policy target-I (the average diameter growth rate of the 35 cm class is 1.1 cm/year). In policy target-II, farmers delay the harvest of trees another 12 years because trees are harvested with more than 50 cm of diameter.

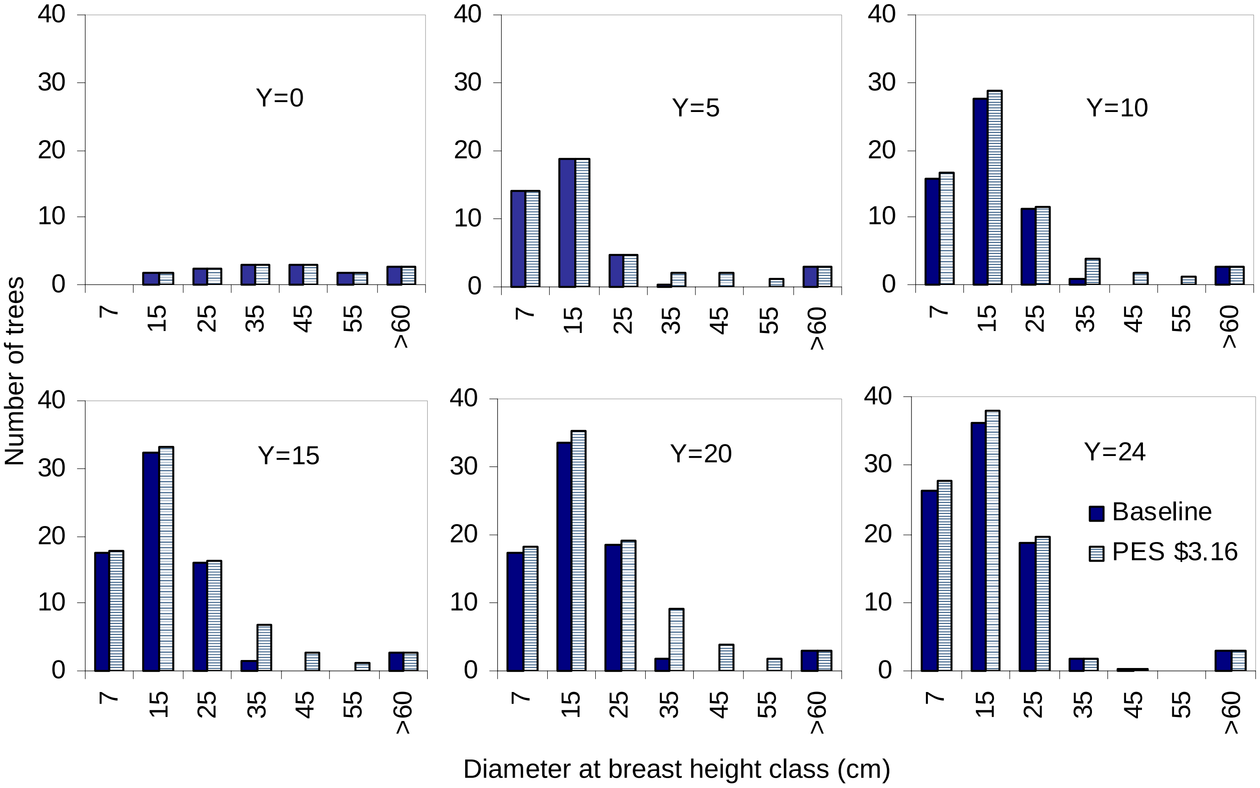


Figure 6.8. Simulated DBH structures (trees/ha) of the baseline scenario vs PES (regime of $1.02, constant annual payments) for the SFS-LIU system in years 0, 5, 10, 15, 20 and 24 (Source: empirical model).

Figure 6.9 looks in detail at the changes in basal area and animal units of three cattle systems, for two policy targets with a PES with annual payment per tree (section 6.3.2.1). Figure 6.9 shows how heard stock decreases while basal area increases due to the PES incentive. However, the three farming systems modify the structure of the tree-cattle components in different ways. The SFS-LIU system, for example, increases the tree component and decreases animal units more than the other two farming systems. With policy target-II, the SFS-LIU system reduces 0.15 AU/ha in 20 years, while the MFS-HIU system reduces 0.06 AU/ha and the LFS-HIU system reduces 0.03 AU/ha during the same period of time. The main point in Figure 6.9 is to show how different farming systems are affected in different ways with a PES policy.

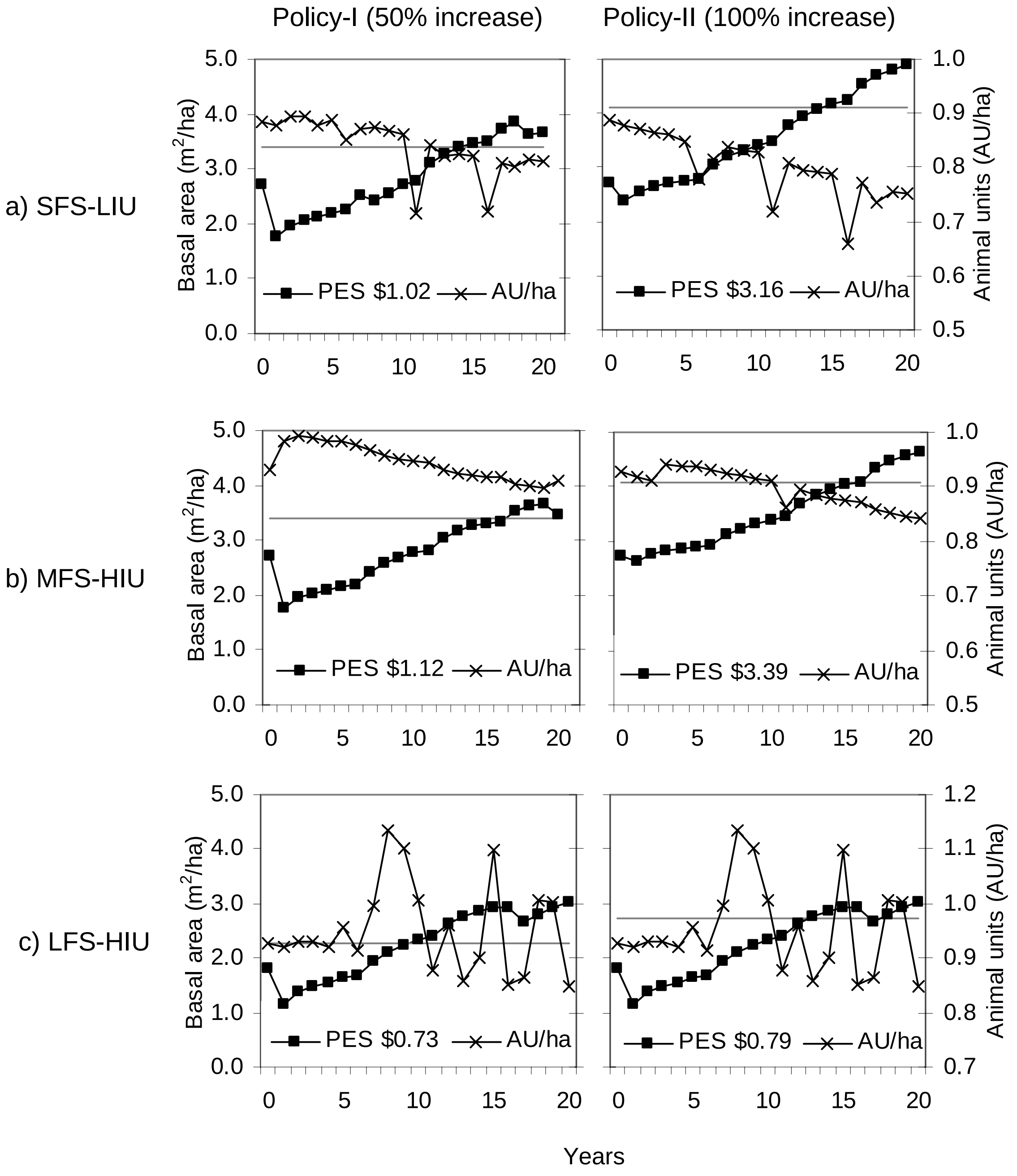


Figure 6.9. Simulated changes in basal area (m^2/ha) and animal units (AU/ha) for three farming system with a PES scheme of constant annual payment per tree, and two policy targets. The horizontal lines are the targeted basal area.

Table 6.10 presents a partial budget of a PES per tree per diameter class (section 6.3.2.2), with the target of increasing tree cover by 50% (policy target-I) in year 10. Table 6.10 only shows the SFS-LIU system. This table shows in detail the net changes in income, and the changes of tree harvesting with a PES payment.

Table 6.10 shows some benefits and costs associated with increasing tree cover that should be accounted for in estimating the incentive. In the case study, there are two new benefits: 1) additional returns from harvesting older trees (in the example, US$84.49 instead of US$62.59), and 2) additional returns from harvesting trees at the end of the policy cycle (in this case, at year 20).[7]

Table 6.10. Partial budgeting of an annual payment of $1.11 per tree in the 35 dbh class only, SFS-LIU system, under the PES regime of payment per tree per diameter class, 20 year projection (NPV/ha in real US$).

	NPV without policy (US $)	**NPV with PES policy (US $)**
Tree component		
Harvest trees 35 cm class	56.67	9.28
Harvest trees 45 and 55 cm classes	62.59	84.49
PES (NPV)	0.00	35.06
NPV tree harvest	119.26	128.83
NPV cattle profit	211.73	210.09
Total NPV*	330.98	338.92

*/ In order to make the producer change their canopy preferences, the PES should offer more profits than the baseline scenario. For this reason, the difference between the two NPVs is not equal to zero; in this case, the producer obtains an extra profit of US$7.94/ha in 20 years.

In summary, the design of a PES for silvopastoral systems should consider two aspects (which differs among producers):

i) foregone net cattle profits: the increase of tree canopy implies a reduction of the pasture area and thus a reduction in cattle profits. As MFS-HIU producers obtain higher profits from cattle, they require higher compensation rates;

ii) foregone net profits from timber harvest: in order to increase tree canopy, producers should not harvest all their tree resources. In the baseline scenario, ranchers harvest the 35 cm trees; with PES, ranchers do not harvest them.

Finally, why does the LFS-HIU system tend to have the lowest payment values? There are two reasons. First, the relative share of cattle gains for the LFS-HIU farmers is lower than the MFS-HIU system (see Table 6.4), which implies that less money is required to

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[7] When the policy ends in year 20, farmers do not have more incentives to keep a high tree density and tree cover is reduced to a lower (and more profitable) canopy level. In order to maintain the canopy reached by the incentive, the PES should be extended more years.

compensate for foregone cattle profits. And second, LFS-HIU farmers have a lower discount rate (3% vs 9.7% for SFS-LIU and MFS-HIU systems), which has two effects: 1) timber profits obtained in the future are less discounted and contribute more to timber benefits (which in turn reduces the PES payment), and 2) the amount of money that is needed to delay tree harvest is lower with low discount rates than with high discount rates. PRICE (1995) showed the effect of the discount rate on agroforestry, showing that moderate rates of discount tend to benefit agroforestry; low discount rates favor pure forest plantations and high discount rates tend to favor pure agricultural products. In the case of the LFS-HIU system, the discount rate makes the tree component attractive, requiring a small incentive to change cattle for trees.

6.3.4 Regional impact of the PES on tree cover

So far, the policy analysis has considered different payments per farming system. In practice, however, instead of a differentiated payment per producer type, a constant payment (regardless of the condition of the producer) is applied to all farmers. This section analyzes a homogeneous (and more realistic) payment in the study area and its impact on the regional level.

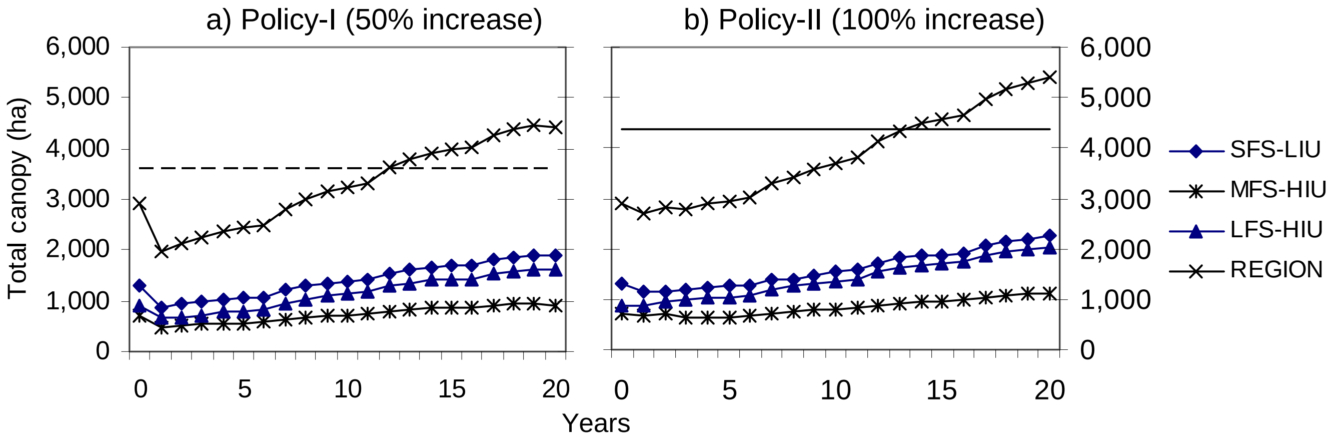

Figure 6.10. Simulated regional canopy levels (in hectares) with a PES policy of an annual payment per tree, with the amounts of (a) $1.02/tree, and (b) $3.16/tree payment, in Cañas and Bagaces. The dashed line is policy target-I (50% increase in canopy) and the solid line is policy target-II (100% increase). Graph (a) shows that a payment of $1.02/tree would achieve policy-I in 12 years. Graph (b) shows that a payment of $3.16/tree would achieve policy-II in 13 years.

Figure 6.10 shows the case of the annual payment per tree (PES introduced in section 6.3.2.1). Figure 6.10a shows a payment of $1.02/tree regardless of the cattle systems. This PES amount represents the estimated payment for the SFS-LIU system to reach a 50% increase in basal area (see Table 6.7). Therefore, LFS-HIU system will receive an extra payment of $0.29/tree while MFS-HIU system will receive $0.10/tree less than that estimated in Table 6.7. Figure 6.10b shows a payment of $3.13/tree, which represents the payment of the SFS-LIU system to reach policy target-II.

Three points can be highlighted in Figure 6.10. First, the PES is a sound instrument to achieve the policy objective. It is possible to design a PES scheme to increase tree cover in cattle farms in Guanacaste. Second, the SFS-LIU and LFS-HIU systems each account for almost 40% of the regional canopy area. It means that both systems are important actors in biodiversity conservation. The exclusion of one system may cause the failure in achieving the policy objectives. Finally, even with fast-growing timber trees, such as *Cordia alliodora* which was used in this research, and an initial resource stock the policy objective can be reached in more than 10 years.

Table 6.11. Simulated regional budgets (NPV in constant US$ dollars 1982-1984=100, per total area of the farming system) with four PES schemes focused on increasing the basal area for two policy targets (50% and 100% increase in current basal area)

PES scheme[§]	**Description**	**Farming System**			**Total**
		SFS-LIU	**MFS-HIU**	**LFS-HIU***	
Pasture area	Hectares	9,441	5,141	9,595	24,177
Producers	Number	155	18	12	185
Policy target-I: increasing basal area by 50% in 10 years					
PES 1	$1.02/tree for all dbh classes	618,213	324,618	487,310	1,430,141
PES 2	$1.10/tree for class 35; $0 for others classes.	331,029	49,880	283,844	664,753
PES 3	$11.66/ha	110,082	59,944	111,878	281,904
PES FONAFIFO[#]	$0.54 per planted tree (7.5 cm class)	378,858	166,931	432,018	977,807
Policy target-II: increasing basal area by 100% in 15 years					
PES 1	$3.16/tree for all dbh classes	2,347,198	1,267,205	2,035,582	5,649,985
PES 2	$1.10 for class 35; $2.01 for class 45; $3.16 for class 55	1,670,869	826,199	1,357,517	3,854,585
PES 3	$32.58/ha	307,588	167,494	312,605	787,687

§/ PES1: annual payment per tree; PES2: annual payment per tree per diameter class; PES3: compensation payment. #/ The FONAFIFO PES for agroforestry is not intended for large-scale producers. The results presented here are simulations intended to show the effect of such payments when pursuing environmental objectives. */ The budget of the three cattle systems was estimated with the same discount factor of 9.7%.

