LAND USE ALLOCATION UNDER MULTIPLE OBJECTIVES IN THE BRAZILIAN AMAZON: CREATING A TOOL TO GUIDE ZONING OF PUBLIC PRODUCTION FORESTS

By

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To my parents.

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LIST OF ABBREVIATIONS

ACLI:	Amazon Conservation Leadership Initiative
BCA:	Benefit-cost analyses
BNDES:	National Bank for Economic and Social Development
CGFP:	Commission for Management of Public Forests
DBH:	Diameter at the Breast Height (1.3 m)
DETER:	Real-time detection system (detection of deforestation in Amazon)
DICOPT:	Discrete and Continuous Optimizer
EMBRAPA:	Brazilian Agricultural Research Corporation
ESALQ/USP:	School of Agricultural Studies “Luiz de Queiroz” at University of São Paulo
FAO:	Food and Agriculture Organization of the United Nations
FFT:	Tropical Forest Foundation
FLONA:	National Forest
FMP:	Forest Management Plan
FNDF:	National Forestry Development Fund
FSF:	Faro State Forest
GAMS:	General Algebraic Modeling System
GDP:	Gross Domestic Product
GIS:	Geographic Information System
IBAMA:	Brazilian Institute for the Environment and the Renewable Natural Resources
IBGE:	Brazilian Institute of Geography and Statistics
INPE:	Brazilian Institute of Spatial Research
IP:	Integer programming
IPEA:	Institute for Applied Economic Research

IMAFLORA:	Institute for Management and Certification in Agriculture and Forestry
IMAZON:	Amazon Institute for the People and the Environment
IRR:	Internal rate of return
ISA:	Socio-environmental Institute
LP:	Linear programming
MDIC:	Brazilian Ministry of Development, Industry and International Commerce
MINLP:	Mixed integer non-linear programming
MMA:	Brazilian Ministry of Environment
mOC:	Marginal opportunity cost
MODIS:	Moderate Resolution Imaging Spectroradiometer
NGO:	Non-governmental organization
NPV:	Net Present Value
NTFP:	Non-timber forest products
PFCA:	Association of Certified Forest Producers in the Brazilian Amazon
PPF:	Production possibility frontier
RIL:	Reduced impact logging techniques
SBS:	Brazilian Silviculture Society
SFB:	Brazilian Forest Service
SFRC:	School of Forest Resources and Conservation
SIVAM:	Amazonian Vigilance System
TCD:	Tropical Conservation and Development Program
UF:	University of Florida
UL:	Unconstrained logging scenario
WFI:	Wide Field Imager

Abstract of Thesis Presented to the Graduate School
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LAND USE ALLOCATION UNDER MULTIPLE OBJECTIVES IN THE BRAZILIAN AMAZON: CREATING A TOOL TO GUIDE ZONING OF PUBLIC PRODUCTION FORESTS

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Logging in natural forests is a vital income generating activity for the Amazon's fragile economy. However, illegal and unplanned logging, largely executed in public lands, is exhausting forests rapidly. In March 2006, a new forestry law (Lei 11,284/2006) established the first directives to manage public lands, including the multiple use of these forests through timber concessions, biodiversity conservation, tourism, mining and other land uses demanded by society. From a social planner's perspective, a new challenge lies in how to maximize the welfare that can be generated from these lands, using them in an efficient way while satisfying dynamic societal preferences.

This study seeks to address the question, from a social planner's perspective in the Brazilian Amazon, of how to optimize the allocation of forest units among multiple land use alternatives, satisfying criteria that are often conflicting – such as forest production and conservation objectives – and assessing the tradeoffs associated with these different choices. To address this question, I developed an optimization model of land use allocation in an Amazonian state forest, taking into account economic information about the expected profits for logging within the state forest. The model developed is able to solve the timber supply problem for the

logging industry, considering the supply of roundwood in public lands and capacity constraints of surrounding mills, and is also able to determine maximum profits from logging subject to a minimum area or score that must be achieved for alternative non-commodity uses. This research represents more than a single case study, as the datasets used in this study cover Amazon's geographic extent and, therefore, results could be applied to any other Amazonian public forest.

The model was then used to estimate Net Present Values for logging under different zoning configurations. In Faro, the State Forest used as a case study in this thesis, the NPV from logging concessions in a baseline scenario could achieve US$ 16.8 million. This value would naturally decline if a larger proportion of the public forest were allocated to other land uses. Next, simulation results and sensitivity analyses were used to determine the production possibility frontier between the production of market and non-market goods. Using this method, opportunity costs were estimated for land uses related to the production of non-market goods, such as biodiversity conservation or livelihood systems promoted by forest dwellers.

The main result of this study is the development of a useful tool to aid social planners in the zoning of public forests in the Brazilian Amazon. Simulations can be used to determine, for each area, efficient zoning alternatives for producing market and non-market goods. In addition, this study revealed that marginal opportunity costs increase when a larger share of the public forest is assigned for alternative land uses, a fact that should be taken into account by planners during public forest zoning. In the case of Faro State Forest, for example, I found that marginal opportunity costs for biodiversity conservation begin around US$ 10,000 and can increase to US$ 170,000 when 43% of the public forest is assigned for this land use. Such results are then discussed in relation to their policy implications and, finally, future areas for research are presented.

CHAPTER 1
INTRODUCTION

Statement of the Problem

Selective logging in natural forests is currently the third most important economic activity in the Brazilian Amazon, after industrial mining and cattle ranching (IPEA, 2002; IBGE, 2004). However, since the beginning of its history, large scale timber logging in upland Amazonian forests has been extensive, predatory and migratory; and has been depleting forests rapidly, often in public lands (Uhl, 1997; Nepstad et al. 1999; Schneider et al., 2000; Asner et al., 2005). While a large proportion of the Amazonian timber production is still illegally generated today (Lentini et al., 2005), a new forestry law, enacted in 2006, established the first directives to take control of and manage public lands, including forest concessions. Thus, this new law represents an opportunity to limit illegal activities and land speculation in public forests.

Unsettled public lands cover one third of the Brazilian Amazon, corresponding to 160 million hectares (IBGE, 1996). After the enactment of the new law, such lands can finally be used to generate economic development through forest concessions, tourism, or mining; or to accommodate other land uses demanded by society, such as livelihood strategies promoted by traditional communities or biological conservation. From a social planner's perspective, a new challenge lies in how to maximize the welfare that can be generated from these lands, using them in an efficient way while meeting dynamic societal preferences. This implies that social planners must take into account the interests of stakeholders involved in the zoning of these forests, as well as the economic forces acting at multiple scales.

The foundation of this problem is related to the question of how to optimize the allocation of forests among multiple land use alternatives, satisfying criteria that are often conflicting, such as timber production and conservation. This issue is important within the current context of

Amazonian public lands, due to the scarcity of economic information to guide decisions regarding the zoning of public forests, including estimates of the monetary value that government could raise through forest concessions.

Study Objectives

The main justification of this study is the need for the development of an analytical tool to guide the decision-making process in the zoning of Amazonian public forests. This tool could be used by social planners[1] to assess efficient alternatives in the management of public lands and to estimate the tradeoffs among zoning alternatives. This study has the following specific objectives:

- Develop a spatially-explicit optimization model to estimate the net returns from logging by taking into account multiple objectives in public forests;
- Apply this model to a specific public production forest in the Brazilian Amazon;
- Determine the production possibility frontier between the production of market and non-market goods, identifying efficient alternatives for land use allocation in the public forest;
- Assess the tradeoffs among land use alternatives by estimating the opportunity costs involved in the production of non-market goods within the public forest.