The three innovative PES payments evaluated in this research achieved similar regional impacts in the canopy level than those shown in Figure 6.10. The main difference among payments, however, is the total cost of the policy. Table 6.11 presents selected policy costs per farming system and aggregated total costs. The PES payment for the simulation of the three cattle systems represents the estimated PES of the SFS-LIU system.

Three main topics can be highlighted in Table 6.11. First, the PES that can achieve policy objectives with the lowest financial cost is the PES by compensating for changes in net income (when tree cover is increased). This PES (PES 3 in Table 6.11) represents 20% of PES-1 and 40% of PES-2. Second, FONAFIFO's PES is higher than the PES-2 and PES-3; however, FONAFIFO's PES is not able to reach the policy targets (see section 6.3.5). Finally, large-scale farmers benefited with almost 40% of the PES in the four cases. This is caused by the combined effect of farm size (average of 800 ha of pastures/farmer) and the producer surplus (i.e. they are paid more money than needed to achieve the policy objective).

6.3.5 FONAFIFO's PES for agroforestry

The Costa Rican Fund for Forest Investment (FONAFIFO, Fondo Nacional de Financiamiento Forestal de Costa Rica) has a PES program focused on agroforestry systems. The incentive is approximately US$1.00 per planted tree (US$0.54/tree real US prices), distributed in three payments: US$0.65 the first year, US$0.20 the second year, and US$0.15 the third year (FONAFIFO 2004). The FONAFIFO's PES for agroforestry was designed based on the cost of planting trees (CAFN 2001). The incentive, then, represents the financial cost of planting trees instead of the value of the environmental service.

The model was run with this PES, and the results showed no changes in tree canopy during the three years of payment. Although producer income slightly increased, the incentive is not enough to change the use of land with current technology in the area.

The difference between both methodologies for estimating the PES (i.e. the one presented in this research and FONAFIFO's) can be better understood by analyzing the starting assumptions about the low tree stock in cattle farms. In this research, I assume that producers have a low tree density because the positive externalities trees produce are not internalized in the producer's income. The PES then corrects the externality by paying producers for not harvesting mature trees.

In contrast, the implicit assumption in FONAFIFO's PES is that producers have low tree densities because they do not have financial resources to plant trees or do not have enough information about the benefits provided by trees. Therefore, FONAFIFO's PES pays for planting trees as a way to correct the market failure (i.e. scarce information or financial resources). This is a common assumption in projects working with technology adoption.

The assumption of low adoption due to lack of information or financial resource is questionable in the tropical dry forest. For example, MUÑOZ (2003) evaluated the local knowledge about the use of trees in pastures and concluded that producers were aware of the environmental and economic benefits that trees provide. In addition, CAMARGO (1999) reports that cattle farmers manage natural regeneration to increase dispersed trees in pastures. The simulation presented in the baseline scenario suggested that producers use pastures at their maximum carrying capacity and that they manage tree cover at the maximum level. The increase of tree canopy implies a reduction in cattle profits. If farmers are offered an extra payment, producers then will increase tree cover. Therefore, the hypothesis of externalities is more justified in the case of cattle ranching in Guanacaste.

Finally, why is not paying for planting trees a good instrument to increase tree canopy? In order to have insight into the economics of paying for planting trees, the simulation model was run with a payment of US$5/tree (greater than 7.5 cm), and where farmers can claim a payment every five years for 20 years. The results are shown in Table 6.12, where four main results can be highlighted. First, basal area actually is increased (due to the increase of recruiting trees), but at a lower level of the policy target: in the three cattle systems, basal area is increased by 20% by year $t=20$. Second, farmers increase the harvest of trees in the 35 cm class by 20%. Farmers do not have an incentive to delay the harvest of trees; therefore, they harvest trees at the commercial size. The environmental service is provided by small-size trees, which provide less environmental services than large-size trees (HIETZ-SEIFERT *et al.* 1996). The total profit, however, has increased threefold for the SFS-LIU and MFS-HIU systems, and have doubled for the LFS-HIU system. **It implies that producers obtain profits from planting trees instead of from providing environmental services.** Indeed, recent evaluations of the Guatemalan PES (AVILA 2003), for example, show that after establishing and receiving the incentive, farmers abandon the plantations. This problem has also been identified in plantations fomented by the FONAFIFO PSA. Finally, the estimated PES in Table 6.12 almost equals the current

FONAFIFO payment for plantations of US$660/ha[8] (FONAFIFO 2004). It implies that a PES for dispersed trees that pays for planting trees is not competitive with a PES for plantations.

Table 6.12. Simulation of a PES for planting trees, with an incentive of US$5/tree (greater than 7.5 cm), for three cattle systems in Cañas and Bagaces (cumulative 20-year values).

	SFS-LIU system	MFS-HIU system	LFS-HIU system
Basal area in year 20			
-Baseline	3.12	2.92	2.53
-Simulated PES for planting trees	3.77	3.72	3.07
Number of recruiting trees			
-Baseline	206.90	185.08	194.35
-Simulated PES for planting trees	267.87	262.33	243.65
Number of harvest trees in the35 cm class (in 30 years)			
-Baseline	41.50	41.50	37.92
-Simulated PES for planting trees	52.29	50.56	45.49
Number of harvest trees in the 45 and 55 cm classes (in 30 years)			
-Baseline	7.98	7.65	6.21
-Simulated PES for planting trees	8.90	8.77	6.87
NPV			
-Baseline	211.73	330.98	751.33
-Simulated PES for planting trees	762.61	997.40	1527.61
-Percent of PES in the NPV (%)	84%	63%	60%

6.4 Policy analysis II: Tax on extensive cattle

This policy analyzes a tax instrument to reach the policy targets of increasing tree cover by 50% in year 10 (policy target-I) or by 100% in year 15 (policy target-II). The tax is imposed on farms that produce cattle with lower tree cover than that targeted by the policy. Only the farms that have less basal area per hectare than the target pay the tax. The tax is intended to penalize extensive cattle production, and to motivate meat production with silvopastoral systems. As with the PES, the tax can be interpreted as the minimum tax that can motivate ranchers to increase tree cover in their farms.

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[8] FONAFIFO offers $630/ha/10 years (in current 2004 US dollars), which implies $660/ha/20 years in real US dollars (1982-1984=100).

Figure 6.11 shows the impact of the tax policy on the basal area of three cattle systems in Cañas and Bagaces. With a tax of approximately US\$12/ha, SFS-LIU and MFS-HIU systems are encouraged to increase the basal area to the policy target-I in year $t=10$. The increase of basal area implies leaving all the tree resources they already have standing as well as increasing the number of regenerated trees. In the case of the LFS-HIU system, policy target-I is reached with a tax of US\$9/ha. With a tax of US\$20/ha, SFS-LIU and MFS-HIU systems may increase tree canopy to the level of policy target-II, while the LFS-HIU system requires a tax of US\$15/ha.

With a tax, producers should pay for two costs: 1) reduction in cattle profits due to an increase of tree area, and 2) payment of taxes if producing with low tree cover. In the long run, the price of meat may also tend to increase and hence, the consumer will also pay for the environmental improvement (PEARCE & TURNER 1990). In other words, consumers will know that the meat they consume is produced by degrading the environment and therefore they should pay for it.

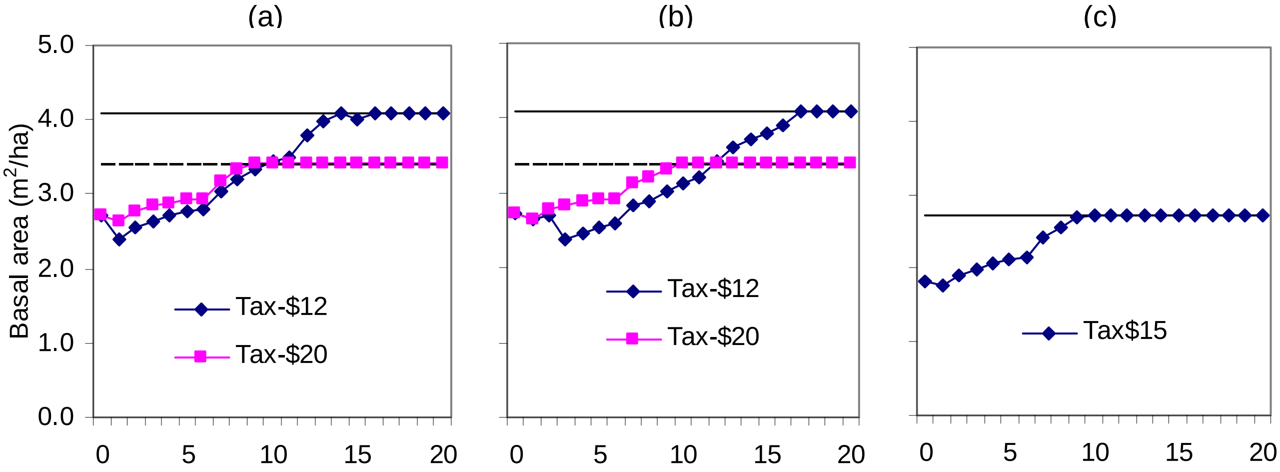

Figure 6.11. Simulated changes in basal area (m^2/ha) due to a tax policy on extensive cattle ranching, for three cattle systems in Cañas and Bagaces, Costa Rica. In the three figures, horizontal lines are the targeted policy level. (a) Tax policy for the SFS-LIU system; (b) tax policy for the MFS-HIU system; (c) tax policy for the LFS-HIU system.

Table 6.13 shows the changes in income caused by the tax policy, where it can be seen that the net reduction in income is similar to the total amount of the PES estimated in Table 6.9. For example, the total PES for the SFS-LIU system was estimated at US\$54, while the net reduction in income with a tax of US\$12 is estimated at US\$59. This means that the overall cost (per hectare) to increase tree canopy by 50% in SFS-LIU farms is between US$54 and US$59/ha, the difference being who should absorb the cost, taxpayers of producers.

As discussed in section 3.1.4, a tax policy can yield similar effects to a subsidy policy. The main difference is who pays for the environmental improvement. With a tax policy the farmer, instead of taxpayers, pays for the increase of tree cover.

Table 6.13. Simulated changes in income under a tax policy for extensive cattle ranching, 20 year projection (NPV/ha in real US$).

	NPV from timber	NPV from cattle	Total NPV (US$)	Net change in income
SFS-LIU system				
Without policy	43.93	211.73	255.65	
With tax policy target-I	39.16	157.65	196.81	-58.84
With tax policy target-II	31.70	76.84	108.54	-147.11
MFS-HIU system				
Without policy	40.43	366.27	406.70	
With tax policy target-I	35.30	297.25	332.55	-74.14
With tax policy target-II	40.93	203.53	244.47	-162.23
LFS-HIU system				
Without policy	87.39	613.26	700.66	
With tax policy target-I	90.35	498.86	589.21	-111.44

In Central America, as elsewhere, a tax policy may create political opposition. One of the reasons for this opposition is the fact that rural areas in Central America are poor and instead of taxing them, they require a subsidy policy. Take the case of the SFS-LIU system, where NPV income per hectare is around US$255 in 20 years. With such a low income, a SFS-LIU farmer may require more than 48 hectares to obtain the national minimum wage of $617/year. With a tax of $12/ha, the same farmer will require more than 63 hectares to gain the minimum income. While a tax affects small-scale producers, the LFS-HIU system is affected to a larger extent since they have more land. For example, with a tax of $15/ha, an average LFS-HIU farmer with 3,000 hectares may pay a tax of US$334,329.

A PES instrument has more political acceptability than a tax instrument. The results presented in this research, however, showed that the LFS-HIU system might benefit more from a PES policy since they have more land and their production surplus is greater than the other two systems.

In summary, the two policies have advantages and disadvantages; some actors may benefit and some others can be affected negatively. The final decision of who absorbs the cost is a political issue that is debated within the society. In this research, the tax instrument was presented to show its potential for pursuing environmental objectives, which were demonstrated to reach similar outcomes to a PES. The potential of the empirical model to simulate policies was also evident.

6.5 Free trade scenario

This section simulates a free trade scenario without a direct policy intervention. It is likely that the future economic scenario of Central America will be mainly influenced by the *Dominican Republic, Central America and the US free trade agreement* (DR-CAFTA), whose ratification by the Costa Rican parliament is still pending but most likely will be approved by the end of 2005. Chapter 5 showed that the most likely outcome of DR-CAFTA on the Costa Rican meat markets is a decrease in domestic meat prices. Export meat prices will probably be unchanged because the US markets are already open. Contrary to meat prices, the DR-CAFTA might increase timber prices because market barriers will be withdrawn, making it easier to export to the US markets. This section analyzes first the impact of lower meat prices and then a scenario with higher timber prices on the cattle and tree resources of farms in the dry tropics.

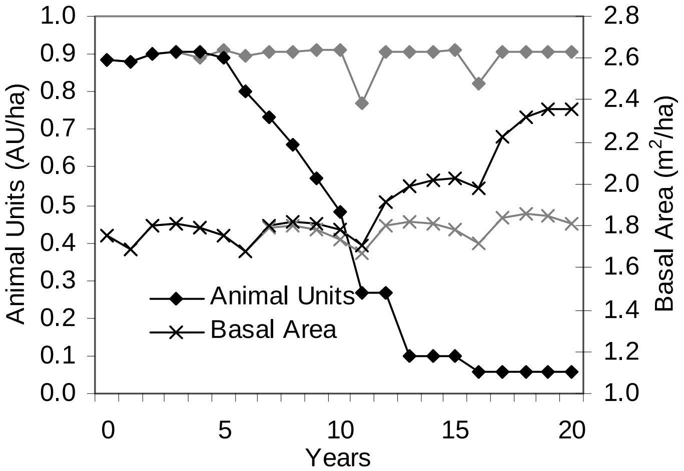

Figure 6.12. Simulated animal units (AU/ha) and basal area (m^2/ha) for a scenario with low meat prices (dark lines) with a baseline scenario (gray lines), SFS-LIU systems, 20 year projection (Source: empirical model).

Figure 6.12 shows the impact of lower meat prices for SFS-LIU producers. If meat prices fall to the lower bound of the forecasted trend (i.e. a smooth decrease until prices are 27% lower than the forecasted mean price at year 20), SFS-LIU producers will deplete their livestock resources. While livestock is reduced to less than 0.1 AU/ha, tree resources increase from year 10 on. This is an expected result since more land is devoted to trees. MFS-HIU and LFS-HIU systems may stay in business even with lower prices. In social terms, a reduction in meat prices might affect 84% of the producers since SFS-LIU encompasses the majority of the farmers.

Although SFS-LIU farmers may be forced out of the cattle industry, the presence of dispersed trees ameliorates the impact of lower meat prices. Table 6.14 compares the cattle-only system with a silvopastoral system and shows that the dispersed trees system has lower reduction in total income than the cattle-only system.

Table 6.14. Simulated net present values (NPV) of the cattle-only and dispersed trees systems under two scenarios (baseline vs. lower meat prices) for three farming systems in Cañas and Bagaces (NPV/ha in real US$ 1982-1984=100).

	SFS-LIU	**MFS-HIU**	**LFS-HIU**
Dispersed trees system			
Baseline scenario	347.84	501.98	833.03
Lower meat prices	308.36	422.57	672.94
Net reduction in income (%)	11%	16%	19%
Cattle-only system			
Baseline scenario	223.00	391.83	659.65
Policy scenario: lower meat prices	176.77	299.20	495.90
Reduction in income (%)	21%	24%	25%

*/ SFS-LIU: Small farm size and low input use system; MFS-HIU: medium farm size and high input use system; LFS-HIU: large farm size and high input use system.
#/ Discount factor for SFS-LIU and MFS-HIU: 9.7%; LFS-HIU: 3.25%.

On the other hand, a scenario with better timber prices might slightly increase producer incomes. Table 6.15 shows that with an increase of 20% in timber prices by year 10, the increase in total income is 5% for SFS-LIU producers, 4% for LFS-HIU producers, and 3% for MFS-HIU producers. However, higher timber prices favored by free trade have a low impact on tree cover since only a 1% increase in tree canopy can be expected. Nonetheless, higher timber prices can improve the profitability of pure forest production, making it more attractive to cultivate forest instead of having an extensive silvopastoral system.

In summary, the primary effects of the free trade policy on SFS-LIU producers can have two different outcomes. First, lower meat prices will force SFS-LIU producers out of business, and tree canopy in these farms will increase. And second, higher timber prices will encourage the production of timber, but the effect on net incomes is not enough to motivate a great change in canopy area of dispersed trees in pastures.

Table 6.15. Simulated NPV (real US$/ha) with the scenario of higher timber prices, for three cattle systems in Cañas and Bagaces, Guanacaste.

	SFS-LIU		MFS-HIU		LFS-HIU	
	Baseline	Higher timber price	Baseline	Higher timber price	Baseline	Higher timber price
Cumulative cattle net benefits	214.07	213.86	371.48	371.44	608.97	608.55
Cumulative timber net benefits	133.77	151.33	130.50	146.50	211.77	246.56
SPS NPV	347.84	365.18	501.98	517.94	820.74	855.11
Net income change	+5%		+3%		+4%	
Increase in canopy	1%		1%		1%	

6.6 Sensitivity analysis

6.6.1 Cattle input prices

This section presents a sensitivity analysis of hay prices and cattle technology. The first scenario consisted of finding the minimum reduction in hay prices that can promote an increase in cattle stocking rates.

The results show that a 10% reduction in hay prices could make LFS-HIU producers increase stocking rates from 1 to 2 AU/hectare. However, MFS-HIU and SFS-LIU systems require higher reductions in hay prices: MFS-HIU requires a 50% price reduction and SFS-LIU requires a 70% reduction in hay prices in order to intensify cattle stocking rates (Table 6.16). The difference in hay price can be explained by the fact that SFS-LIU obtain the lowest cattle profits, and then they need a steeper decrease in prices to increase cattle stocking rates.

Table 6.16. Simulated NPV for the baseline scenario and a 70% reduction in hay prices, for the SFS-LIU system, 20 year projection (NPV/ha in real US$ 1982-1984=100).

	NPV at the baseline scenario	NPV with a 70% lower hay cost	Net income increase (%)
Cattle profits	238.55	240.50	
Timber profits	147.68	146.25	
Total profits	386.24	386.75	0.13%

In the study area, the use of hay supplements is more common in MFS-HIU and LFS-HIU systems. The general practice is that farmers cultivate their own hay in the irrigated land. Therefore, it is likely that LFS-HIU producers can obtain lower hay prices than the market price. In addition, a reduction of hay prices appears to have a low impact on income increases among SFS-LIU farmers. Table 6.16 shows that a 70% reduction in hay prices can increase SFS-LIU less than 0.2% of the farm income. For this reason, a policy directed at encouraging the use of hay is not recommendable for SFS-LIU producers with the current technology.

6.6.2 Cattle technology

The calving rate, i.e. the proportion of breeding cows which bear live calves during the year, can be improved with better cattle management such as the provision of adequate supplements and pasture maintenance. For the SFS-LIU system, the current calving rate was estimated at 60%, MFS-HIU and LFS-HIU systems have calving rates estimated at 80%. In addition, improved pastures have better carrying capacities during the dry season than *Hyparrhenia rufa*. In this section, a sensitivity analysis on calving rates and pastures are addressed.

Table 6.17 shows the net change in incomes by changing calving rates and using improved pastures. The table shows that better cattle management can have a significant impact on farmer incomes. The use of improved pastures without changing cattle management will slightly increase incomes (3%). For this reason, a change in pastures should be accompanied with better cattle practices to reduce costs of cow maintenance.

Table 6.17. Simulated changes in NPV with improved calving rates and improved pastures, SFS-LIU system, 20 year projection (NPV/ha in real US$ 1982-1984=100).

	Baseline (*H. rufa* and 60% calving rate)	Calving rates 70%	Calving rates 80%	Improved pastures
Net cattle profit	214.07	303.88	388.46	222.06
Net timber profit	133.77	132.71	132.54	132.55
Total net profits	347.84	436.58	520.99	356.90
Income change (%)		26%	50%	3%
Change in canopy area (%)		-2%	-3%	-0.1%

As expected, the intensification of cattle by having better calving rates and using improved pastures reduces the area covered with dispersed trees. A 70% improvement in calving rates reduces total tree canopy by 2%; and an 80% calving rate and improved pastures can reduce tree canopy by 3%.

6.7 Discussion: Silvopastoral policies for biodiversity conservation in the dry tropics of Costa Rica

6.7.1 Farming systems and PES

ZBINDEN & LEE (2005) analyzed factors that motivate households to participate in the Costa Rican *Pago por Servicios Ambientales* (payment for environmental services, PSA). They analyzed three PES programs, namely reforestation, sustainable management, and forest protection (for an explanation of the programs see CASTRO *et al.*, 2000). ZBINDEN & LEE (2005:270) reported that the Costa Rican PSA tend to go “disproportionately to better-educated, wealthier families who posses larger farms and forest areas, and who are better diversified into non-farm income-generating sources”. My results agree with ZBINDEN & LEE’S (2005) findings and take the discussion one step forward by analyzing the economics of the PES at the farm level. In our case study, the wealthier cattle systems are the LFS-HIU producers, the MFS-HIU system represents medium-scale producers with a high use of external inputs, and the SFS-LIU systems are farmers with more access restrictions to natural and financial assets (section 4.2). LFS-HIU producers have large farms (average of 3,000/ha), have large areas under forest or natural regeneration, and depend less on the farm for their income.

My results showed that LFS-HIU systems tend to have the lowest willingness to accept (i.e. PES monetary payment) to increase tree cover due to the combined effect of relatively low cattle profits (they produce with similar technology to the SFS-LIU system) and low discount rates (which favor tree profits over cattle profits). Given the lowest willingness to accept, LFS-HIU farmers tend to have the greatest *producer surplus* in the presence of a single PES rate, making the sales of environmental services an attractive activity for them. GRIEG-GRAN *et al.* (2005) hypothesized that in the *"quasi subsidy cases"* where PES schemes offer a flat payment (as in the Costa Rican PES), small-scale and poor farmers may have the highest producer surplus due to the low opportunity cost of their land. My findings, however, contradict this hypothesis, at least for cattle ranching in Costa Rica, showing that large-scale farmers tend to have the highest producer surplus and to benefit the most from flat PES rates. GRIEG-GRAN *et al.* (2005) did not take into account the discount rate effect in their hypothesis, which makes small-scale producers more dependent on short-run profits.

How can the PES be designed in order to increase equity or to be a more poor-friendly policy? GRIEG-GRAN *et al.* (2005), PAGIOLA *et al.* (2005), and ZBINDEN & LEE (2005) suggest three strategies to reduce the inequity problems of the PES instrument: 1) reducing transaction costs related to the access of payments, 2) limiting the area of landowners who benefit from the program, and 3) making different payments per farming systems. The results presented in this research contribute to the discussion of these strategies.

Reduction of transaction costs. GRIEG-GRAN *et al.* (2005) and PAGIOLA *et al.* (2005) mention that transaction costs are important factors that limit the access of poor farmers to PES programs in Latin America. My results show that even in the case of low transaction costs, the PES payment does not increase rural incomes. The main reason for this outcome is that the PES pays for the opportunity cost of land; in other words, producers receive the same income but from different sources. Only in the presence of producer surplus, the farmer obtains extra revenues. However, as discussed above, large-scale farmers are more likely to have the highest producer surplus. When producers already have forest, a reduction of transaction cost can have an impact on incomes and on conservation. In the forest case, the incentive has the objective of avoiding deforestation while the case study here is intended to increase tree cover from agricultural landscapes.

Limiting the area to be benefited by the PES. The Costa Rican PES restricts the access to the PES program to a maximum of 300 ha/landowner (FONAFIFO 2004). This policy is intended to avoid a small number of large-scale farmers from benefiting from FONAFIFO's annual budget. The main problem with limiting the access of large-scale farmers, however, is that large areas may be preferred from an environmental standpoint. For example, 100 hectares may contribute more to biodiversity conservation than two or three hectares. Since the ultimate objective of the PES policy is biodiversity conservation, it does not make sense to limit the area affected by the policy. My results show that LFS-HIU farmers can contribute almost 40% of the total tree cover. A restriction in farm area may reduce the chance of the policy to achieve the environmental objective.

Differentiating the payments per farming system. Since different types of producers have different willingness to accept, the PES could be designed specifically for each type of producer. This strategy identifies the minimum payment every group of farmers is willing to accept to increase tree canopy. However, there are two concerns with this approach. First, although a differentiated payment increases the chances of including poor farmers in a PES program, it is not likely to be an instrument to increase household incomes. PAGIOLA *et al.* (2005), for example, found that PES payments were designed to pay for the minimum willingness to accept in four case studies in Latin America. With such payments, the net household income is not modified, only the source of income (e.g. environmental services instead of cattle ranching). Second, a differentiated payment can create problems identifying and deciding which farms receive the highest and lower payments. For example, in our case study, MFS-HIU farmers require higher payments than LFS-HIU farmers: how can it be (politically) justified to pay $1.12/tree to a middle-scale farmer and $0.79/tree to a large-scale farmer if both systems have farms between 800 and 1000 hectares? Given the political and social implications of a differentiated payment, this strategy should be considered with caution. This kind of solution can be used in small areas, but it is not a generally recommended strategy.

As ZBINDEN & LEE (2005) pointed out, it appears that pursuing environmental goals conflicts with achieving equity goals in the case of the PES policy. FERRARO & SIMPSON (2002) advocate the use of direct incentives to achieve biodiversity objectives. In a similar fashion, I advocate more direct policy instruments to reduce poverty in rural areas. My results show that policies directed at increasing cattle productivity (such as improving calving rates and pastures) can have a more direct impact on rural incomes. Intensification of cattle technology, however, may reduce the area with trees if environmental services are not internalized into the producer's budget. The PES can be used to counteract the negative effects of pro-poor policies. Therefore, the PES should be seen as an instrument for biodiversity conservation, not as an instrument of poverty alleviation although poor farms undoubtedly can have non-economic benefits from conserving biodiversity (PAGIOLA *et al.* 2005).

6.7.2 Direct incentives vs. indirect incentives for biodiversity conservation

My results show that a direct incentive such as a PES policy is a powerful instrument to increase tree cover in cattle farms and thus conserving biodiversity in agricultural landscapes. FERRARO & KISS (2002) and FERRARO (2001) point out four issues that make direct incentives more preferable than indirect incentives for biodiversity conservation. First, the institutional support that needs a direct incentive initiative is less than or as complex as an indirect instrument. The advantage of a direct incentive is that practitioners can focus the efforts on generating the environmental service. Second, a direct payment approach can be more cost-efficient than any indirect approach (FERRARO 2002). Third, direct payments can benefit poor farmers by improving cash flows, providing wealth, and diversifying sources of household income. Fourth, direct payments (and indirect approaches) are not self-financed activities and require an ongoing financial cashflow.

My results can be used to discuss the last two issues. As presented before, a direct payment such as a PES for agroforestry does not necessarily benefit poor farmers. Rather, in Guanacaste, large-scale farms benefit the most from a PES policy. Indirect instruments, that have been coined as integrated conservation and development projects (ICDP) and community-based natural resource management (CBNRM) can have a clear advantage over a direct instrument in achieving conservation and development objectives simultaneously. The main concern about indirect incentives, however, is that in most cases these kind of projects reach neither objective (WELLS *et al.* 1999). Nonetheless, a correct approach of the needs and objectives of farmers can tackle some problems of indirect incentives when the double objective of conservation and development is pursued (HELLIN & SCHRADER 2003). A direct incentive such as a PES is not likely to be adjusted towards a poor-friendly instrument and at the same time successfully achieve conservation objectives.

Regarding the ongoing financial cost that can imply a PES incentive, my results show that the increase of tree cover by 50% can be attained in 10 to 15 years. When the incentive finishes, the farmer returns to the optimal canopy level because the market level is the one that generates more profits. This situation makes sense in pure-market systems: as long as consumers pay for the environmental service, farmers can provide it. FERRARO (2002) and FERRARO & SIMPSON (2002) mention that ICDP projects can have the same financial-dependency as direct incentives.

SCHERR *et al.* (2004) mention that direct payments (e.g. PES policies) will likely predominate in the promotion of biological corridors for protected areas while indirect approaches (mainly ecolabeling, i.e. to certify that products were produced in ways consistent with biodiversity conservation) will likely dominate future conservation initiatives in tropical countries. It makes sense: in areas with specific conservation needs (such as biological corridors), direct incentives can be promoted to focus energies on achieving the environmental objective. In cases where conservation and development objectives are pursued, and where the conservation objective is a desirable but not necessary outcome, indirect incentives can be promoted.

6.7.3 Lessons in designing PES

However, its impact depends on how the PES is designed. The most common payment scheme, paying for planting trees, although can have some results in forestry, has the lowest impact on increasing tree cover in silvopastoral systems in Guanacaste. Even more, a paying for planting trees scheme (which provide less environmental services than forests) is not economically competitive with a PES for forest plantations, since the former is as expensive as a PES for forest plantations.

Contrary to a paying for planting trees scheme, the schemes focused on standing trees or on changes in net basal area are more competitive and can increase tree cover in cattle farms. These two payment schemes can increase tree cover and are relatively cheap alternatives for increasing biodiversity conservation in tropical landscapes. A payment for changes in basal area requires lower financial resources than paying for standing trees. The former also has the advantage of being administratively more efficiently because the basal area indicator is easier to estimate in field. I recommend the use of both PES payments (i.e. paying for standing trees and for basal area) for policies that are being promoted in silvopastoral systems.

The financial cost estimated in this research, however, does not consider the *administrative* costs of the policy. Costa Rica has the advantage of already having the institutional and organizational framework to work with PES. Nonetheless, the application of the policy should also estimate the administrative costs of the policy.

One question remains: how to decide weather to promote a 50% or a 100% canopy level increase. It will depend on the *willingness to pay* by the service receivers. A PES policy is a market-based mechanism where government intervention is required to make a market and where receivers pay for the service. The PES will lie between the minimum willingness to accept by the cattle producers and the maximum willingness to pay by the service receivers. This research has contributed by estimating the supply-side of the environmental market in order to have the greatest benefits. In addition, this research has highlighted some administrative problems that decision-makers can confront when dealing with a PES instrument. In order to establish the demand side of the market, more research is needed.

There are some cases where the increase of tree cover is needed as part of a general strategy for biodiversity conservation, such as in the Mesoamerican Biological Corridor. In this case, the conservation system consists of protected areas and their corridors. The corridor, however, almost always is part of the agricultural landscape and policy intervention is required to increase tree cover in such landscapes. In order to increase tree cover, policy makers can make use of direct incentives, such as a direct payment to producers (SCHERR *et al*. 2004). The policy target in this case will depend on the biological requirements of the species that will use the corridor and the working budget of the implementing agency. The results presented in this research can help to estimate financial requirements. For these cases, a tax instrument can also be considered for analysis.

6.7.4 PES for forest or for agroforestry?

From a conservation standpoint, although agroforestry contributes to biodiversity conservation (Section 2.1), it cannot replace forests for conservation purposes (SCHROTH *et al*. 2004). However, agroforestry can be a second-best option for providing environmental services for biodiversity conservation in projects focused on increasing tree cover in agricultural landscapes.[9] In Guanacaste, an efficient PES payment can be between \$33/ha/20 years and \$233/ha/20 years (depending upon the payment scheme) in order to increase tree canopy by 100% in 15 years. In their reforestation program, FONAFIFO pays an average of \$330/ha/10 years (real US\$ 1982-1984=100; equal to \$630/ha in current 2004 terms) (FONAFIFO 2004), which can represent \$660/ha in 20 years. Clearly, the PES for cattle ranchers is a cheaper option for improving biodiversity conservation in the dry areas of Guanacaste.