The importance of this study is demonstrated by two facts: first, for the first time, a model is designed to solve the typical timber-supply problem and the land allocation problem[2]

[1] Social planners can be defined as bureaucrats and decision makers working for state and federal agencies that will be responsible for coordinating the planning and the execution of Forest Management Plans (FMP) for public forests. Arguably, in some cases, such social planners can also be represented by members of supervisory committees, which are consulting bodies to be formed for each public forest to provide advice about management decisions.

[2] Timber supply is commonly investigated in harvest scheduling and forest tactical planning problems in which the management of a given forest unit is optimized considering its supply of timber, capacity constraints of the surrounding mills, and other physical constraints in the timber production. Furthermore, land allocation problems are concerned with finding the minimum number of units or the minimum cost to achieve a given score for an attribute, such as biological conservation, or to achieve a minimum number of conserved species, among others. These problems are now capable of taking into account the integration of production and non-commodity uses. Both types of problems in natural resource management modeling will be reviewed in the next chapter.

simultaneously. Second, despite the fact that the optimization model represents a case study in the sense that it was applied for a specific Amazonian public land, Faro State Forest, the databases used in this study cover the extent of the Brazilian Amazon, and could be used immediately for the zoning of any other Amazonian public forest. Both issues will become evident in the next chapters.

CHAPTER 2
STUDY RATIONALE AND LITERATURE REVIEW

According to the Global Forest Resources Assessment 2005 (FAO, 2005), Brazil has, today, the second largest forested area in the world (478 million hectares), but it also has the world's highest deforestation rate, equal to 3.1 million hectares per year. Most of this deforestation is concentrated in the Brazilian Amazon, where forests are still being converted to agricultural use. A large part of this deforestation is viewed, by Brazilian society, from a negative viewpoint, considering the importance of such forests in conserving biological diversity and forest environmental services, watershed conservation, the provision of livelihoods to local peoples, and global climate regulation. Further, it has been shown in the past couple of decades that some specific techniques can be used to conserve the forest structure during logging, mitigating the environmental impacts and improving the economic efficiency of harvesting operations (Barreto et al., 1998; Holmes et al., 2000).

The Brazilian Amazon encompasses 9 states (~ 5 million km^2) and covers roughly 60% of Brazil's total area (IBGE, 1997). The region is still sparsely populated by 21 million inhabitants, concentrated mainly (70%) in urban areas. The Amazonian economy is strongly based on rural activities and contributed only 7% of Brazilian gross domestic product (GDP) in 2002 (IPEA, 2002). This is surprising considering the large availability of natural resources, with 300 million hectares of forests (IBGE, 1997) having potential for timber and non-timber forest product (NTFP) production. On the other hand, historically Amazonian natural capital has not been efficiently used to generate social capital and economic development. While deforestation continues in the Brazilian Amazon, new mechanisms to promote the rational use of its forests are needed, including a comprehensive strategy to manage public lands.

This chapter is organized as follows. First, I will provide some historical background about logging in the Brazilian Amazon and some data about its socio-economic importance. Second, the main structural problems related to the logging sector will be discussed. Third, justifications for the importance of managing public lands in the region and the new Brazilian law focusing on this issue will be presented. The final section will discuss past literature on different types of spatial modeling in natural resource management.

History and Socio-Economic Importance of the Logging Sector in the Amazon

Selective logging has occurred in the Amazonian estuary since the 17^{th} century (Rankin, 1985). For the first two centuries, logging was restricted to estuarine forests along the main Amazonian rivers, with high value species harvested for European markets (Barros and Uhl, 1995; Zarin et al., 2001). It was only in the 1950s that the first industrial mills were established in the estuary to produce sawn-wood and veneer using foreign capital, with markets oriented toward exportation (Barros and Uhl, 1995; Pinedo-Vasquez et al., 2001).

In the 1960s and 1970s, intensive government investments opened access to extensive portions of inland upland forests mainly through the construction of roads. Such investments enabled the development of extensive and highly predatory logging in upland forests, fueled by government subsidies for individuals to inhabit the region, the depletion of hardwood species in southern Brazil, and the large availability of unclaimed lands in the Amazon (Uhl et al., 1997; Stone, 1998a; Veríssimo et al., 1998; Veríssimo et al., 2002b).

The first areas explored during the road construction period supplied some of the most important Amazonian logging centers scattered in these older logging frontiers, such as Paragominas and Sinop (Lentini et al., 2004) (Figure 2-1). Timber stocks in older frontiers have been largely depleted after 3 decades of unplanned and predatory logging, in addition to conversion of forests to agricultural use. Timber companies in these frontiers have been gradually deciding whether to cease operations, to invest in technological improvements, or to move to newer frontiers (Stone, 1997).

Some official roads, such as the Cuiabá-Santarém and the Transamazon, allowed the migration of timber firms from older to newer frontiers. Such roads were also constructed during the late 1960s to early 1970s, as a purposeful strategy of the military Brazilian government to secure control over lands through human occupation. However, despite the fact that forests in the proximity of the Transamazon have been harvested for more than 30 years, the relative inaccessibility to this region during the rainy season and the control exercised over local resources by smallholders who inhabit the region partially saved these forests from the same fate of forests in older frontiers (Lima and Merry, 2003; Merry et al., in press). In 2004, 26 logging centers were located within intermediate frontiers (Figure 2-1), representing ¼ of the timber production, revenues and jobs generated by the Amazonian logging industry. Then, as a consequence of timber firm migration, large availability of high value timber, and forest clearings for more intensive cattle ranching and agriculture, timber production within new frontiers, such as Novo Progresso and Castelo de Sonho (Pará State), increased by more than 80% in the past 8 years (Lentini et al., 2005) (Figure 2-1).

Logging is, today, one of the three most important economic activities in the Brazilian Amazon, after industrial mining and cattle ranching (IPEA, 2002; IBGE, 2004). Logging also tends to rapidly develop inland cities since timber firms tend to be concentrated in urban logging centers, because of the availability of infra-structure (mainly roads), commerce and specialized services, electrical power, and large availability of labor (Stone, 1997; Uhl et al., 1997; Stone, 1998a; Veríssimo et al., 2002b; Lentini et al., 2004). In 2004, the 82 logging centers established in the Brazilian Amazon encompassed 3,132 timber mills that consumed 24.5 million m^3 of roundwood, generating a gross revenue of US$ 2.3 billion (Lentini et al., 2005). Logging is also an important activity for employment generation, representing 380,000 jobs (Lentini et al., 2005).

Markets for Amazonian Wood. From the demand side, the exhaustion of the timber stocks from natural forests and the increasing restrictions on harvesting forests in southern Brazil stimulated increased timber production in the Amazon. Most of this production is used to supply domestic markets with cheap civil construction materials. In 2002, two-thirds of the Amazonian wood consumed in the state of São Paulo – the primary consumer of Amazonian wood products in the world (Figure 2-2) – was destined for low value added uses in civil construction, such as structures for roofing or forms for concrete structures (Sobral et al., 2002). The low value added to Amazonian wood products contributes to the low interest from domestic markets in purchasing products generated through sound forest practices, such as forest certification (Veríssimo et al., 2005).

However, Amazonian participation in international tropical timber markets is likely to increase in the future due to the exhaustion of natural timber stocks in Malaysia and Indonesia (Uhl et al., 1997; Vincent, 1997). In fact, the proportion of exported wood from the Brazilian Amazon increased from 14% of the total production in 1998, or 1.6 million m^3 , to 36% in 2004, or 3.7 million m^3 (Veríssimo and Smeraldi, 1999; Lentini et al., 2004, 2005) (Figure 2-2). Further, not only the quantity, but also the quality, of the Amazonian exported wood products has recently changed. According to the Brazilian Ministry of Overseas Commerce (MDIC, 2007), the value of wood products exported from the Amazon increased from US$ 381 million in 1998 to US$ 1 billion in 2006, mainly due to the increase in the participation of finished wood products – such as furniture, flooring or other value added wood parts – in the Amazon’s wood exports (Figure 2-3).