In addition to the cost-effective characteristics, agroforestry is a holistic land-use system, in which trees and crops are combined in systems that can fit social and economic characteristics of rural areas. Agroforestry has been a policy instrument for increasing rural incomes and providing timber and agricultural products in traditional farming systems (KANT & LEHRER, 2004). Agroforestry also has been a policy for increasing production of agricultural and tree crops (ADESINA & COULIBALY, 1998), for evenly distributing workload (RÜGNITZ, 2004) as a buffer against unexpected fluxes in market prices (RAMIREZ & SOSA, 2000; RAMIREZ *et al.,* 2001), and for social cohesion and empowerment (OTSUKA *et al.* 2001; SCHROEDER & SURYANATA, 1996).

6.7.5 Impact of free trade on cattle systems in Guanacaste.

In a scenario of tree trade, SFS-LIU producers may be affected negatively. The model predicts that production with similar technology to the current used by the SFS-LIU system will not be profitable. Small-scale producers can have different reactions to free trade, for example: 1) they can be forced out of business, leaving land for the market; or 2) they can improve cattle technology to compete in local or export markets. The results presented here raise concerns about the possible outcomes, and more research is needed to analyze the best policy option for the SFS-LIU system in the study area.

6.7.6 Assumptions and limitations of the model

The main assumptions of the model were introduced in Chapter 5; their implications on the results are summarized below.

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[9] When farmers already have forest, the PES should be directed for avoiding changes in the use of land. In such cases, the PES for agroforestry should not be promoted.

a) Positive biophysical interactions between trees and cattle (where shade and fodder for cattle are the most important) were not considered. These biophysical interactions imply that trees and cattle are supplementary products: the increase in one product (say fodder trees) can increase the amount produced of the second product (say cattle). Higher levels of tree canopy or longer rotation cycles can be expected when trees offer positive benefits to cattle production. However, the effects are neither linear nor constant, and can be positive or negative. If tree canopy is highly increased (say more than 50% of the plot), cattle production might be affected. In addition, positive biophysical interactions can have low economic values. MONTERROSO (in process) found that it could be necessary to have almost 1 ha of *Enterolobium cyclocarpum* to feed one animal unit during the dry season in Cañas.

b) The interaction between trees and pasture production was assumed to be linear and negatively related. However, ESQUIVEL *et al.* (in prep.), who researched these relationships in the Cañas area, reported that *Brachiaria* pastures increase standing biomass production with medium-level shade (up to 15%), suggesting that a positive-sloped quadratic function would better fit these pastures. In addition, Jaragua grass reduces productivity with high rates of shade. The results presented here found an optimal crown cover of 12%, but more research is recommended to have better estimates of pasture production under tree shade.

c) The timber growth model was estimated with expert knowledge, where cattle stocking rates were assumed to cause low timber growth rates (diameter growth rates between 0.8 and 1.5 cm/year). The timber growth model also assumed a negative relation between cattle stocking rates and natural regeneration. Since little research has been developed in these fields for tropical countries, more research is needed on these topics.

d) The model assumed that prices are exogenous. This assumption implies that the model can be applied to small-scale areas, such as the region presented in this research or other biological corridors. For greater areas of influence, the model should be adjusted to consider endogenous prices.

e) The model assumes that producers manage their tree resources in a way that assures a constant harvest over time, whereas in reality, farmers harvest trees sporadically. Both the current tree density found in ESQUIVEL *et al.* (in prep.) and the optimal tree densities found in this research suggest that policy intervention can focus on improving the management (i.e. diameter structure of stands) of dispersed trees to assure sustainable levels of tree canopy in pastures. If a PES or tax policies are implemented in Cañas and Bagaces, technical assistance for producers is recommended to accompany the instrument to assure the optimal canopy level is achieved.

PART III

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 7

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

In the introduction chapter, three main contributions of this research were highlighted, namely: analysis of agroforestry policies, confrontation of economic theory with empirical analysis, and empirical bioeconomic models for agroforestry. Chapter one also stated three specific research questions for the case study in Cañas and Bagaces: 1) which is the optimal steady-state of dispersed trees in pastures in both counties, 2) which policy instrument is more likely to increase areas covered with trees in both counties, and 3) can silvopastoral systems increase rural incomes in the dry tropics of Cañas and Bagaces. In this chapter, I firstly discuss the three main contributions of the research and then briefly review the research questions in light of previous chapters. The chapter also includes topics for further research.

7.1 Analysis of agroforestry policies

This research presented a systematic procedure to analyze policies for agroforestry, which consists of two main components:

1) *The farming systems approach (FSA)*. Policy analysis begins with the analysis of the socioeconomic and biophysical characteristics of the rural area. The FSA is used as the theoretical framework for such analysis because it offers a holistic approach (which is demanded by the recent sustainable livelihood approach) as well as a pragmatic methodology (i.e. cluster analysis). The FSA is used for: i) grouping producers with similar characteristics (i.e. farming systems), which then become the policy recommendation ‘domains’, and ii) describing and identifying key variables and elements (based on systems theory) of every farming system.

2) *Economic theory to simulate policies. The FSA is descriptive rather than* explanatory. Therefore, a further theoretical framework is needed for simulating policies. I used economic theory for this analysis although theoretical frameworks from other social sciences could also be used depending upon the interest of the study. I based the analysis on the natural resource economic theory, whose objective is to find sustainable management systems for natural resources. With help of a profit maximization model, I simulated the outcomes of policies on trees and cattle for the three main farming systems in Guanacaste. Given the intertemporal characteristics and presence of externalities in agroforestry, the discussion of economic theory was a necessary component of the dissertation. Section 7.2 further discusses economic theory for agroforestry.

7.2 Economic theory for agroforestry analysis

Chapter three reviewed three theoretical approaches to analyze the economics of agroforestry: neoclassical microeconomic theory, joint production theory, and natural resource economic theory. Neoclassical microtheory fails to address the case of intertemporal allocation and externalities that are relevant for agroforestry and silvopastoral systems. Joint production theory offers an understandable framework for analyzing the problem of resource allocation in agroforestry, but empirical applications are limited. For empirical applications, joint production advocates the use of mathematical programming. Natural resource economic theory is based on optimal control theory. However, empirical analysis is solved with dynamic optimization or non-linear optimization models. Therefore, empirical studies based on both joint production theory and natural resource economic theory can be addressed with the same solving approach, i.e. mathematical programming.

The difference between the natural resource economic theory and joint production theory is that the former explicitly incorporates the concept of steady state in the management of the natural resource. By incorporating such a concept, the sustainability of the resource is guaranteed as well as that the resource is at their socially optimal level. Joint production assumes that the forest component is at the optimal level. The researcher should find the optimal rotation, which then this value is incorporated in mathematical programming models.

Empirical evidence in Cañas (ESQUIVEL *et al.* in prep.) showed that farmers do not manage their tree resources at the optimal steady-state level. For this reason, I recommend that the first policy action is to promote sustainable tree stands in cattle farms throughout the study area. However, one question remains: can a policy be simulated with the assumption that farmers manage tree resources at the optimal steady-state level? As in a laboratory condition, the assumption of a steady-state is a model condition that can be used for *a priori* policy analysis in homogeneous and controlled market conditions. In addition, we can assume that when a policy instrument such as a PES is developed and applied in a real-world situation, more information is provided to producers and they can look for more sustainable production systems. The PES can send correct signals to economic players and force them to look for rational use of the resource. In general, we can state that the natural resource economic theory and its empirical application through non-linear bioeconomic models are suitable tools to analyze the economics of agroforestry and silvopastoral systems in tropical countries.

7.3 Bioeconomic models for agroforestry

The bioeconomic model introduced in chapter five is an innovative instrument for analyzing silvopastoral policies in the tropics. It jointly analyzes the cattle and timber components in intertemporal and dynamic settings. It can easily be adjusted to incorporate characteristics and variables from other regions. Related to the timber component, the model jointly solves two key problems found in the management of tree and forest resources: 1) the diameter structure that assures a sustainable harvest, and 2) the transition path from current diameter distribution to the optimal diameter structure.

The construction of the empirical bioeconomic model was faced with three challenges. First, it was necessary to simulate a silvopastoral system, which implied a joint analysis of the timber, pasture, and cattle components in the same unit of land. This challenge was undertaken by incorporating two functions in the model, a relationship among canopy and pasture production, and a relationship among cattle stocking rates and regeneration of trees. Second, a simulation of timber tree growth for tropical timber species was required. I chose the approach of simulating one timber species (namely *Cordia alliodora*) by using a diameter growth model. However, the timber growth model requires support from empirical studies to better address the growth of tree species in silvopastoral systems. For example, it is required to study the impact of cattle stocking rates on timber growth rates. Finally, real-world data was needed to run the model. For this reason, a detailed description on the procedure to estimate coefficients and compilation of data was presented in chapter five. One of the main problems faced when using empirical bioeconomic models in tropical countries is that much of the data needs to be estimated in the field. The FSA helps to reduce this task by homogeneously grouping producers and facilitating the analysis by focusing on ‘typical’ farms.

7.4 Research questions

7.4.1 Can an optimal steady-state be estimated for dispersed trees in pastures in Cañas and Bagaces?

The empirical model presented in this research is a useful tool to find the optimal steady-state for dispersed trees in pastures. As mentioned before, an optimal steady-state for dispersed trees can assure the sustainability of the resource, which in turn can contribute to biodiversity conservation in the dry tropics. The model presented in this research can be used to find optimal steady-states for both cattle and tree resources of farms in Guanacaste and other tropical areas. Regarding the tree component, the model jointly solves two key problems found in the management of tree and forest resources: 1) the diameter structure that assures a sustainable harvest, and 2) the transition path from current diameter distribution to the optimal diameter structure.

The optimal steady-state differs among cattle systems; farm technology and intensification influence the area devoted to trees. Three optimum steady-state solutions were found, one for each farming system (i.e. SFS-LIU, MFS-HIU, and LFS-HIU systems). The farming system that obtains the highest cattle profits (MFS-HIU) is also the one that has the lowest tree density. This suggests that tree density will be a function of the kind of technology employed in cattle production. More intensive cattle technology tends to reduce the tree density in pastures. Agroforestry researchers and extensionists should pay attention to different types of producers when transferring agroforestry technology.

What is the optimal combination of trees and cattle in silvopastoral systems? Although this question appears to be simple, no answer has been given in the literature yet. For the dry tropics of Guanacaste, the optimal combination of components differs among farming systems. At the steady-state, the optimal density of trees (from 10 to 65 cm) is 56 tree/ha for the SFS-LIU system, 50 trees/ha for MFS-HIU system, and 51 trees/ha for LFS-HIU system. Tree cover (expressed in canopy area) at the steady-state is 1,700 m^2/ha for the SFS-LIU system, 1,600 m^2/ha for the MFS-HIU system, and 1,300 m^2/ha for the LFS-HIU system. Regarding cattle resources, the optimal stocking rate (with current pasture and management technology) was 0.9 AU/ha for the SFS-LIU and LFS-HIU systems, and 1.0 AU/ha for the MFS-HIU system.

Current diameter structure of trees in cattle farms differs from an optimal diameter structure, implying that dispersed trees in pasture may be depleted in the future. Although the average tree cover reported in empirical studies in Cañas is similar to the optimal canopy level found in this research, tree density at the steady-state highly differs from current average density of 13 trees/ha in cattle farms. This implies that farmers maintain almost the optimal tree cover, but with old trees. If a scenario without recruiting trees is maintained, the sustainability of the system is questionable. The model presented in this research shows an optimal structure that assures the preservation of tree resources. The model also shows that the optimal structure can be reached in 15 years with a low-cost conversion path. In order to assure sustainability of dispersed trees in pastures, efforts should be directed to change the current diameter structure of trees in cattle farms. An immediate policy action can be directed to improve the management of tree resources of cattle farms. An implementation of a PES or tax policy may also require the farmer to be accompanied with technical assistance to assure that the optimal level of tree density is achieved.

7.4.2 Which policy instrument is more likely to increase tree cover in Cañas and Bagaces?

The promotion of better tree management, i.e. sustainable diameter structures, can be the first policy action for increasing tree cover and promoting higher rural incomes. As noted before, current tree diameter structures in Cañas and Bagaces are not sustainable. By promoting better diameter structures, higher canopies can be expected as well as higher incomes.

If correctly design, the payment for environmental services (PES) is a powerful instrument for increasing tree cover at the farm and regional levels. Simulation shows that the PES can increase tree cover by 50% or by 100% depending upon the total incentive and the design of the instrument. Four payment schemes were tested: payment for standing trees, payment for standing trees per diameter class, payment per changes in basal area, and payment per planting trees. In order to increase tree canopy by 50%, payment amounts per hectare per 20 years rank between US$26 and US$63 for the SFS-LIU system, US$26 and US$63 for the MFS-HIU system, and US$3.4 and US$56 for the LFS-HIU system. Regarding an increase in tree cover by 100%, payment amounts per hectare per 20 years rank between US$32 and US$271 for the SFS-LIU system, US$56 and US$302 for the MFS-HIU system, US$7 and US$56 for the LFS-HIU system. At the regional level, the total budget for 20 years (NPV) to increase tree canopy by 50% in an area of 24,000 hectares ranks between US$282,000 and US$1,430,000. In order to increase tree cover by 100%, total budget ranks between US$788,000 and US$5,650,000.

The PES scheme that yields the lowest financial budget is paying for changes in net basal area; this payment is also administratively friendly because the basal area indicator is easier to estimate in field. The PES that pays for compensation of changes in net incomes can be used to set different payments per basal area. Taking as an example the estimated PES of the SFS-LIU system, the PES can pay US$11.66/ha to farms with average basal area higher than 3.4m^2/ha but lower than 4.1 m^2/ha (policy target-I) and US$32.58/ha with farms with average basal areas higher than 4.1 m^2/ha (policy target-II). Since the farmer can decide over the density and structure of the stands, the payment encourages the conservation of remnant trees with diameter greater than 50cm. The basal area as indicator of tree cover can be easier to estimate in field than the accounting of tree per diameter class.

The PES for planting trees (e.g. FONAFIFO PES for agroforestry) yields lower canopy levels with similar budgets than a PES that pays for standing trees or for changes in basal area. With a payment for planting trees, producers obtain profits for planting trees, not for providing environmental services. Producers continue harvesting trees at the commercial size (in our case at 35 cm diameter). With payments for standing trees or with payments for changes in basal area, producers are encouraged to both increase the density of older trees (i.e. delaying the harvest of trees) and increase the number of planted trees.

The PES for agroforestry is not an instrument that can be used to address both conservation and poverty issues. Large-scale farms have the lowest willingness to accept to increase tree cover in their pastures. This implies that with flat PES rates, they obtain the highest producer surplus and consequently more profits from the incentive. The willingness to accept is influenced by the profits generated by the cattle and timber components. The farm type that obtains more profits from the cattle component will tend to require a higher PES payment. In addition, producers with high discount rates will require higher payments to compensate for delayed timber profits.

Direct incentives such as PES policies are powerful instruments to increase tree cover in cattle farms; direct incentives can focused on specific conservation strategies. In areas with specific conservation needs (such as biological corridors), direct incentives can be promoted to focus energies on achieving the environmental objective. In cases where conservation and development objectives are pursued, and where the conservation objective is a desirable but not necessary outcome, indirect incentives can be promoted.

A PES for silvopastoral systems focused on increasing tree cover in agricultural landscapes has economic and social advantages compared with a PES for forest plantation. The estimated PES for dispersed trees is between $33/ha and $233/ha (depending upon the payment scheme); current FONAFIFO payment for forest plantation is $660/ha (in real US dollars 1982-1984=100). In addition, agroforestry is a holistic land-use system in which forest and crops are combined in systems that can fit social and economic characteristics of rural areas.