Structural Problems Related to Logging in the Brazilian Amazon

Unfortunately, a significant share of Amazonian timber production comes from illegal sources. The poor adoption of sound forest management practices by timber companies (Silva, 1997; Sabogal et al., 2006), and the easy access to public lands, stimulate a migratory and extensive pattern in the logging industry and along with the continuous conversion of exploited forests to low productivity agricultural land. Timber companies continue to move to new forest frontiers while old ones are depleted by logging and forest fires (Nepstad et al., 1999; Asner et al., 2005). Several factors are associated with these problems. Human resources to control and monitor logging and to train forest workers to apply best practices are scarce. Moreover, while public lands are abundant, forest regulations and inefficient enforcement systems encourage illegal logging.

The Boom-Bust Economic Pattern

There is a predominant pattern early on with respect to development of rural local economies dependent on selective logging. Often there is exponential growth in the generation of revenues and jobs locally, as a result of harvesting of valuable timber and the establishment of sawmills (Schneider et al., 2000). Due to unsustainable logging practices, after a couple of decades forests become impoverished and are more susceptible to fires (Nepstad et al., 1999). Forest conversion to agricultural commodities such as cattle ranching and soybean production is often the next step for these lands.

However, the climatic conditions in 45% of the Amazon (~ 225 million hectares) are not appropriate for establishing large scale agriculture (Schneider et al., 2000). Without huge investments in technology, such as the development of new agricultural varieties more adapted to the local climatic conditions and technical assistance in these regions, the social and economic negative impacts of the local forest resources exhaustion are significant, provoking unemployment and an intensification of poverty. The local logging sector eventually collapses or migrates to new regions due to the lack of raw material.

Land Tenure

At least $^1/_3$ of the Brazilian Amazon (~ 160 million hectares) is represented by unsettled lands, designated terras devolutas, that are neither completely inventoried nor demarcated by the government (IBGSE, 1996; Lentini et al., 2004). These lands have a large potential for timber and NTFP production. A study conducted by Veríssimo et al. (2000) estimated that there were 114 million hectares of forests (23% of the Brazilian Amazon) with potential to create production forests in that year. However, forest resources on these lands, frequently occupied by communities, ranchers or loggers, are jeopardized by illegal logging and other unregulated activities (Barreto et al. 2006). At the same time, current Brazilian regulations create perverse incentives for illegal activities on public lands because they forbid the licensing of forest management operations without definitive land use rights. Without interventions, public lands will continue to be depleted by illegal activities and to be converted to extensive low productivity land uses, such as cattle ranching.

Illegal Logging

At least 40% of the Amazonian roundwood production was harvested illegally in recent years (Lentini et al., 2004, 2005; IBAMA, unpublished). Less than 5% of the roundwood harvested in the Brazilian Amazon follows good directives for forest management and only 3% or less of this production comes from certified operations (Ilana Gorayeb, personal communication, September 1st, 2006). The reasons for illegal logging include factors on the demand side, such as the low interest in payment for sound environmental practices. On the supply side, as discussed earlier, the large availability of non-monitored public lands is a disincentive for the adoption of good forest practices.

At the same time, there are several deficiencies in law enforcement and monitoring of illegal logging. First, enforcement agencies are fragile and inefficient, allowing corruption of public agents. There is also a lack of resources to adopt modern technology systems in the monitoring of logging, such as remote sensing techniques. Third, loggers typically argue that regulations to license forest management plans are excessive (Sabogal et al., 2006). Finally, there is a low probability that loggers fined for irregular practices will actually pay their environmental debts. A 2003 case study in State of Pará showed that only 2% of the legal proceedings related to environmental crimes were carried out until their conclusion (Brito and Barreto, 2005).

What is Needed to Address these Problems?

Brazilian society has recently taken several measures to reduce illegal logging. Hundreds of forest management plans were cancelled by the Federal Environmental Agency IBAMA in 2003-4 in an attempt to halt illegal logging and decrease deforestation rates in the Brazilian Amazon. In 2005, several governmental organizations conducted three large scale investigations into illegal behavior and corruption in the forest sector. Highly corruptible systems, such as the old system for authorizing roundwood transportation, which was based on paper documents, are gradually being replaced by electronic licensing systems. Specific regulations for forest management, often complicated enough to prevent the adoption of reduced impact logging (RIL), were simplified, aiming to decrease transaction costs for managed timber. Finally, electronic systems monitoring deforestation in the Brazilian Amazon are being improved to generate reports more frequently, such as the DETER (Real-Time Detection System), using sensors such as the MODIS (Moderate Resolution Imaging Spectroradiometer) and the WFI (Wide Field Imager) (INPE, 2007).

A second set of measures deals with problems related to land tenure. Federal and State governments have been pursuing regional planning and land rights regularization. In 2006, a new law was enacted to provide legal instruments to control and manage public lands in the Brazilian Amazon, including forest concessions. Concessions could help with land tenure problems by providing larger geographic and economic stability for timber companies, stabilizing the logging frontiers. They could also decrease conflicts between loggers and traditional communities inhabiting public lands, and decrease deforestation and the availability of illegal timber in public forests. Thus, concessions might deliberately stimulate the adoption of sound forest management practices and forest certification, since the main challenge to the adoption of these mechanisms, the chaotic land tenure, will be mitigated (Schneider et al., 2000; Veríssimo et al., 2000, Veríssimo et al., 2002a; Amaral and Amaral Neto, 2005).

The Management of Public Forests Law

The Brazilian federal law 11,284/2006 was enacted in March 2006, generated from an intense debate between several sectors within the society during the last decade. The new law creates rules to manage public forests, including national and state forests already created and other public lands still not inventoried by the government. It also creates a Federal Forestry Fund (FNDF) to foment forest based activities in Brazil, and the Brazilian Forest Service (SFB), a federal agency focused on controlling the fund and supervising forest concession contracts. According to the Law, public forests can be destined for three uses: creation of conservation units, as national and state forests; allocated as forest concessions; and for the direct use of traditional communities dwelling in such areas.

The law is gradually being implemented. The federal government started a decentralization process in which licensing processes of forest management plans and deforestation will be transferred to state agencies. Also, SFB staff is being formed. Finally, some state governments are also creating new state forests. For example, the State of Pará, the most important timber producer in the Amazon, recently created three state forests, totaling an area of 7.8 million hectares.

Forest Concessions in Brazil. The Brazilian Ministry of the Environment estimates that in the first 10 years after the implementation of the law, the forest area under concessions could reach 13 million hectares[1], generating governmental revenues of US$ 80 million and a total economic impact of US$ 820 million. The Ministry estimates that 140,000 new jobs would be directly and indirectly created through concessions (MMA, 2005). Forests designated for concessions will be divided into different plot sizes to guarantee access to small (< 10,000 hectares), medium (10,000 – 40,000 hectares), and large producers (40,000 – 200,000 hectares) (MMA, 2005).

Criteria to be considered in the concession auctions will include not only best prices, but also lower predicted environmental impacts, higher direct social benefits, higher economic efficiency and higher aggregation of value in production. The minimum prices in the concession auctions will be established by the SFB and by the Commission for Management of Public Forests (CGFP), an independent consulting body formed to help the government in decisions related to the management of public forests.