The tax instrument is a suitable instrument that can be used to increase tree cover in the dry tropics; its main concern is the political opposition that emerges from the affected parties. A tax on cattle ranching can be used to increase tree cover in tropical areas because it produces similar outcomes to a PES. Its main weakness is the political opposition that emerges from the affected sectors.

Both the PES and the tax on extensive cattle can yield similar results in increasing tree canopy in cattle farms. The PES is a mirror instrument of a tax policy. However, a tax policy can confront political opposition to be implemented. For quasi-subsidy PES, the main disadvantage is its dependence on governmental budgets –which may be scarce. The difference between a tax and a quasi-subsidy PES is centered on who is assumed to pay for the environmental improvement. A PES assumes that taxpayers should pay for more tree canopy while a tax policy charges to cattle producers the costs of the policy.

However, if the PES approaches a real market, i.e. where service consumers pay for the environmental improvement, then the PES can be a suitable and powerful instrument to increase tree cover. The tax instrument is not applicable in the pure market case.

7.4.3 Can dispersed trees in pastures increase rural incomes in Cañas and Bagaces?

Dispersed trees in pastures generate higher profits than a cattle-only system. Dispersed trees in pastures generate 35% more profits than pure cattle production; this explains why silvopastoral systems are widespread in the area. In addition, dispersed trees reduce the impact of low cattle prices (compared with a cattle-only production system) since total net income is less affected when producers obtain profits from timber trees. In a scenario of lower meat prices (free trade and open market), silvopastoral systems remain the most profitable activity for MFS-HIU and LFS-HIU systems.

The PES for silvopastoral systems in Guanacaste can have a reduced impact on poverty alleviation. Only in the presence of producer surplus, the farmer obtains extra revenues. However, as discussed above, large-scale farmers are more likely to have the highest producer surplus. The restriction of areas to be benefited by the PES can limit the impact on achieving the environmental objective. A payment per farming systems can be difficult to implement in a nation-scale policy. The use of direct incentives for poverty alleviation is more recommended.

Income can be increased with better cattle management, such as better calving rates and higher pastures carrying capacities (which may imply improved pastures). Higher incomes can be promoted with better cattle management such as higher stocking rates and increases in pasture carrying capacity. The increase of income through the tree component can be achieved with better tree densities and diameter structures. The promotion of better cattle management can be undertaken through extension programs. Therefore the implementation or restructuring of technological transfer programs by both the governmental and social institutions is recommended. Cattle intensification, however, can reduce the area devoted to trees. For this reason, the use of combined instruments (i.e. a PES with technology transfer programs) is recommendable in Cañas and Bagaces.

A free trade scenario (i.e. scenario without policy) will impact the SFS-LIU system and will slightly increase tree cover at the regional level. A free trade scenario may increase tree cover by two effects. First, the reduction of cattle ranching may favor the regeneration of tree cover in pastures. Second, higher timber prices increase tree cover. This research showed that the likely increase in timber prices would only slightly increase tree cover. Therefore, the increase of tree cover promoted by a free trade scenario will be produced by abandonment of pastures and not by higher timber prices. Regarding the cattle component, if free trade reduces meat prices by more than 15% of their current level, SFS-LIU system will be forced out of business. Since 84% of producers belong to this system, the social impact of lower meat prices can be high. Intensification of the SFS-LIU farms can increase incomes and make them more competitive in an open-market scenario. However, since intensification of cattle ranching may reduce tree canopy (e.g. the SFS-LIU system has more tree canopy than the MFS-HIU system), a combination of income-focused policies and PES policies are recommendable in the study area.

7.5 Further research

Greater complications can be added to the model to simulate other silvopastoral situations and problems, at the farm and regional level. For example, the model can incorporate the cutting of non-commercial classes to allow for faster transition paths. In addition, the model can consider price premiums for greater diameter classes to account for market preferences.

The topics that require further research to improve our knowledge and understanding of the economics of agroforestry policies with relevance to environmental services in tropical countries are:

- Determine the economic importance of the shade and forage provided by trees dispersed in pastures. Do extensive silvopastoral systems provide other financial benefits than timber revenue?

- Develop more information and data about the production of pastures under the shade of tropical trees, and develop bioeconomic models to simulate such interaction.

- Develop tree growth models for silvopastoral systems where the cattle stocking rate is a variable of timber growth.

- Quantify the demand-side of the market to determine the willingness to pay for conservation of the consumer, so that a market for environmental services can be developed.

- Extend the model to consider a regional level where prices are endogenously determined in order to simulate greater areas for policy intervention.

- Determine the minimum canopy level in agricultural landscapes that can be promoted to enhance biodiversity conservation in tropical areas. How much tree cover is enough for biodiversity conservation?

- Extend the model to consider other agricultural and forest activities that are relevant for the tropical dry forest of Central America.

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APPENDIX A
METHODOLOGY AND RESULTS OF THE FARM TYPOLOGY

This appendix presents the methodology for farm typology, which was based on ESCOBAR AND BERDEGUÉ (1990) and KÖBRICH *et al*. (2003). The farmer typology was done with cluster analysis with production data from the National Livestock Census (MAG *et al.* 2001) and adjusted with survey information. The typology based on cluster analysis guarantees that the formed groups have the maximum variability among groups and the minimum variance within groups (KAUFMAN AND ROUSSEEUW 1990, ESCOBAR AND BERDEGUÉ 1990). These are desirable characteristics in farm types in order to have clear recommendation 'domains' (TRIPP *et al*. 1990, KÖBRICH *et al*. 2003, SOLANO *et al*. 2000, ESCOBAR AND BERDEGUÉ 1990).

7.6 Methodology

The methodology consisted of two phases. In the first phase, a rapid rural appraisal (RRA or 'sondeo'), which was intended to pre-identify possible farming systems, consisted of five visits to the study area and ten interviews with key informants. This phase also included the search for secondary information such as biophysical characteristics of the study area. In the second phase, the main farm types were identified based on multivariate analysis (i.e. cluster analysis) and validated with surveyed information (ESCOBAR AND BERDEGUÉ 1990, KÖBRICH *et al*. 2003). Since the first phase (i.e. RRA) does not need any further explanation, this section will describe the multivariate analysis (cluster analysis) and survey methodology only.

7.6.1 Cluster Analysis

Cluster analysis was run for the calving-and-fattening systems only (155 farms) because fattening-only, dual purpose, and dairy farms were considered as different production systems. The data used came from the Census of Livestock (MAG et al. 2000). The variables used for the multivariate analysis and their simple statistics are shown in Table A.1. There were two kinds of data: 1) ordinal variables, i.e. total farm area and socking rates, and 2) binary variables, which take values of 0 and 1. Most of the variables (i.e. 11 over 13) were binary. The variables shown in Table 4.2 represent production aspects only because the information provided in the livestock census (MAG et al. 2001) did not contain other kind of variables. Cluster analysis was a previous step to obtain farm types. Cluster analysis helped to reduce the sample and gave insights about the farm types in the area.

Table A.1 Variables used for multivariate analysis and their simple statistics.

	Description	**Count**	**Average**	**STD**	**Min**	**Max**
Farm Area	Total farm area in hectares	155	186.4	369.5	1.4	2700
Stocking rate	Animal units* per pasture area (A.U./ha)	155	0.87	0.82	0.04	5.00
Fattening	Whether the farmer finish males. 0=no; 1 otherwise.	155	0.12	0.32	0.0	1.0
Breeding	Whether the farmer has Brahman breed. 0=no; 1 otherwise.	155	0.95	0.21	0.0	1.0
Wheel	Whether the farmer has wheels. 0=no; 1 otherwise.	155	0.14	0.34	0.0	1.0
Channel	Whether the farmer has Irrigation channels. 0=no; 1 otherwise.	155	0.04	0.19	0.0	1.0
Vaccine	Whether the farmer vaccine animals. 0=no; 1 otherwise.	155	0.36	0.48	0.0	1.0
Vitamins	Whether the farmer vitamins animals. 0=no; 1 otherwise.	155	0.40	0.49	0.0	1.0
Minerals	Whether the farmer gives minerals to animals. 0=no; 1 otherwise.	155	0.95	0.22	0.0	1.0
Parasite control	Whether the farmer have parasite control in animals. 0=no; 1 otherwise.	155	0.95	0.21	0.0	1.0
Antibiotics	Whether the farmer gives antibiotics to animals. 0=no; 1 otherwise.	155	0.20	0.40	0.0	1.0
Hormones	Whether the farmer applies hormones to animals. 0=no; 1 otherwise.	155	0.03	0.16	0.0	1.0
Pasture Fertilization	Whether the farmer fertilize pastures. 0=no; 1 otherwise.	155	0.06	0.25	0.0	1.0

* 1 Animal Unit = a cow of 400kg. Source: Livestock Census of Costa Rica 2001 (MAG *et al.* 2001).

Multivariate analysis was done with the CLUSTER and FASTCLUS commands of SAS (SAS Inst. 1996, KHATTREE AND NAIK 1995). The average linkage, Ward's minimum variance, and the *k*-means methods were run and compared (SAS Inst. 1996, KHATTREE &

NAIK 1995). As suggested by KAUFMAN & ROUSSEEUW (1990) for the kind of data we had, a dissimilarity matrix (using a spreadsheet) was constructed for the average linkage and Ward's minimum variance methods. Standardized variables were used for the *k*-means method. Since *k*-means method grouped farms closer to our expectations (i.e. our hypothesis about the type of farmers we could find in the study area), we used this grouping structure for subsequent analysis.

7.6.2 Survey and Cluster Adjustments

Verification and adjustment of the defined clusters was done by comparing the clusters obtained with the *k*-means method with the social and forest information collected with a survey. A stratified random sampling (SCHEAFFER *et al.* 1990) was chosen for farm survey, where the previously defined clusters were used as strata, with a total sample of 75 farms (error 12%, based on farm area). Sampled farmers were selected with random numbers within each cluster.

A semi-structured interview was preferred because it allowed a greater communication at the same time that provided qualitative and quantitative indicators (GEILFUS 2000). Two topics were selected for the interview, namely cattle management and tree and forest resources. The research only considered cattle ranchers for the study. However, agricultural production elements were taken into account if ranchers had agricultural production integrated into their farming system. Previously defined questions and the two topics were used as a reference guide. Table A.2 gives more details about the variables selected for the interview. The survey was run from October 29th to November 10th 2001.

The clusters adjustments were done by contrasting the clusters with our observations. The adjustment consisted mainly on discarding clusters and adding-up (or splitting) clusters of similar (different) characteristics.

Table A.2. Variables Asked in the Semi-Structured Interview at Canas and Bagaces 2001.

Production information	**Tree and forest resources**
Farmer activities: Area dedicated for each activity Irrigated area and crops Main kind of cattle production (e.g. calving, fattening, etc.) Main kind of grasses Cattle infrastructure (e.g. fences, wheels) Financial resources: Credits, insurance Marketing of agricultural and livestock products Production strategies during dry season, for example: Reduction of herd size Use of feeding supplements Grazing in secondary forest Social organization	Trees and forest Purposes and uses of trees in the farm Main species in the farm Area with forest and secondary forest. Marketing of timber Silvopastoral systems Main silvopastoral systems presented in the farm (e.g. dispersed trees, live fences, grazing in secondary forest, riparian trees, windbreaks) Management of silvopastoral systems Species for each silvopastoral system

7.6.3 Farming Systems Description

BERTALANFFY (1995) proposes four actions to be followed in systems description: 1) identification of system properties; 2) representation of the system's relationships; 3) identification of concepts presented in the system; and 4) identification of the feedback mechanism. Steps 1 and 2 were done with cluster analysis and validated with the survey; steps 3 and 4 were done qualitatively with information from the RRA, census and surveyed data, and information from key informants.

7.7 Results: Farmer Typology

7.7.1 Cluster Results

Only the results of the k-means method are reported, because they gave results closer to our expectations. The cluster analysis suggested four groups of farmers, as it is shown by the statistics for variables of ten clusters of Table A.3. In this stage, cubic clustering criterion and pseudo *F* statistic strongly increase, the R^2 is high, and the within-cluster standard deviation is low. This combination shows that the groups formed at this stage had a minimum variance within groups and the maximum variance among groups. The option with two clusters also presented higher pseudo F and CCC results, but it has the lowest R^2 and the highest within-cluster standard deviation.

Table A.3. Statistic for variables for ten clusters: k-means method.

No. of Cluster	Within STD[†]	R^2	CCC[#]	PSF[‡]
10	0.256	0.851	10.29	92.53
9	0.277	0.824	8.38	86.13
8	0.293	0.802	7.56	85.45
7	0.305	0.783	7.60	89.35
6	0.331	0.742	6.10	86.35
5	0.357	0.699	5.33	87.56
4	**0.380**	**0.656**	**6.01**	**96.73**
3	0.433	0.551	4.87	94.05
2	0.479	0.447	11.98	124.69
1	0.642	0.000	0.00	-

[†] Within-cluster standard deviation; [#] Cubic Clustering Criterion; [‡] Pseudo *F* statistic.

At this stage, it is important to mention general characteristics of the clusters. Cluster 1 was conformed by 128 farms; this cluster grouped farms from 1 to 800 hectares. Cluster 2 was composed by 16 farms whose stocking rates were higher than average. There were two reasons for high stocking rates: 1) the farmers were using up-to-dated technology, or 2) there were Census errors –we tested these hypotheses during the survey. Cluster 3 was conformed by the two biggest farms whose area was greater than 2000 hectares. Finally, cluster 4 was conformed by 9 farms whose area was between 300 hectares and 2000 hectares. The variables that were more relevant in farms clustering were farm size, stocking rate, and grass fertilization. Hence, cluster one grouped more than 63% of total farms.

Cluster 1, conformed by 128 farms (63% of total farms), gave an idea of the technical homogeneity of the farms in the study area. We could expect that farm technology was very similar among farms. With the survey, we tried to find variables to split cluster 1 into two groups.

7.7.2 Adjustment with Surveyed Data

Survey helped to have a closer look at the cattle production systems. Collected data suggested that clusters 3 and 4 had similar characteristics (farms with more than 500 hectares) so we grouped them into one system. Cluster 2, which grouped the farms with the highest cattle stocking rates represented an unreal situation in the area –therefore these farms were not considered in the study. In addition, cluster 1 could be split into two subgroups, depending upon the farm size and presence of improved pastures.

Farms with pasture areas bigger than 150 hectares were chosen to form the second group. Cluster 1 was split at 150 hectares because all these farms had farm areas bigger than 200 hectares. During the survey, farmers mentioned that a big farm in the area could be higher than that size. In addition, farmers with more than 200 hectares have invested in improved pastures. Improved pastures allow them to feed more animals during dry season. Then, this type of farmers can be thought to belong to an ‘investment’ producer, i.e. a one that makes relatively higher use of inputs for cattle production.

On the other hand, farmers below 150 hectares of pastures do not regularly purchased inputs. This type of producers are small-scaled and low-input-use farmers.

In summary, adding up the dual purpose and fattening-only systems, five types of farmers were identified in the study area: small-scale calving (i.e. cluster 1 with farms having pasture area smaller than 150 hectares), dual purpose, fattening-only, medium-scale calving (cluster 1 with farms having pasture area bigger than 150 hectares), and large-scale farmers (clusters 3 and 4). Dairy farms were not considered because they were unusual cases in the area with only 4 farms.

Dual purpose and fattening-only systems had similar characteristics to small-scale calving system (i.e. cluster 1 with less than 150 hectares). More over, when we added-up technical, social and tree characteristics elicited from the survey a unique cluster was evident. Small-scale calving, dual purpose, and fattening-only, then, were grouped as ‘small farm-scale and low-input-use (SFS-LIU) system’. The medium-scale calving (cluster 1 with farms bigger that 150 hectares) was named as ‘medium farm-size and high-input-use (MFS-HIU) system’. Finally, the large-scale farms were named as ‘large farm-size and high-input-use (LFS-HIU) system’. A detailed description of technical, social and environmental characteristics of the farm typology is presented in Chapter 4.