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[1] On July 9, 2007, the SFB concluded the first public forest inventory, including indigenous lands, conservation units, human settlements and other public forests. This inventory represents a starting point for land use planning in public lands, allocation of these areas for concessions, and elimination of illegal activities. The inventory totals 194 million hectares, of which 92% are located in the Brazilian Amazon (SBS, 2007).

The length of the contracts will vary between one forest cycle, typically 35 years according to forest management regulations, and 40 years. Concession contracts can be cancelled for several reasons, including desistence and devolution of the contract by the company, bankruptcy, and non-adherence to the forest management plan. Beyond agencies' monitoring measures, independent audits will be carried out in intervals no greater than three years. Revenues generated from concessions in public forests will be divided among state government (30%), counties (40%) and FNDF (40%). In conservation units, such as national and state forests, IBAMA will also have a share of the revenues (Figure 2-4).

Each public forest will be required to have an advisory committee and a specific management plan prior to the establishment of concessions and other land uses. The goal of this management plan is to establish directives for zoning potential land uses, meeting societal demands in relation to the public forest use. In the next section, a brief literature review on spatial modeling in natural resources management will be presented, contextualizing the research question and the objectives of this study, presented in the first chapter.

Literature Review on Spatial Modeling

Under the directives of the new forest law, society has to make decisions in relation to the best use of the public forests to accommodate multiple objectives. These objectives may be conflicting, such that there are tradeoffs among different land-uses. From the public planner perspective, this also implies, in situations in which a "win-win" outcome cannot be reached, that the sought solution needs to express societal values about efficiency and distributional equity (Loomis, 2002).

In the literature, the foundation of this problem is related to determining an appropriate allocation of land among competing uses. Economists have explored this problem, using a social planner's perspective, by modeling land use alternatives that are able to present acceptable tradeoffs among competing demands (Rothley, 1999). In forestry and natural resource management literature, two main types of problems were investigated using land use modeling: (1) the reserve site selection problem, which aims to conserve the maximum number of species or biological features with a minimum cost or minimum number of reserves; and (2) harvest scheduling problems, which are concerned with the optimization of production forests to achieve higher efficiency in the harvest schedule, minimizing costs related to logging or dealing with ecological constraints. These two main streams of literature will be briefly presented bellow.

Problems concerned with the reserve site selection issue started to be formulated in the earlier 1980's, originated in research fields such as conservation biology, operations research, and regional science (Church et al., 1996; Costello and Polasky, 2004). Two main types of sub-problems are the set coverage problem, which deals with how to have a given number of covered species with a minimum cost or number of reserves; and the maximal coverage problem, in which the objective is to maximize the number of conserved species for a fixed budget (Church et al., 1996; Ando et al., 1998; Onal and Briers, 2002). Latter work in this area used land prices and other economic information, such as timber stumpage values or net present value for productive activities, to make such models more realistic in choosing areas to create reserves (Ando et al., 1998; Polasky et al., 2001; Polasky et al., 2005).

Recent literature in reserve site selection problems mostly attempts to find solutions through mathematical programming, since these techniques can guarantee an efficient solution[2] (Rothley, 1999). Such problems are also recognized as intrinsically integer programming (IP) problems, since the several different formulations reported in the literature typically creates a

[2] In economics, the term efficiency refers to the generation of an outcome with a minimum waste or minimum cost. In this way, an efficient solution is achieved when a given method generates the solution associated with the least cost or the highest possible total benefit.

binary variable expressing whether a given area will be assigned for a network of reserves. Other possible investigated approaches include goal programming (Onal and Briers, 2002) and heuristic techniques. The latter has been reported in this literature as an alternative for computational difficulties generated by large IP problems normally solved using the branch-and-bound algorithm, the standard algorithm to solve IP problems. The size of the branch-and-bound tree will increase and be exponentially more difficult to solve as the number of binary variables increases. The branch-and-bound algorithm is not often capable of solving these large problems. Therefore, other heuristic approaches have been developed (Onal and Briers, 2002).

As mentioned earlier, a second common type of literature in natural resource management and land use modeling is represented by harvest scheduling and forest tactical planning problems. Such problems are mainly concerned with optimizing production forest use, maximizing their economic returns or minimizing costs related to logging. Road construction planning is an issue that can be addressed using these approaches (Murray, 1998). In this way, some of the past work in this area (e.g., Karlsson et al., 2004) has dealt with the classical timber supply problem. Such models are used in long-run planning of forest operations in which the best decisions regarding the use of equipment, harvesting of timber resources, processing capacity in the mill, allocation of harvest teams, transportation, and storage, among several other factors, can be assessed jointly. Most of these problems can be solved through linear programming techniques using the simplex algorithm (Murray, 1999). Improvements in tools such as Geographical Information Systems and optimization software allowed the design of much more complex models in forestry dealing with other possible spatial constraints, such as avoiding adjacency among harvested stands to benefit native species in logged forests (Carter et al., 1997; Murray, 1999; McDill and Braze, 2000).

Also, as discussed for the reserve site selection problems, those more complex problems in forestry required more sophisticated formulations such as IP programming. Integer variables allow models to assign for a given stand a specific management regime or to choose among several options to locate roads (Murray, 1998). However, as discussed before, IP formulations can be computationally challenging, requiring perhaps several heuristic algorithms to be used to address such problems, as can be illustrated by Clark et al. (2000), Richards and Gunn (2000), Bettinger et al. (2002), Boyland et al. (2004), and Batten and Zhu (2005).

Spatial modeling optimization in forestry became so interesting for the field of operation research that in 2000 an entire issue of Forest Science [46 (2)] was dedicated to such problems. In this issue's introductory article, Murray and Snyder (2000), highlighted five main areas for continuing research in spatial modeling optimization in forestry: (i) reserve site selection problems; (ii) adjacency concerns in harvest scheduling; (iii) road access network in harvest scheduling; (iv) hierarchical forest management planning processes; and (v) integration of production and conservation considerations. The latter point is the main issue of this work and will be better discussed bellow.

Some recent literature in spatial modeling in natural resource management has focused on the implicit tradeoffs between conservation and commodity production. The rationale is to determine through modeling and simulations the production possibility frontier (PPF) between these goals. Such PPF curves show, at one extreme, the maximum economic value that a given area or landscape can generate without any production of the non-market goal and, in the other extreme, the maximum generation of the ecological attribute in the absence of economic activities. Each point between these two extremes in the PPF is an efficient point, in the sense that it is impossible to increase the production of one good without decreasing the production of the other. There is a growing quantity of studies in the literature estimating the PPF or assessing marginal costs for the relationship between market and non-market goals. In forestry, economic goals often have being measured through stumpage values or the societal welfare generated through logging.

A non-exhaustive list of studies in the literature on this issue includes Calkin et al. (2002), in which non-market goals were represented by wildlife persistence in natural areas; Hurme et al. (2007), evaluating habitats for the Siberian flying squirrel (*Pteromys volans*) in Finland; Montgomery et al. (1994), estimating a marginal cost curve associated with the survival likelihood of the northern spotted owl (*Strix occidentalis caurina*); Nalle et al. (2004), estimating the PPF between economic surpluses from timber management and porcupine and wild owl populations; and Rohweder et al. (2000), investigating the PPF between silvicultural regimes and habitats for several wildlife species. Using the land value under economic uses, some studies also generated opportunity cost maps for conservation, such as Naidoo and Adamowicz (2006), for the Mbaracayu reserve in Paraguay; and Chomitz et al. (2005), for a region in southern Bahia, Brazil.

Rarely has this previous work in spatial modeling in natural resource management taken into account multiple objectives in relation to forest use, often assessing a dichotomist choice for land use – productive and conserved forest units, or commodity and non-commodity use. Also, this literature rarely investigated situations related to zoning of conservation units, with the exception of Sabatini et al. (2007), in which the authors evaluated effective zoning designs in conservation units to achieve biological protection goals. As far as I have been able to ascertain, no published study assessed the issues described in this section for Amazonian forests. This study seeks to fill part of this gap.

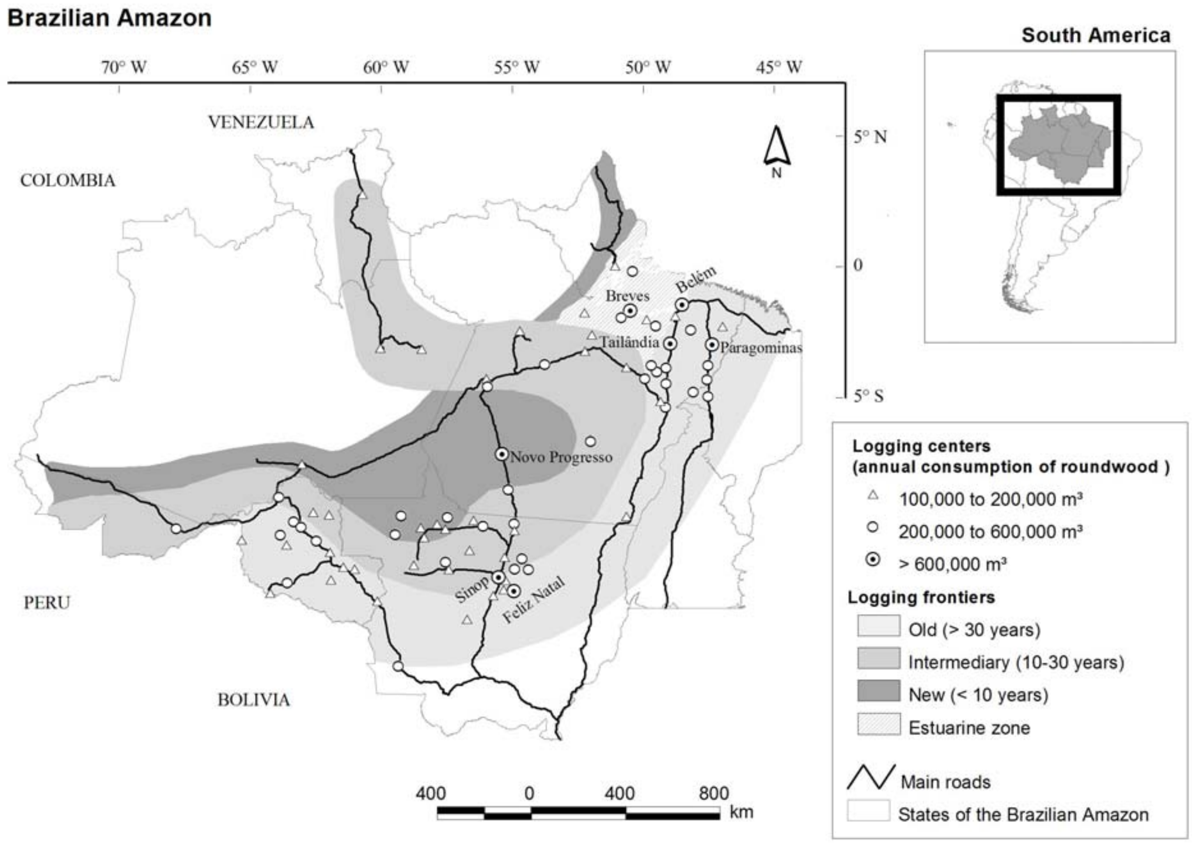

Figure 2-1. Logging centers and logging frontiers in the Brazilian Amazon, 2004. Reproduced with permission. Extracted from Lentini et al. (2005), figure 7, p. 38.

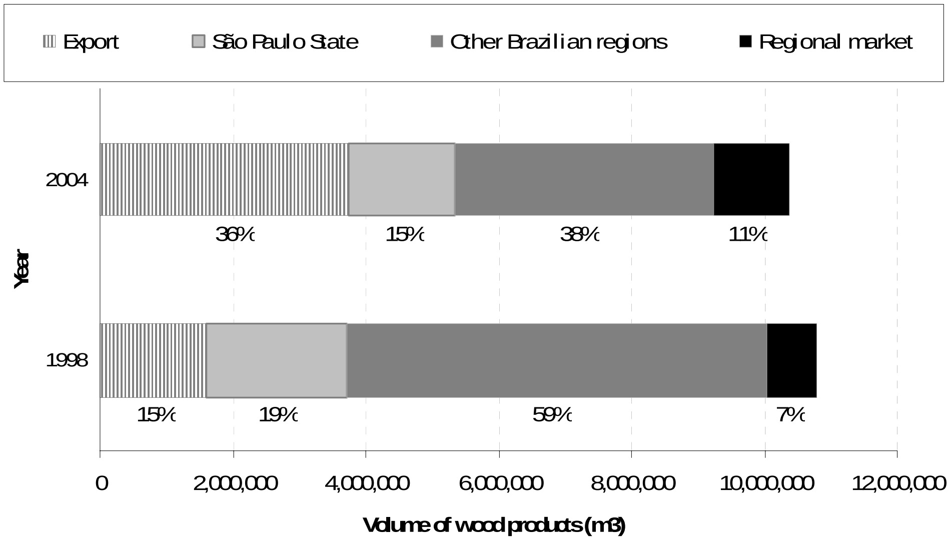

Figure 2-2. Markets for the wood production from the Brazilian Amazon in 1998 and 2004. (Source: Adapted from Lentini et al. 2004, 2005).

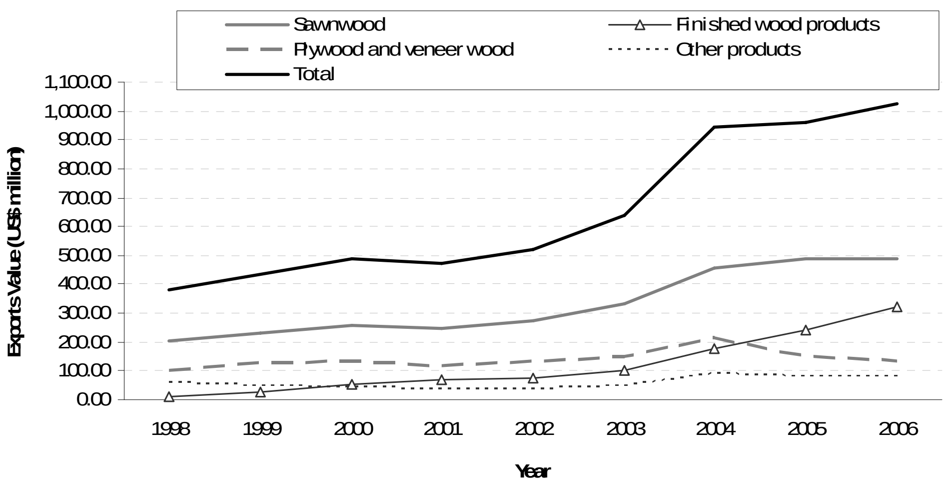

Figure 2-3. Evolution of the value of wood products exported from the Brazilian Amazon between 1998 and 2006. (Source: Brazilian Ministry of Development, Industry and International Commerce, http://aliceweb.mdic.gov.br, Last accessed March 10, 2007).