APPENDIX B

VARIABLES, COEFFICIENTS AND INDEXES OF THE EMPIRICAL BIOECONOMIC MODEL

Table B.1. Variables used in the Bioeconomic Model

Variable	Description	Units of Measure
Control variables		
REP_t	Number of cattle to hold as replacement	Animal heads
$FED_{j,t}$	Number of animal units fed with supplements in season j, time t	Animal Units
CUT_t	Number of trees harvested in time t	Number of trees
$NEWT_t$	New trees planted in time t	Number of trees
State Variables		
HRD_t	Herd, in number of cows in time t	Animal heads
$DEN_{t,dbh}$	Number of trees in diameter class dbh at time t	Number of trees
Model Variables		
LR_t	Livestock revenue in time t	Constant US Dollars
LC_t	Livestock cost in time t	Constant US Dollars
WR_t	Timber revenue in time t	Constant US Dollars
SS_t	Number of steer sold in time t	Steer heads
HS_t	Number of heifer sold in time t	Heifer heads
$FOR_{j,t}$	Animal units that one hectare can feed in season j, time t	AU/hectare
$U_{t,dbh}$	Upgrowth, i.e. number of trees moving up of each class due to growth	Number of trees
$M_{t,dbh}$	Tree mortality of diameter class dbh at time t	Number of trees
CC_t	Tree crown in time t	Hectares
BA_t	Total basal area at time t	m^2 /hectare
AU_t	Animal units in time t	Animal Units
Initial Conditions		
HRD_0	Initial hers size ($t=0$)	Number of cows
$DENS_{d,0}$	Initial number of trees of diameter $_d$ ($t=0$)	Individuals

Appendix B.2. Coefficients and Indexes used in the bioeconomic model

Coefficient	Description	Units of Measure
Coefficients		
ps_t	Price of steers in time t	Dollars per kg ($/kg)
ph_t	Price of heifers in time t	Dollars per kg ($/kg)
$pREP_t$	Price of cull cows in time t	Dollars per kg ($/kg)
$pfed_t$	Price of supplement staff in time t	Dollars per Animal Units ($/AU)
pwd_t	Price of timber in time t	Dollars per m^3 ($/$m^3$)
vc_t	Variable cost per cow in time t	Dollars per cow ($/cow)
wdc_t	Cost of timber extraction in time t	Dollars per m^3 ($/$m^3$)
$pasto_{j,t}$	Animal units that one hectare of pasture can maintain during season j, time t	Animal units per hectare (AU/ha)
DF_t	Discount factor at time t	
i	Discount rate	Percentage
w_c	Weight of cattle class *c*	Kilograms per head
cr	Calving rate	Percentage
$mort$	Cow mortality rate	Percentage
shd	Shade factor: reduction of pasture as increase of canopy	Percentage
vol_{dbh}	Average volume of tree with commercial diameter dbh	Cubic meters (m^3)
G_{dbh}	Average diameter increment for class dbh	Centimeters (cm)
W_{dbh}	Width of the diameter class dbh	Centimeters (cm)
$treemort_{dbh}$	Tree mortality of class dbh	Percentage
$basalarea_{dbh}$	Basal area per tree at the midpoint of diameter class dbh	m^2 / tree
Indexes		
t	Time	t=0,…30.
j	Seasons, dry and rainy	Dry: j=0 Rainy: j=1
c	Cattle class	S= steer, H=heifer, rep=replacement cow, fs=finished steer
dbh	Diameter class	1= 5-10 cm dbh 2= 10-20 dbh 3= 20-30 dbh 4= 30-40 dbh 5= more than 40 cm dbh

APPENDIX C

THE NONLINEAR OPTIMIZATION MODEL PROGRAMMED IN GAMS[10]

```
$TITLE   THE DISPERSED TREES NONLINEAR OPTIMIZATION MODEL -BASELINE-
$onsymxref onsymlist onuellist onuelxref
$Ontext
The model finds optimal management of cattle and trees in the silvopastoral
system 'dispersed trees in pastures'. For the cattle component, the model finds:
-The optimal herd stock (expressed as cows and animal units) (state variable).
-The replacement of cows (control variable).
-The animal units that should be feed with supplements (control variable).

For the tree component, the model finds:
-The optimal area with trees (expressed as tree density, basal area
 and canopy) (state variable)
-The number of recruiting trees (control variable)
-The number of harvest trees (control variable)

The description of the model is found in: Monterroso, A.O. (2005), Bioeconomic
models and agroforestry policy analysis: applications to silvopastoral systems
in Guanacaste, Costa Rica. Ph.D. Dissertation, CATIE, Costa Rica.

Date: August 2005. File: DTNLM-BL.gms
$Offtext
*========================================================*
*      1. SET DECLARATION AND SET DEFINITIONS            *
*========================================================*
SETS
t           years /0*60/
tfirst (t)  first period
tlast (t)   last period
t5 (t)      years as multiple of five /1,6,11,16,21,26,31,36,41,46,51,56/
tpsa(t)     years for psa /1*20/
j           seasons in one year /dry, rain/
c           cattle class /steer, heifer, cow/
DBH         dbh categories /dap7, dap15, dap25, dap35, dap45, dap55/
```