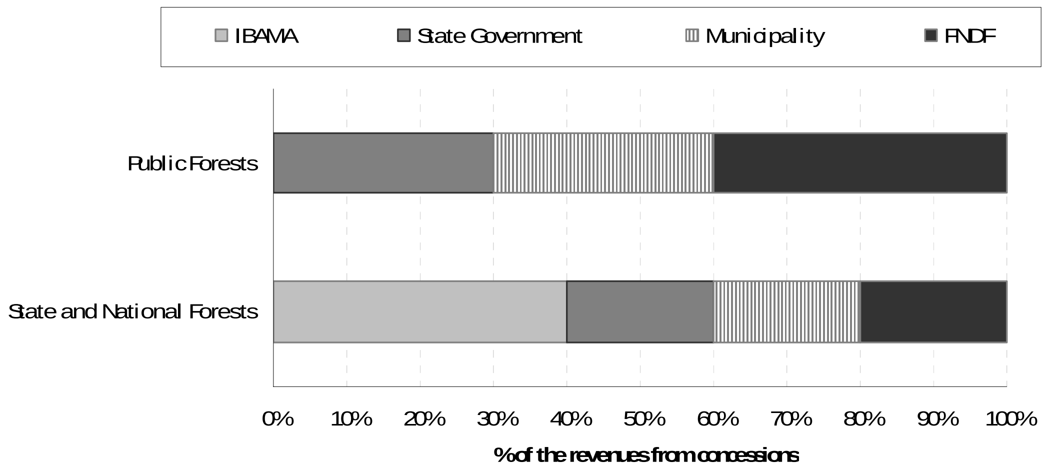

Figure 2-4. Destination of government revenues generated by logging concessions in conservation units, as national and state forests, and in public forests. (Source: Brazilian Law 11,284/2006).

CHAPTER 3
METHODS

My study developed an optimization model used to allocate public forest across multiple land uses. To parameterize this model, and to provide economic information to evaluate the tradeoffs between the production of market and non-market goods, some measure of the economic value of the land under commodity use was necessary. According to economic theory, under perfect market conditions, the value of the land should equal its NPV in its highest and best use (Polasky et al., 2001). In the case of state forests in the Brazilian Amazon, the NPV under timber logging is a reasonable estimate, since it is a societal preference to maintain forest cover in such areas, even though economic uses such as cattle ranching and soybean typically could achieve higher economic returns than logging (Schneider et al., 2000; Margulis, 2003; Arima et al., 2005).

This also implies that if areas within state forests are not being used for logging concessions, but are being reserved for community use or biological conservation, that the expected NPV under logging in such areas is a proxy for the opportunity cost of these uses. By definition, opportunity costs are the costs of foregone opportunities (Naidoo et al., 2006), and should be taken into account by social planners when they decide to reserve public lands for the production of non-market goods. Social planners may choose non-commodity uses if such choices reflect societal preferences, or if they believe that the market land value does not reflect the full social value of the land due to externalities or environmental amenities produced by these lands (Polasky et al., 2001).

Economic returns from logging were calculated using a model that predicts the spatial variation in net returns due to infra-structure conditions in each forest and the expected costs to harvest timber. A Geographic Information System (GIS) was built to combine spatially-explicit information to provide data for the optimization model. The third step was to generate a theoretical model to address the research problem and program this model in optimization software. This model was used in simulations to estimate the production possibility frontier (PPF) between logging and alternative land uses and investigate the opportunity costs for these alternative uses in a specific public forest.

The chosen public forest is embedded in the Calha Norte region, which will be presented in the next section. Calha Norte was used to estimate the net economic returns from logging and the roundwood demand from the logging centers in the surroundings of the public forest. Then, a case study represented by this public forest was used in the optimization model. These steps will be detailed in the following sections.

The Calha Norte Region and Faro State Forest

Calha Norte (expression that literally means “northern trench”) is located in the north of the Amazon, including portions of the states of Pará, Amazonas, Roraima and Amapá; delimited by a window with coordinates 62°13’12”W - 4°16’48”N (northwest corner) and 47°51’00”W - 5°19’12”S (southeast corner) (Figure 3-1). The region totals 132 million hectares, equivalent to approximately $^{1}/_{4}$ of the Brazilian Amazon. Calha Norte was chosen because it still has little evidence of human occupation and economic activities – in large part due to its topography. At least 50% of its area has high slopes and 80% are lands that are unsuitable for agriculture (IBGE, 2002). Moreover, the region is surrounded by important logging centers, including older centers with increasingly exhausted local stocks of raw material (Veríssimo et al., 2006).

Recently, this region has been the focus of several governmental efforts aimed at guaranteeing the conservation of its natural resources. In fact, the region was the focus of different initiatives of land use planning, starting in the 1980s, since the Brazilian military government believed that Calha Norte was a strategic region for the development of infra-structure projects and measures to protect frontier zones[1]. In March 2007, Calha Norte had 64 million hectares of protected areas – indigenous lands, conservation units, and military lands – equivalent to 40% of its total area. At least 30% of these protected areas are conservation units in which the direct use of the forests is legally allowed, including extractive reserves, or state and national forests. State and national forests total 20 million hectares in Calha Norte, including 7.4 million hectares of state forests created in December 2006 by the government of Pará State, such as Faro State Forest (FSF), the public forest used as a case study in the optimization model.

FSF (635,935.72 hectares) is surrounded by other protected areas on its northern (Trombetas-Mapuera indigenous land), eastern (FLONA Saracá-Taquera and Trombetas river biological reserve) and western (Nhamundá-Mapuera indigenous land) borders (Figure 3-1). FSF is covered by dense forests and presents little evidence of logging and human occupation in the extreme eastern and southern portions (IMAZON, 2006). Faro was chosen because it is the smallest public forest in Calha Norte region (0.4% of Calha Norte and 4.4% of the public forest area in the region), facilitating computational procedures during the modeling.

The Spatially-Explicit Net Returns to Logging Model

This model was constructed over past spatial-economic models that estimated the viability for logging across Amazon's forests (Stone, 1998b; Veríssimo et al., 1998; Veríssimo et al.,

[1] Calha Norte was the name of the first development plan for the region created after the re-establishment of the democratic civil government in Brazil, in 1985. The plan proposed the implementation of infra-structure and colonization projects, taking advantage of the large extents of land without economic activities, the incipient population dwelling in the region, and several frontier zones. Among these measures, the plan foresaw the construction of the Perimetral Norte highway, the development of the São Paradão hydroelectric plant, the increase of military installations in the area, and the establishment of colonization projects settling indigenous peoples in agricultural plots. The planning was carried out in secret by the military, pretentiously due to national security reasons (Hecht and Cockburn, 1990). Most of the measures foreseen by the plan were forgotten, and concerns about territorial security in frontier zones were re-assumed by the SIVAM project (Amazonian Vigilance System), created in 1990 and implemented in 1997.

2000; Lentini et al., unpublished). Such models created maps identifying, in a binary classification (e.g., viable and non-viable), which forested area were economically accessible for logging, based on wood prices and the variable costs associated with logging, such as harvesting, transportation and processing costs. This new model, however, estimates the value of the net returns from logging (per m^3 of roundwood basis), defined here as the profits for loggers plus stumpage prices.

The model uses an algorithm modified from a GIS routine in ArcView 3.2a called CostDistance. The algorithm calculates, for each forest cell, the highest economic return from the logging of 1 m^3 of harvested roundwood by finding a least cost path (e.g., the cheapest transportation option) between the mills and the harvested forests. As a result, the model calculates the maximum profit by assigning the logging of each cell on the map to the logging center able to harvest this cell with the largest difference between prices for processed wood and the variable costs. After the modeling, cells associated with negative profits are assigned as unviable for logging. The model evaluates, for each logging center, three different prices representing three timber value classes (high, medium and low value species). The model then generates a map in raster format (1 km^2 cell size) for each class.

Variable costs include harvesting, transportation[2], transaction and processing costs. The latter two are assumed to be fixed across the Brazilian Amazon (Table 3-3). Transaction costs are related to the access of legal logs (e.g., documents, elaboration of the forest management

[2] All variable costs are expressed on a cubic meter basis. Since harvesting and transportation costs are partially a function of fixed costs associated with logging operations, such as the construction of roads and infra-structure, they should vary depending on the logging intensity in a given harvested area. Logged forests with lower logging intensities should present relatively higher harvesting and transportation costs. Due to the lack of data to calculate these variations in harvesting and transportation costs, however, in this study, I assumed such costs to be uniform in stands with different logging intensities.

plans, and licensing permits). Processing costs considered are average costs for medium and large size sawmills equipped with one band-saw, the most common type of timber mill in the Amazon (Stone, 1997; Lentini et al., 2005). The average efficiency in converting raw material to sawn-wood used in the calculations is the typical efficiency of medium size sawmills in the Brazilian Amazon, equal to 39% (Lentini et al., 2005).

Modeling is executed by combining a map expressing transportation costs in each cell of the map (a friction coefficients map) with a map expressing the logging center location. The centers are used by the algorithm as the origin cells of the modeling, and are associated in this second map with a maximum bearable transportation cost for each center, equal to the difference between prices and harvesting, transaction, and processing costs.

In the first map, friction coefficients were generated using the average costs to transport roundwood in every access surface type (e.g., paved and dirty roads, rivers) (Table 3-2). Natural obstacles to roundwood transportation, such as high slopes, or hydroelectric dams, were arbitrarily assigned to have higher friction coefficients. Modeling also took into account the cost to transport timber through non-existent roads that would have to be built to make harvesting possible, using data estimated by Lentini et al. (unpublished). Beyond transportation costs, other spatial data used in the friction coefficients map were:

(i) Endogenous roads. Roads built by private agents were mapped by IMAZON in 2003 (Brandão and Souza, 2006; IMAZON, unpublished). In 2003, the study region contained 67,200 km of roads, from which only 28,000 km were official roads. The friction coefficient map was built over these pre-existing roads and the navigable rivers described below.

(ii) Navigable rivers for roundwood transportation, mapped by IMAZON using data provided by surveys in the timber industry until 1999 (IMAZON, unpublished).

(iii) Forest cover in the Brazilian Amazon (IBGE, 1997) provided information about potential areas for logging. This map was updated excluding the deforested areas until 2004 (INPE, 2006; compiled by IMAZON, unpublished).

Prices and costs (Table 3-2 and 3-3) were collected in 2004 through field surveys executed by IMAZON interviewing 680 timber mills' owners and managers, representing 27% of the Amazon's firms (Lentini et al., 2005). From this database, 519 interviews, embedded in Calha Norte, were used in this work. I assumed in this work average prices for sawn-wood at the mill gate for the domestic Brazilian market. As discussed in Chapter 2, it is the main consumer of Amazonian wood.

The Land Use Allocation Model

I will use the following notation. First, $i = (1, ..., n)$ represents the forest stands within a given public forest. Then, $j = (1, ..., m)$ denotes the logging centers surrounding the public forest. Following, $k = (1, ..., z)$ represents different timber value classes in the forest stands. Finally, $u = (1, ..., r)$ represents exclusive land use alternatives in each public forest stand.

One of the possible formulations for the objective function of this problem is formally shown in Equation 3-1. The objective is to maximize economic returns from logging within the public forest (denoted by π) by choosing the volumes that will be harvested per hectare (X_{ijk}) in each stand *i* from each timber value class *k* to each logging center *j* and choosing which stands to assign to each land use *u* (Y_{iu}).

Total returns from logging (π) will be equal to the sum of the product – across the stands *i*, logging centers *j* and timber classes *k* – of the harvested volumes per hectare (X_{ijk}), the profits per cubic meter (P_{ijk}), and the area of the stand (A_i). The equation is then multiplied by δ_{iu} , which expresses the potential of each stand for each alternative land use. In this first case of logging only, values are equal to “0” (no potential for logging) or “1” (with potential). Then, all terms are multiplied by the binary decision variable Y_{iu}, which is equal to “1” if a given stand is assigned for logging. A given stand would not be harvested, generating zero profits, if at least one of the two following conditions holds: (i) if the potential of the stand (δ_{iu}) for logging is equal to zero; (ii) if the decision variable Y_{iu} is equal to zero.

$$\max_{X_{ijk},Yiu} \pi = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{z} X_{ijk}\, P_{ijk}\, A_i\, \delta_{iu}\, Y_{iu} \qquad \text{and} \quad u = LOGGING \qquad (3\text{-}1)$$

The best stands for logging have a combination of large harvestable timber stocks (X_{ijk}) and high profits on a m^3 basis (P_{ijk}). This optimization problem contains important constraints. In the first set, the model deals with the typical supply problem for the logging industry. The first constraint (equation 3-2) constraints harvest to the available timber supply in each stand *i* for each have timber class *k* (denoted by S_{ik}).

$$\sum_{j=1}^{m} X_{ijk} \leq S_{ik} \quad \forall\, i \qquad (3\text{-}2)$$

A second constraint relates to the milling capacity in the logging centers. The total volume harvested through concessions must ultimately be equal or lower than the total milling capacity of surrounding logging centers for each center *j* (denoted as D_j).

$$\sum_{i=1}^{n}\sum_{k=1}^{z} (X_{ijk}\, A_i) \leq D_j \quad \forall\, j \qquad (3\text{-}3)$$

If the social planner decides to assign the entire public forest for logging and will only reserve unprofitable areas for logging to alternative uses, the decision variable Y_{iu} can be dropped from the objective function. This first scenario, named unconstrained logging, was simulated using the two constraints expressed above. Ultimately, compared to subsequent scenarios, it revealed the tradeoffs involved in considering different land uses within the public forest.

In the second scenario, logging and other alternative land uses are considered in the model. To incorporate the binary decision variable Y_{iu} in the model, an additional constraint was constructed to force, at most, only one land use alternative *u* for each stand *i*. There are two ways to construct this constraint. In equation 3-4A, it was imposed that the sum of Y_{iu} for each *i* has an upper bound equal to 1. In equation 3-4B, the constraint establishes that the sum of Y_{iu} across all stands (*i*) and land uses (*u*) has an upper bound equal to *n* (i.e., the total number of stands).

$$\sum_{u=1}^{r} Y_{iu} \leq 1 \,\forall i \tag{3-4 A}$$

$$\sum_{i=1}^{n} \sum_{u=1}^{r} Y_{iu} \leq n \tag{3-4 B}$$

In the second scenario, the social planner imposes a minimum cumulative number of stands or a minimum score for land use alternatives other than logging, expressed as L_u^*. For example, if the social planner decide that at least 30% of the state forest should be reserved for livelihood systems, L_u^* should be at least 0.3 *n* – considering that all potential areas for this land use have the same weight (i.e., uniform values for δ_{iu}), a condition that does not necessarily need to hold. This constraint, expressed in equation 3-5, establishes that the sum of the product of the decision variable Y_{iu} and the potential δ_{iu} has a lower bound equal to this minimum cumulative score.

$$\sum_{i=1}^{n} Y_{iu}\, \delta_{iu} \geq L_u^* \quad \forall\, u \neq LOGGING \tag{3-5}$$

Since the optimization model may assign a given land use for stands that are not connected to each other, creating a fragmented landscape, a final concern was to create a constraint able to impose a minimum connectivity level among stands for certain uses. An extensive literature exists which presents the potential benefits for biological conservation when reserves are created in larger landscape patches (e.g., Harrison and Bruna, 1999). Some ecologists, however, argue that harvesting executed with reduced-impact logging (RIL) techniques would not create fragmentation of surrounding reserves (F.E. Putz, personal communication, April 12th, 2007). In the same way, some connectivity for stands assigned for livelihood systems or logging would be arguably desirable to decrease overall costs for management of these units.