---

[10] GAMS (BROOKE *et al.* 1998)

```
farmer      cattle production system /small, medium, large/;
tfirst (t) = yes$(ord(t) eq 1);
tlast (t)  = yes$(ord(t) eq card(t));

*=======================================================*
*   2. PARAMETER DECLARATIONS AND PARAMETER DEFINITIONS   *
*=======================================================*
*---------------------------------------------------------
* 2.1 Common parameters
*---------------------------------------------------------
PARAMETER
YEAR (t) Parameter that converts the labels of t into numbers
$include year60.prn
;
PARAMETER
i (farmer) Discount rate /small 0.097, medium 0.097, large 0.0325/;

PARAMETER
DF(t,farmer) Discount factor at year t for producer system;
DF(t,farmer) = 1/((1+i(farmer))**(year(t)));
DISPLAY DF;
*---------------------------------------------------------
* 2.2 Parameters of the CATTLE component
*---------------------------------------------------------
TABLE
PRICE (t,c) 'Steer, heifer, and cow prices 2003-2033 (real US$/kilo)'
$include meatprice.prn
;
*$include meatpricepolicy.prn meatprice.prn
PARAMETERS
WEIGHT (c) Average weight of cattle classes
        /steer  235, heifer  195, cow 400/
PASTO (farmer,j) Animal units that one hectare of pasture can sustain during season j
        /small  .dry    =1
         small  .rain   =2.27
         medium .dry    =1.1
         medium .rain   =6.8
         large  .dry    =1
         large  .rain   =2.27/
PRICEfeed (farmer,j) Expected feed prices (colones per animal unit)
        /small  .dry    =44
         small  .rain   =68
         medium .dry    =58
         medium .rain   =68
         large  .dry    =44
         large  .rain   =68/
vCOST (farmer) Variable cost per cow head
        /small 59, medium 65, large 60/
CR (farmer) Calving rate in percentage
        /small 0.6, medium 0.8, large 0.8/;
SCALAR
MR Mortality rate in percentage /0.01/
HRD0 Herd initial value in number of cows /0.7/
REEMPLAZO Replacements of cows to be used with years 2003 to 2013;
REEMPLAZO = hrd0*0.1;
```

```
*-------------------------------------------------------
* 2.3. Parameters of the TREE component
*-------------------------------------------------------
TABLE
timberprice (t,dbh) timber prices for policy analysis (colones per m3)
$include timberprice.prn
;
PARAMETERS
growth (dbh) Average dbh growth per year (periodic annual increment)
        /dap7 1.35, dap15 1.5, dap25 1.34, dap35 1.11, dap45 0.79, dap55 0.35/
rango (dbh) Rangos de los intervalos
        /dap7 5, dap15 10, dap25 10, dap35 10, dap45 10, dap55 10/
midpoint (dbh) Mid point of dbh
        /dap7 7.5, dap15 15, dap25 25, dap35 35, dap45 45, dap55 55/
vol (dbh) average volume per tree at dbh class
        /dap35 .28, dap45 .45, dap55 .66/
pes (dbh) payment for environmental services
        /dap7 0, dap15 0, dap25 0, dap35 0, dap45 0, dap55 0/
treemort (dbh) Tree mortality by dbh
        /dap7 .1, dap15 .1, dap25 .1, dap35 .1, dap45 .1, dap55 .1/
remnant (farmer) Extra basal area to account for remnant trees
        /small 1.353241036, medium 1.353241036, large 0.8899741/
basalarea (dbh) Mean basal area of a tree at the dbh midpoint;
basalarea (dbh) = 3.1415926*(midpoint(dbh)/200)**2;

TABLE
initial (farmer,dbh) "Initial density per dbh category per farmer system"
        dap7   dap15   dap25   dap35   dap45   dap55
small     0      1.8     2.5     3.1     2.9     1.9
medium    0      1.8     2.5     3.1     2.9     1.9
large     0      1.2     1.7     2.1     1.9     1.3   ;

*=========================================================*
*           3. VARIABLE DECLARATION                   *
*=========================================================*
*-------------------------------------------------------
* 3.1 The OBJECTIVE variable
*-------------------------------------------------------
VARIABLES
Z Profit maximization

*-------------------------------------------------------
* 3.2. Variables of the CATTLE component
*-------------------------------------------------------
*3.2.1 CATTLE CONTROL VARIABLES
REP (t,farmer) Replacement cows and heifers in time t
FED (t,farmer,j) Animal Units feed with feedstuff in season j and time t

*3.2.2 CATTLE STATE VARIABLE
HRD (t,farmer) Herd in number of cows

*3.2.3 MODEL VARIABLES
LR (t,farmer) Livestock revenue in year t
LC (t,farmer) Livesctock cost in year t
SS (t,farmer) Steer sell in year t
HS (t,farmer) Heifer sell in year t
```

```
FORAGE (t,farmer,j) Forrage availability in time t season j
AU (t,farmer) Animal Units
*TVC Terminal value cattle


*--------------------------------------------------------
* 3.3 Variables of the TREE component
*--------------------------------------------------------
*3.3.1 CONTROL VARIABLES
PLANTATION (t,farmer) Number of new trees let in the field at time t
HARVEST35 (t,farmer) tree harvest dbh 35
HARVEST45 (t,farmer) tree harvest dbh 45
HARVEST55 (t,farmer) tree harvest dbh 55

*3.3.2 STATE VARIABLE
DENSITY (t,farmer,dbh)  tree density per dbh category in time t

*3.3.3 MODEL VARIABLES
WR(t,farmer) Total volume revenue at time t
CC (t,farmer) Total tree canopy in year t
BA (t,farmer) Total basal area in year t
PSA (t,farmer) psa
TVT (farmer) Terminal value trees;

*--------------------------------------------------------
* 3.4 Nonegativity and initial conditions
*--------------------------------------------------------
POSITIVE VARIABLES REP, FED, HRD, LR, LC, SS, HS, AU,
                HARVEST35, HARVEST45, HARVEST55, PLANTATION, DENSITY, CC, BA;
HRD.FX('0',farmer)=HRD0;
DENSITY.l(t,farmer,dbh)=20;

*=========================================================*
*           4. EQUATION DECLARATION                  *
*=========================================================*
*--------------------------------------------------------
* 4.1 The OBJECTIVE function
*--------------------------------------------------------
EQUATIONS
PROFITsmall Objective function of SMALL cattle system
PROFITmedium Objective function of MEDIUM cattle system
PROFITlarge Objective function of LARGE cattle system
*--------------------------------------------------------
* 4.2 Equations for the CATTLE component
*--------------------------------------------------------
*4.2.1 Cattle objective equations
SSELL (t,farmer) Steer sell in year t
HSELL (t,farmer) Heifer sell in year t
LREVADJ (t,farmer) Livestock revenues during adjustment years (0 to 10)
LREVENUE (t,farmer) Livestock revenue for years 11 on
LCOST (t,farmer) Livesctock cost in year t

*4.2.1 Cattle state equations
HERD2004 (t,farmer) Herd equation year 2004
HERDADJ (t,farmer) Herd equation of motion during the adjustment years 2 to 10
HERD (t,farmer) Herd equation of motion for years 11 on
```

```
FAVAILABLE (t,farmer,j) Forrage availability at time t season j
AUN (t,farmer) Animal Units conversion
AUmax(t,farmer) AU maximum
FEQUI (t,farmer,j) Forage feeding supplemenst and animal units equilibrium time t season j

*--------------------------------------------------------
* 4.3 Equations for the TREE component
*--------------------------------------------------------
*4.3.1 Tree OBJECTIVE equation
WOODREVENUE (t,farmer) Wood harvest at time t

*4.3.2 Tree STATE equations
densityfirst(t,farmer,dbh) Initial density per dbh category
DEN7(t,farmer,dbh) Equation of motion of dbh 7.5
DEN15(t,farmer,dbh) Equation of motion of dbh 15
DEN25(t,farmer,dbh) Equation of motion dbh 25
DEN35(t,farmer,dbh) Equation of motion dbh 35
DEN45(t,farmer,dbh) Equation of motion dbh 45
DEN55(t,farmer,dbh) Equation of motion dbh 55
EQBA (t,farmer) Total basal area at time t
CANOPY (t,farmer) Equation of canopy time t
EQUIDEN35 (t,farmer) equilibrium dbh 35
EQUIDEN45 (t,farmer) equilibrium dbh 45
EQUIDEN55 (t,farmer) equilibrium dbh 55
pagoservicios(t,farmer) pago servicios ambientales
law (t,farmer)  law to simulate policies
cattletree (t,farmer) equation that relates PLANTATION as a function of cattle stocking rate

*--------------------------------------------------------
* 4.4 Terminal conditions
*--------------------------------------------------------
TERMC (t,farmer) Terminal conditions for cattle
TERMT (t,farmer) Terminal conditions for trees;

*=========================================================*
*            5. EQUATION DEFINITIONS                     *
*=========================================================*
*--------------------------------------------------------
* 5.1 The CATTLE model
*--------------------------------------------------------
HERD2004 ('1',farmer)..
        HRD ('1',farmer) =e= (1-MR)*HRD('0',farmer) + reemplazo - reemplazo;
HERDADJ(t+2,farmer)$(ORD(t) LT CARD(t)-51)..
        HRD (t+2,farmer) =e= (1-MR)*HRD(t+1,farmer) + REP(t,farmer)-reemplazo;
HERD (t+11,farmer)..
    HRD(t+11,farmer)=e=(1-MR)*HRD(t+10,farmer)+REP(t+9,farmer)-REP(t+1,farmer);
SSELL (t,farmer) ..
        SS(t,farmer) =e= HRD(t,farmer)*(CR(farmer)/2);
HSELL(t,farmer) ..
        HRD(t,farmer)*(CR(farmer)/2) =e= REP(t,farmer)+ HS(t,farmer);
LCOST (t,farmer) ..
        LC(t,farmer)=e=HRD(t,farmer)*vCOST(farmer)+SUM(j,FED(t,farmer,j)
                    *PRICEfeed(farmer,j));
LREVADJ(t,farmer)$(ORD(T) LT CARD(T)-49)..
        LR(t,farmer) =e= (SS(t,farmer)*PRICE(t,'steer')*weight('steer'))
               + (HS(t,farmer)*PRICE(t,'heifer')*weight('heifer'))
```

```
                + (reemplazo)*PRICE(t,'cow')*weight('cow');
LREVENUE(t+11,farmer)..
        LR(t+11,farmer) =e=(SS(t+11,farmer)*PRICE(t+11,'steer')*weight('steer'))
                   + (HS(t+11,farmer)*PRICE(t+11,'heifer')*weight('heifer'))
                   + (REP(t+1,farmer)*PRICE(t+11,'cow')*weight('cow'));
FAVAILABLE (t,farmer,j)..
         FORAGE (t,farmer,j) =e= Pasto(farmer,j)*(1-CC(t,farmer));
FEQUI (t,farmer,j) ..
         FORAGE(t,farmer,j) + FED(t,farmer,j) - AU (t,farmer) =g= 0;
AUN (t,farmer) ..
         AU(T,farmer)=e=(HRD(t,farmer)*1)+(HRD(t,farmer)*cr(farmer)*0.3)
                       +REP(t-1,farmer)*0.65 + 0.06;
AUMAX(t,farmer)..
         AU(t,farmer) =l=pasto(farmer,'rain');
TERMC(t,farmer)$(ORD(T) GT CARD(T)-10).. AU (T,farmer) =E= AU (T-1,farmer);

*-------------------------------------------------------
* 5.2 The TREE model
*-------------------------------------------------------
densityfirst(tfirst,farmer,dbh) ..
         density (tfirst,farmer,dbh) =e= initial(farmer,dbh);
DEN7(t+1,farmer,'dap7')..
      density(t+1,farmer,'dap7')=e=(1-treemort('dap7'))*density(t,farmer,'dap7')
                             -(growth('dap7')/rango('dap7'))
                             *((1-treemort('dap7'))*(density(t,farmer,'dap7')))
                             +  (plantation(t,farmer))$t5(t);
DEN15(t+1,farmer,'dap15')..
 density(t+1,farmer,'dap15') =e= (1-treemort('dap15'))*density(t,farmer,'dap15')
                            + (growth('dap7')/rango('dap7'))
                            *((1-treemort('dap7'))*(density(t,farmer,'dap7')))
                            -(growth('dap15')/rango('dap15'))
                            *(1-treemort('dap15'))*(density(t,farmer,'dap15'));
DEN25(t+1,farmer,'dap25')..
 density(t+1,farmer,'dap25') =e= (1-treemort('dap25'))*density(t,farmer,'dap25')
                             + (growth('dap15')/rango('dap15'))
                             *(1-treemort('dap15'))*(density(t,farmer,'dap15'))
                             - (growth('dap25')/rango('dap25'))
                             *(1-treemort('dap25'))*density(t,farmer,'dap25');
DEN35(t+1,farmer,'dap35')..
 density(t+1,farmer,'dap35') =e= (1-treemort('dap35'))*density(t,farmer,'dap35')
                             + (growth('dap25')/rango('dap25'))
                             *(1-treemort('dap25'))*density(t,farmer,'dap25')
                             - (growth('dap35')/rango('dap35'))
                             *(1-treemort('dap35'))*density(t,farmer,'dap35')
                                                - harvest35 (t,farmer);
DEN45(t+1,farmer,'dap45')..
 density(t+1,farmer,'dap45') =e= (1-treemort('dap45'))*density(t,farmer,'dap45')
                                                + (growth('dap35')/rango('dap35'))
                                                      *(1-treemort('dap35'))*density(t,farmer,'dap35')
                                          - (growth('dap45')/rango('dap45'))
                                          *(1-treemort('dap45'))*density(t,farmer,'dap45')
                             - harvest45(t,farmer);
DEN55(t+1,farmer,'dap55')..
 density(t+1,farmer,'dap55') =e= (1-treemort('dap55'))*density(t,farmer,'dap55')
                                          + (growth('dap45')/rango('dap45'))
                                                *(1-treemort('dap45'))*density(t,farmer,'dap45')
```

```
                                        - harvest55(t,farmer);
EQBA (t,farmer)..
  ba (t,farmer) =e= sum(dbh, (density(t,farmer,dbh)*basalarea(dbh)))
                                   +remnant(farmer);
EQUIDEN35 (T,farmer)..
        density(t,farmer,'dap35')-harvest35(t,farmer) =g= 0;
EQUIDEN45 (T,farmer)..
        density(t,farmer,'dap45')-harvest45(t,farmer) =g= 0;
EQUIDEN55 (T,farmer)..
        density(t,farmer,'dap55')-harvest55(t,farmer) =g= 0;
WOODREVENUE (t,farmer)..
  WR (t,farmer) =e= (harvest35(t,farmer)*vol('dap35')*timberPRICE(t,'dap35'))
                 +(harvest45(t,farmer)*vol('dap45')*timberPRICE(t,'dap45'))
                 +(harvest55(t,farmer)*vol('dap55')*timberPRICE(t,'dap55'))
                 - (plantation(t,farmer)*0.5);
PAGOSERVICIOS(t,farmer)..
        psa (t,farmer) =e= (density(t,farmer,'dap35')*pes('dap35'))$tpsa(t)
                  +(density(t,farmer,'dap45')*pes('dap45'))$tpsa(t)
                  +(density(t,farmer,'dap55')*pes('dap55'))$tpsa(t);
CANOPY (t,farmer)..
        CC (t,farmer) =e= 0.0022205 + 0.050175*ba(t,farmer);
LAW(t,farmer)..
        ba(t,farmer) =g= 0$tpsa(t);
cattletree(t,farmer)..
        plantation(t,farmer) + 34.7826087*AU(t,farmer) =l= 80;
TERMT(tlast,farmer)..
        TVT (farmer) =e= (wr(tlast,farmer)/i(farmer))*df(tlast,farmer);

*-------------------------------------------------------
* 5.3. OBJECTIVE Function
*-------------------------------------------------------
PROFITsmall ..
        Z =E= SUM (t, ((LR(t,'small')- LC(t,'small'))*df(t,'small')
                 +WR(t,'small')*df(t,'small')
                 + PSA(t,'small')*df(t,'small')))+tvt('small');
PROFITmedium ..
        Z =E= SUM (t, ((LR(t,'medium')- LC(t,'medium'))*df(t,'medium')
                 +WR(t,'medium')*df(t,'medium')
                 + PSA(t,'medium')*df(t,'medium')))+tvt('medium');
PROFITlarge ..
        Z =E= SUM (t, ((LR(t,'large')- LC(t,'large'))*df(t,'large')
                 +WR(t,'large')*df(t,'large')
                 + PSA(t,'large')*df(t,'large')))+tvt('large')/100;

*============================================================*
*            6. SOLVE INSTRUCTIONS                    *
*============================================================*
Model
    DBHsmall DTNLM for SMALL-SCALE producer in Guanacaste
   /PROFITsmall, SSELL, HSELL, LREVADJ, LREVENUE, LCOST, HERD2004, HERDADJ,
    HERD, FAVAILABLE, AUN, AUmax, FEQUI, WOODREVENUE, densityfirst, DEN7,
    DEN15, DEN25, DEN35, DEN45, DEN55, EQBA, CANOPY, EQUIDEN35, EQUIDEN45,
    EQUIDEN55, pagoservicios, law, cattletree, TERMC, TERMT/

    DBHmedium DTNLM for MEDIUM-SCALE producer in Guanacaste
   /PROFITmedium, SSELL, HSELL, LREVADJ, LREVENUE, LCOST, HERD2004, HERDADJ,
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   HERD, FAVAILABLE, AUN, AUmax, FEQUI, WOODREVENUE, densityfirst, DEN7,
   DEN15, DEN25, DEN35, DEN45, DEN55, EQBA, CANOPY, EQUIDEN35, EQUIDEN45,
   EQUIDEN55, pagoservicios, law, cattletree, TERMC, TERMT/

   DBHlarge DTNLM for LARGE-SCALE producer in Guanacaste
  /PROFITlarge, SSELL, HSELL, LREVADJ, LREVENUE, LCOST, HERD2004, HERDADJ,
   HERD, FAVAILABLE, AUN, AUmax, FEQUI, WOODREVENUE, densityfirst, DEN7,
   DEN15, DEN25, DEN35, DEN45, DEN55, EQBA, CANOPY, EQUIDEN35, EQUIDEN45,
   EQUIDEN55, pagoservicios, law, cattletree, TERMC, TERMT/;
Option nlp=minos;

Solve DBHsmall using nlp maximizing z;
Solve DBHmedium using nlp maximizing z;
Solve DBHlarge using nlp maximizing z;

*=====================================================*
*           7. WRITING OUTPUT                         *
*=====================================================*
PARAMETER
OPT1 OPTIMAL VALUES FOR CATTLE SUBMODEL small
CCRRsm cummulative revenue small;
OPT1(t,'small',"Herd-Stock")=hrd.l(t,'small');
OPT1(t,'small',"Animal-Uni")=AU.l(t,'small');
OPT1(t,'small',"Replcemnt")=REP.l(t,'small');
opt1(t,'small',"Supplement")=fed.l(t,'small','dry');
OPT1(t,'small',"dry-season")=forage.l(t,'small','dry');
OPT1(t,'small',"U-REVENUE")=(LR.L(t,'small') - LC.L(t,'small'));
OPT1(t,'small',"REVENUE")=(LR.L(t,'small') - LC.L(t,'small'))*df(t,'small');
CCRRsm('0')= OPT1('0','small',"REVENUE");
LOOP(t,CCRRsm(t+1) = CCRRsm(t)+OPT1(t+1,'small',"revenue"));
OPT1(t,'small',"Cum-Rev")=CCRRsm(t);

PARAMETER
OPT2 OPTIMAL VALUES CATTLE medium
CCRRme cummulative revenue medium;
OPT2(t,'medium',"Herd-Stock")=hrd.l(t,'medium');
OPT2(t,'medium',"Animal-Uni")=AU.l(t,'medium');
OPT2(t,'medium',"Replcemnt")=REP.l(t,'medium');
OPT2(t,'medium',"Supplement")=fed.l(t,'medium','dry');
OPT2(t,'medium',"dry-season")=forage.l(t,'medium','dry');
OPT2(t,'medium',"U-REVENUE")=(LR.L(t,'medium') - LC.L(t,'medium'));
OPT2(t,'medium',"REVENUE")=(LR.L(t,'medium') - LC.L(t,'medium'))*df(t,'medium');
CCRRme('0')= OPT2('0','medium',"REVENUE");
LOOP(t,CCRRme(t+1) = CCRRme(t)+OPT2(t+1,'medium',"revenue"));
OPT2(t,'medium',"Cum-Rev")=CCRRme(t);

PARAMETER
OPT3 OPTIMAL VALUES CATTLE large
CCRRla cummulative revenue large;
OPT3(t,'large',"Herd-Stock")=hrd.l(t,'large');
OPT3(t,'large',"Animal-Uni")=AU.l(t,'large');
OPT3(t,'large',"Replcemnt")=REP.l(t,'large');
OPT3(t,'large',"Supplement")=fed.l(t,'large','dry');
OPT3(t,'large',"dry-season")=forage.l(t,'large','dry');
OPT3(t,'large',"U-REVENUE")=(LR.L(t,'large') - LC.L(t,'large'));
OPT3(t,'large',"REVENUE")=(LR.L(t,'large') - LC.L(t,'large'))*df(t,'large');
```

```
CCRRla('0')= OPT3('0','large',"REVENUE");
LOOP(t,CCRRla(t+1) = CCRRla(t)+OPT3(t+1,'large',"revenue"));
OPT3(t,'large',"Cum-Rev")=CCRRla(t);

PARAMETER OPT4 OPTIMAL VALUES TREE SUBMODEL SFS-LIU
CCTTsm CUMMULATIVE TIMBER REVENUES SMALL FARMS;
OPT4(t,'small',"dap7")=DENSITY.l(t,'small','dap7');
OPT4(t,'small',"DAP15")=density.l(t,'small','dap15');
OPT4(t,'small',"DAP25")=density.l(t,'small','dap25');
OPT4(t,'small',"DAP35")=density.l(t,'small','dap35');
OPT4(t,'small',"DAP45")=density.l(t,'small','dap45');
OPT4(t,'small',"DAP55")=density.l(t,'small','dap55');
OPT4(t,'small',"TOTAL-TREES")=sum(dbh, density.l(t,'small',dbh));
OPT4(t,'small',"total-w/dap7")=density.l(t,'small','dap15')+density.l(t,'small','dap25')+density.l(t,'small','dap35')+density.l(t,'small','dap45')+density.l(t,'small','dap55');
OPT4(t,'small',"HARVEST35")=harvest35.l(t,'small');
OPT4(t,'small',"HARVEST45")=harvest45.l(t,'small');
OPT4(t,'small',"HARVEST55")=harvest55.l(t,'small');
OPT4(t5,'small',"NEWTREES")=PLANTATION.l(t5,'small');
OPT4(t,'small',"CANOPY")=CC.L(T,'small');
OPT4(t,'small',"basal-area")=ba.l(t,'small');
OPT4(t,'small',"U-T-Rev")=wr.l(t,'small');
OPT4(t,'small',"T-REVE")=wr.l(t,'small')*DF(t,'small');
CCTTsm("0")= WR.L("0",'small')*df("0",'small');
LOOP(t,CCTTsm(t+1) = CCTTsm(t)+(wr.l(t+1,'small')*df(t+1,'small')));
OPT4(t,'small',"Cum-TREE")=CCTTsm(t);
OPT4(t,'small',"PES")=PSA.L(T,'small');

PARAMETER OPT5 OPTIMAL VALUES TREE SUBMODEL SFS-LIU
CCTTme CUMMULATIVE TIMBER REVENUES MEDIUM FARMS;
OPT5(t,'medium',"dap7")=DENSITY.l(t,'medium','dap7');
OPT5(t,'medium',"DAP15")=density.l(t,'medium','dap15');
OPT5(t,'medium',"DAP25")=density.l(t,'medium','dap25');
OPT5(t,'medium',"DAP35")=density.l(t,'medium','dap35');
OPT5(t,'medium',"DAP45")=density.l(t,'medium','dap45');
OPT5(t,'medium',"DAP55")=density.l(t,'medium','dap55');
OPT5(t,'medium',"TOTAL-TREES")=sum(dbh, density.l(t,'medium',dbh));
OPT5(t,'medium',"total-w/dap7")=density.l(t,'medium','dap15')+density.l(t,'medium','dap25')+density.l(t,'medium','dap35')+density.l(t,'medium','dap45')+density.l(t,'medium','dap55');
OPT5(t,'medium',"HARVEST35")=harvest35.l(t,'medium');
OPT5(t,'medium',"HARVEST45")=harvest45.l(t,'medium');
OPT5(t,'medium',"HARVEST55")=harvest55.l(t,'medium');
OPT5(t5,'medium',"NEWTREES")=PLANTATION.l(t5,'medium');
OPT5(t,'medium',"CANOPY")=CC.L(T,'medium');
OPT5(t,'medium',"basal-area")=ba.l(t,'medium');
OPT5(t,'medium',"U-T-Rev")=wr.l(t,'medium');
OPT5(t,'medium',"T-REVE")=wr.l(t,'medium')*DF(t,'medium');
CCTTsm("0")= WR.L("0",'medium')*df("0",'medium');
LOOP(t,CCTTsm(t+1) = CCTTsm(t)+(wr.l(t+1,'medium')*df(t+1,'medium')));
OPT5(t,'medium',"Cum-TREE")=CCTTsm(t);
OPT5(t,'medium',"PES")=PSA.L(T,'medium');

PARAMETER OPT6 OPTIMAL VALUES TREE SUBMODEL SFS-LIU
CCTTme CUMMULATIVE TIMBER REVENUES large FARMS;
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OPT6(t,'large',"dap7")=DENSITY.l(t,'large','dap7');
OPT6(t,'large',"DAP15")=density.l(t,'large','dap15');
OPT6(t,'large',"DAP25")=density.l(t,'large','dap25');
OPT6(t,'large',"DAP35")=density.l(t,'large','dap35');
OPT6(t,'large',"DAP45")=density.l(t,'large','dap45');
OPT6(t,'large',"DAP55")=density.l(t,'large','dap55');
OPT6(t,'large',"TOTAL-TREES")=sum(dbh, density.l(t,'large',dbh));
OPT6(t,'large',"total-
w/dap7")=density.l(t,'large','dap15')+density.l(t,'large','dap25')+density.l(t,'large','dap35')+density.l(t,'l
arge','dap45')+density.l(t,'large','dap55');
OPT6(t,'large',"HARVEST35")=harvest35.l(t,'large');
OPT6(t,'large',"HARVEST45")=harvest45.l(t,'large');
OPT6(t,'large',"HARVEST55")=harvest55.l(t,'large');
OPT6(t5,'large',"NEWTREES")=PLANTATION.l(t5,'large');
OPT6(t,'large',"CANOPY")=CC.L(T,'large');
OPT6(t,'large',"basal-area")=ba.l(t,'large');
OPT6(t,'large',"U-T-Rev")=wr.l(t,'large');
OPT6(t,'large',"T-REVE")=wr.l(t,'large')*DF(t,'large');
CCTTsm("0")= WR.L("0",'large')*df("0",'large');
LOOP(t,CCTTsm(t+1) = CCTTsm(t)+(wr.l(t+1,'large')*df(t+1,'large')));
OPT6(t,'large',"Cum-TREE")=CCTTsm(t);
OPT6(t,'large',"PES")=PSA.L(T,'large');

DISPLAY OPT1, OPT2, OPT3, OPT4, OPT5, OPT6;

EXECUTE_UNLOAD 'CATTLE-LA.GDX' opt3;
execute 'gdxxrw.exe CATTLE-LA.GDX output=c:\otto\RESULTS\baseline\baselineprueba.xls
par=opt3 RNG=CATTLE-lacost!';
*EXECUTE_UNLOAD 'CATTLE-ME.GDX' opt2;
*execute 'gdxxrw.exe CATTLE-ME.GDX output=c:\otto\RESULTS\baseline\baseline.xls par=opt2
RNG=CATTLE-ME!';
*EXECUTE_UNLOAD 'CATTLE-SM.GDX' opt1;
*execute 'gdxxrw.exe CATTLE-SM.GDX output=c:\otto\RESULTS\baseline\baseline.xls par=opt1
RNG=CATTLE-SM!';

EXECUTE_UNLOAD 'TREE-LA.GDX' opt6;
execute 'gdxxrw.exe TREE-LA.GDX output=c:\otto\RESULTS\baseline\baselineprueba.xls par=opt6
RNG=TREE-LAcost!';
*EXECUTE_UNLOAD 'TREE-ME.GDX' opt5;
*execute 'gdxxrw.exe TREE-ME.GDX output=c:\otto\RESULTS\baseline\baseline.xls par=opt5
RNG=TREE-ME!';
*EXECUTE_UNLOAD 'TREE-SM.GDX' opt4;
*execute 'gdxxrw.exe TREE-SM.GDX output=c:\otto\RESULTS\baseline\baseline.xls par=opt4
RNG=TREE-SM!';
```

APPENDIX D

EXPORT MEAT PRICES, SLAUGHTER AND FEEDER CATTLE PRICES, AND TIMBER PRICES IN COSTA RICA

Table D.1. Time series data for meat export prices in Costa Rica, 1951-2003

Year	FOB US millions	Amount (Tons)	Price US$/kg	US CPI 1983-84=10C	Real export prices
1951	0.0	15.0	0.3	26	1.15
1952	0.1	140.5	0.7	26.5	2.64
1953	0.0	68.9	0.7	26.7	2.62
1954	0.0	38.9	0.6	26.9	2.23
1955	0.0	19.7	0.6	26.8	2.24
1956	0.1	76.3	0.8	27.2	2.94
1957	0.1	365.5	0.4	28.1	1.42
1958	0.9	1,936	0.5	28.9	1.73
1959	2.9	4,800	0.6	29.1	2.06
1960	4.3	7,200	0.6	29.6	2.03
1961	2.7	4,800	0.6	29.9	2.01
1962	2.7	3,800	0.7	30.2	2.32
1963	5.1	7,100	0.7	30.6	2.29
1964	6.0	8,700	0.7	31	2.26
1965	3.1	4,500	0.7	31.5	2.22
1966	5.3	7,000	0.8	32.4	2.47
1967	8.6	10,400	0.8	33.4	2.40
1968	12.0	14,700	0.8	34.8	2.30
1969	15.2	16,600	0.9	36.7	2.45
1970	18.1	17,400	1.0	38.8	2.58
1971	20.4	18,500	1.1	40.5	2.72
1972	28.3	23,300	1.2	41.8	2.87
1973	31.4	20,500	1.5	44.4	3.38
1974	34.2	28,300	1.2	49.3	2.43
1975	32.0	29,800	1.1	53.8	2.04
1976	40.4	30,300	1.3	56.9	2.28
1977	44.2	31,900	1.4	60.6	2.31
1978	60.1	34,600	1.7	65.2	2.61
1979	81.6	31,600	2.6	72.6	3.58
1980	70.7	26,000	2.7	82.4	3.28
1981	73.9	33,200	2.2	90.9	2.42
1982	53.1	24,300	2.2	96.5	2.28
1983	31.9	13,900	2.3	99.6	2.31
1984	43.5	20,500	2.1	103.9	2.02
1985	55.7	28,100	2.0	107.6	1.86
1986	72.3	36,665	2.0	109.6	1.82
1987	61.5	28,211	2.2	113.6	1.94
1988	52.6	23,799	2.2	118.3	1.86
1989	49.7	21,148	2.3	124	1.85
1990	48.6	18,801	2.6	130.7	1.99
1991	69.3	26,459	2.6	136.2	1.91
1992	44.0	17,310	2.5	140.3	1.78
1993	63.7	25,736	2.5	144.5	1.73
1994	51.0	22,470	2.3	148.2	1.55
1995	43.6	21,158	2.1	152.4	1.38
1996	42.2	20,800	2.0	156.9	1.27
1997	28.3	12,900	2.2	160.5	1.37
1998	24.0	10,236	2.3	163.0	1.41
1999	27.2	13,600	2.0	166.6	1.20
2000	30.7	14,560	2.1	172.2	1.22
2001	25.5	11,200	2.3	177.1	1.30
2002	20.1	8,300	2.4	179.9	1.33
2003	22.3	9,700	2.3	184.0	1.25

Source: MIDEPLAN 2004.

Table D.2. Monthly prices of cattle classes (1996-2003), as reported in slaughterhouses and in Cañas' auction (colones/kg).

Year	M	Price chuck Colon/kg	Male carcass price (C/kg)	Female carcass price (C/kg)	Slaughter steer price (C/kg)	Slaughter heifer price (C/kg)	Steer price (C/kg)	Heifer price (C/kg)	Feeder steer price (C/kg)	Feeder heifer price (C/kg)	Feeder heifer price (C/kg)	Slaughter cow price
1996	1	367.53	312	279	175	143						
1996	2	358.33	315	293	177	150						
1996	3	344.14	314	291	177	150						
1996	4	342.73	318	291	180	151						
1996	5	341.87	318	294	179	153						
1996	6	350.02	325	313	184	162						
1996	7	372.25	334	305	187	157						
1996	8	399.39	331	307	185	157						
1996	9	393.83	337	310	189	158						
1996	10	402.77	341	313	190	161						
1996	11	406.88	346	317	194	164						
1996	12	410.50	349	323	193	166						
1997	1	419.37	350	325	191	167						
1997	2	467.93	355	329	200	173						
1997	3	492.20	371	344	209	183						
1997	4	486.70	406	382	230	196						
1997	5	445.56	424	395	240	203						
1997	6	439.26	435	415	246	214						
1997	7	458.83	436	415	246	220						
1997	8	473.02	438	416	245	215						
1997	9	455.48	438	420	242	218						
1997	10	443.33	436	418	242	217						
1997	11	463.02	440	420	249	209						
1997	12	482.66	444	423	250	219						
1998	1	486.41	457	434	255	220						
1998	2	490.21	461	439	260	226						
1998	3	488.62	468	447	261	230						
1998	4	481.41	485	459	272	235						
1998	5	491.22	498	471	279	256						

Year	M	Price chuck Colon/kg	Male carcass price (C/kg)	Female carcass price (C/kg)	Slaughter steer price (C/kg)	Slaughter heifer price (C/kg)	Steer price (C/kg)	Heifer price (C/kg)	Feeder steer price (C/kg)	Feeder heifer price (C/kg)	Feeder heifer price (C/kg)	Slaughter cow price
1998	6	478.58	505	479	277	243						
1998	7	471.81	512	487	289	250						
1998	8	452.76	516	490	291	249						
1998	9	456.89	520	488	289	250						
1998	10	461.55	515	488	289	249						
1998	11	465.73	515	490	290	250						
1998	12	470.06	518	484	290	247						
1999	1	480.20	513	482	287	243	.	.				
1999	2	496.69	511	474	285	241	282	235			220	210
1999	3	501.35	516	473	289	238	299	259	246		238	229
1999	4	499.63	532	489	299	247	307	243	233		242	228
1999	5	510.32	525	479	296	245	303	242			223	206
1999	6	508.64	517	472	292	241	301	253			224	213
1999	7	512.84	517	472	290	242	307	252	264		243	230
1999	8	516.00	520	475	291	243	305	248	263	232	235	216
1999	9	538.87	521	476	290	242	290	248	232	234	237	220
1999	10	555.47	523	478	294	244	292	240	235	236	233	217
1999	11	578.77	523	478	293	245	281	233	244	233	228	213
1999	12	582.68	521	477	292	243	285	235			239	226
2000	1	578.84	529	487	268	271	286	247	244		244	234
2000	2	595.67	534	493	299	253	295	241	298		241	233
2000	3	599.44	559	519	314	265	320	253		251	242	235
2000	4	615.60	575	533	323	273	305	258			250	256
2000	5	618.96	574	531	323	272	312	255	247	265	255	236
2000	6	602.06	579	529	324	271	320	259		263	253	245
2000	7	605.15	576	534	319	270	336	268	287	261	263	238
2000	8	601.48	581	540	324	274	331	285	238	268	263	243
2000	9	604.79	587	545	326	276	348	276	278	265	274	247
2000	10	600.99	590	547	384	277	331	266	236		261	248
2000	11	653.56	596	553	331	279	334	259		269	269	253

Year	M	Price chuck Colon/kg	Male carcass price (C/kg)	Female carcass price (C/kg)	Slaughter steer price (C/kg)	Slaughter heifer price (C/kg)	Steer price (C/kg)	Heifer price (C/kg)	Feeder steer price (C/kg)	Feeder heifer price (C/kg)	Feeder heifer price (C/kg)	Slaughter cow price
2000	12	663.72	590	548	331	277	291	257	255	262	264	246
2001	1	653.10	598	555	333	285	303	229		272	244	220
2001	2	656.27	607	565	339	290	337	285	262	280	271	234
2001	3	681.64	629	587	353	284	370	317		303	310	233
2001	4	677.22	663	617	381	314	421	342		305	281	253
2001	5	709.93	701	650	395	336	408	339	298	327	274	259
2001	6	713.98	695	649	388	343	468	370	380		337	329
2001	7	725.38	729	684	409	355	485	381	380		355	350
2001	8	759.45	735	690	412	357	453	361	397	374	352	343
2001	9	838.69	729	684	409	353	472	398		350	335	291
2001	10	784.89	726	684	407	354	439	393		354	348	332
2001	11	821.50	720	679	402	351	449	358	379	389	350	343
2001	12	811.77	722	682	405	351	469	376			356	338
2002	1	825.94	734	692	411	353	475	402		359	376	298
2002	2	832.82	745	700	419	357	493	387			364	352
2002	3	855.09	753	708	424	360	433	369	408	371	356	347
2002	4	854.61	759	718	429	366	491	324	436			332
2002	5	807.14	747	709	422	363	503	401	349		343	352
2002	6	774.34	721	682	409	351	476	420	396	354	364	323
2002	7	797.10	727	687	411	351	517	412	370	356	397	334
2002	8	804.06	729	692	410	354	484	413	360	360	359	372
2002	9	794.47	716	680	402	348	464	431		349	371	306
2002	10	776.96	713	677	399	340	469	380	355		357	342
2002	11	775.45	702	668	392	342	436	369		335	377	313
2002	12	790.41	705	668	396	340	460	394	364		350	342
2003	1	797.37	721	683	402	344	431	376	333	339	344	307
2003	2	802.28	723	685	408	347	415	366	270	330	307	303
2003	3	808.36	729	694	413	352	422	327	298	340	360	317
2003	4	813.49	729	693	413	352	449	391		339	355	299
2003	5	820.49	731	694	416	361	482	385	350	341	342	303

Year	M	Price chuck Colon/kg	Male carcass price (C/kg)	Female carcass price (C/kg)	Slaughter steer price (C/kg)	Slaughter heifer price (C/kg)	Steer price (C/kg)	Heifer price (C/kg)	Feeder steer price (C/kg)	Feeder heifer price (C/kg)	Feeder heifer price (C/kg)	Slaughter cow price
2003	6	826.95	731	691	414	355	446	383	350	346	346	321
2003	7	836.02	734	698	413	355	457	382	345	342	360	305
2003	8	889.97	732	701	411	358	449	381	287	335	353	295
2003	9	996.77	730	697	410	356	421	355	362	339	331	305
2003	10	978.41	741	700	416	356	431	351	380	286	333	308
2003	11	1069.42	754	703	429	363	426	351	383	337	327	301
2003	12	1096.19	756	708	429	363	397	325	232	331	315	305

Source: Chuck prices 85%: CORFOGA (2004); slaughterhouses and auction prices: CNP (2004).

Table D.3. Exports (amount and total value), and relative prices, for five Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua), 1961-2003

	Exports (cubic meters)		Value of exports (1000$)		Relative prices $/m^3	
	Sawnwood (C)	Sawnwood (NC)	Sawnwood (C)	Sawnwood (NC)	Sawnwood (C)	Sawnwood (NC)
1961	246,250	64,050	8,558	3,693	34.75	57.66
1962	224,100	71,200	7,558	4,673	33.73	65.63
1963	238,250	63,250	8,950	3,616	37.57	57.17
1964	283,300	61,600	11,858	4,054	41.86	65.81
1965	291,900	55,500	10,700	3,685	36.66	66.40
1966	427,850	57,350	11,423	3,921	26.70	68.37
1967	465,550	57,300	12,107	4,061	26.01	70.87
1968	555,850	42,950	15,563	2,925	28.00	68.10
1969	453,600	37,400	17,469	2,418	38.51	64.65
1970	426,350	31,550	16,822	2,245	39.46	71.16
1971	563,650	26,450	26,035	2,286	46.19	86.43
1972	830,150	40,250	35,645	3,630	42.94	90.19
1973	782,800	43,300	46,467	3,994	59.36	92.24
1974	626,500	55,900	43,934	6,132	70.13	109.70
1975	591,600	53,448	48,665	9,509	82.26	177.91
1976	543,197	63,041	43,250	7,245	79.62	114.93
1977	591,950	58,750	43,507	6,303	73.50	107.29
1978	527,250	50,850	45,311	5,847	85.94	114.99
1979	406,450	44,150	41,483	6,448	102.06	146.05
1980	272,950	33,250	20,581	5,391	75.40	162.14
1981	323,450	40,050	25,138	7,176	77.72	179.18
1982	373,100	29,400	43,463	6,018	116.49	204.69
1983	322,950	16,650	39,444	3,730	122.14	224.02
1984	273,800	14,500	35,500	3,584	129.66	247.17
1985	240,500	20,500	34,508	4,394	143.48	214.34
1986	238,076	15,800	35,649	2,450	149.74	155.06
1987	312,660	19,000	47,840	4,055	153.01	213.42
1988	374,600	14,200	65,362	3,586	174.48	252.54
1989	325,600	20,378	117,899	3,496	362.10	171.56
1990	232,000	12,500	107,739	5,141	464.39	411.28
1991	445,600	24,500	76,572	7,882	171.84	321.71
1992	762,934	63,925	124,751	49,598	163.51	775.88
1993	292,262	55,732	65,985	24,914	225.77	447.03
1994	334,550	58,011	64,875	18,448	193.92	318.01
1995	340,200	57,100	122,764	21,653	360.86	379.21
1996	504,000	62,900	163,758	24,565	324.92	390.54
1997	709,200	57,200	217,161	22,607	306.21	395.23
1998	634,639	38,417	188,693	17,368	297.32	452.09
1999	372,486	37,700	101,690	13,502	273.00	358.14
2000	363,315	50,844	77,529	19,364	213.39	380.85
2001	389,800	38,000	82,766	16,960	212.33	446.32
2002	327,079	37,241	67,481	14,660	206.31	393.65
2003	327,079	37,241	67,481	14,660	206.31	393.65

Source: FAOSTAT (2004).