It is not the scope of this study to give a verdict about fragmentation created by adjacent logged and unlogged stands, but rather demonstrate that desired spatial configurations can be programmed. In reality, these issues can quickly gain a lot of complexity if we consider that desired spatial configurations depend not only on the number of connected stands but also the shapes of the reserves and the habitat requirements of different species.

Therefore, in a third simulation, the model incorporates a final constraint (equation 3-6) which imposes a minimum connectivity score for stands assigned to biodiversity conservation and livelihood systems. This constraint can be built establishing that *f* can also represent the stands $i = (1, ..., n)$. Then, a matrix of distance among stands ($dist_{if}$) of $n \, x \, n$ elements was created, in which every a_{if} element is equal to “1” if two stands are adjacent and “0” if they are not. The matrix diagonal, in which $i = f$, is set equal to 0. This method was adapted from adjacency constraints found in the literature known as NOAM (new ordinary adjacency matrix) constraints (McDill and Braze, 2000). If two stands assigned for the same land use *u* are adjacent, they add 1 to the total adjacency score for this land use type (noted as Adj^*). An important condition for this constraint work is that $f > i$, avoiding double-counting the adjacency among stands.

$$\sum_{i=1}^{n} Y_{iu}\, Y_{fu}\, dist_{if} \geq Adj^{*} \quad \forall u \tag{3-6}$$

Building the Optimization Model

This section describes the data and operational details of the optimization model. Four potential land uses were considered (notation *u* in the land allocation model): logging, mining, biodiversity conservation and livelihood systems. Manipulation of the spatially-explicit data presented in this section was done using ESRI ArcView 3.3 and ESRI ArcMap 9.1.

Timber supply in Faro. There is a lack of recent information about timber species distribution in the Brazilian Amazon. Detailed forest inventories were conducted in a few specific sites (for example, IMAZON and FFT sites in Paragominas, Pará, and EMBRAPA sites in the FLONA Tapajós, Santarém, Pará) or by timber companies for harvest planning purposes. For this reason, this study used data from RadamBrasil, a project with a wide geographical range that compiled sample forest inventories in all Amazonian States in the 1970s. It is still the most comprehensive survey of tree species available for the region.

Currently there is some literature focusing on estimating tree species distribution from RadamBrasil data using kriging techniques, as Steege et al. (2003). However, such work does not estimate the distribution of merchantable timber across the Brazilian Amazon and this may be considered an important constraint to large-scale planning of logging activities in Amazonian public forests. In this study, a map of timber species volume above 35 cm of diameter at breast height (DBH), provided by Sales & Souza Jr. (unpublished), was used, and was developed by applying a kriging technique to RadamBrasil data. This map expresses timber volume on a cubic meter per hectare basis for cells of 1 km wide.

To be useful in this work, it was necessary to estimate the proportion of this total volume that corresponds to merchantable timber species and, moreover, the proportion of the commercial volume that is formed by trees above 50 cm DBH – the minimum cutting diameter required by Brazilian regulations. Then, this information was adapted to estimate the proportion of high, medium, and low value species in the merchantable timber volume > 50 cm DBH. M. Schulze and A. Macpherson (personal communication, March 12th, 2007) provided some data about the proportion of merchantable volume (> 50 cm DBH) from total volume (> 35 cm DBH) for three research sites in the Amazon – Fazenda Agrosete (Paragominas, Pará), Fazenda Cauaxi (Paragominas, Pará) and FLONA Tapajós (Santarém, Pará). These data also took into account the proportion of defective trees during the harvesting, such as hollowed trees or trees with defective stems. Data from these sites show that, for each cubic meter of roundwood > 35 cm DBH in the forest, on average, 0.41 m^3 will be non-defective and merchantable > 50 cm DBH.

Leonardo Sobral (personal communication, March 14th, 2007), provided some data on the distribution of volume by timber species in the Fazenda Rio Capim, Paragominas, Pará State. Timber species were aggregated into economic classes using the classification proposed by Lentini et al. (2005). The authors created timber value classes based on the confidence intervals ($\alpha = 5\%$) of the average sawn-wood prices of indicator species in each economic value class. It was estimated that on average 6% of the exploitable volume is composed of high value species, 63% medium value, and 31% low value timber.

From all estimated available merchantable volume in Faro, the optimization model took into account a maximum available supply of 30 m^3 ha^{-1}, the maximum harvestable volume allowed by Brazilian regulations for management cycles of 35 years. It was assumed for the optimization model that timber stocks in each timber class are non-declining over subsequent harvest cycles. Implications of this assumption will be better discussed in the last chapter.

Milling capacity in the logging centers. Lentini et al. (2005) provided estimates of the total capacity to process roundwood in the logging centers located in proximity to Faro. A portion of this amount of roundwood is currently being supplied by private lands. Using data from IBAMA (unpublished) of roundwood volume legally harvested in private lands in Calha Norte in 2004, I estimated the milling capacity of roundwood from public lands in the region as the difference between the roundwood consumption in the logging centers and the amount authorized through deforestation and forest management plans on private lands. This amount is equal to 71% of the total regional milling capacity in 2004.

Potential areas for biodiversity conservation. In 1999, ISA, a Brazilian NGO, led a wide consultation with several stakeholder groups (government, NGOs and research institutions) to identify hotspots for biodiversity, which would be recommended to be protected as conservation units. The map generated in this consultation presents the hotspots in a classification of five different levels of importance for conservation based on a score given by specialists related to their biological diversity. This map (ISA et al., 1999) was used to identify areas within Faro with high potential for biodiversity conservation.

Potential areas for livelihood systems. Barreto et al. (2006) and IMAZON (unpublished) created a map of forests with evidence of human occupation in the Amazon. In this map, areas with evidence of human occupation encompassed mining permits, deforested areas until 2004, urban zones, official human settlements in rural areas, and areas located within a radius of 10 km from forest fires identified by satellites between 1996 and 2006. The latter areas are potentially being used by forest dwellers in their livelihood strategies. As discussed before, according to the

Management of Public Forests Law, occupied forests will be reserved for exclusive use of their dwellers. However, to investigate the compromises among competing land uses, I considered that social planners can choose the total proportion of the public forest that will be reserved for the use of traditional forest communities. Therefore, this map was used to identify, in Faro, the areas with potential for livelihood systems, defined in categories as older occupied areas – forest fires detected between 1996-2002 – and recently occupied areas – forest fires between 2003-6; and the areas with potential for mining.

Potential areas for logging. The map of potential for agriculture in Brazil (IBGE, 2002) was used to identify areas within Faro with steep or very steep slopes. High slopes would in theory increase the logging costs and, therefore, decrease the returns from logging. I assumed a decrease of 30% in the net returns in high slope forests. Then, areas with very high slopes (> 45°) were considered forbidden for logging, following directives from the Brazilian Forest Code (Lei 4,771/1965). Forest stands inside Faro with such topographic conditions were considered without potential for logging.

Operational modeling aspects. Faro State Forest (FSF) has a total area, calculated in GIS, of 637,500 hectares. Faro was converted into raster format formed by 255 stands (i.e., notation *i* in the land allocation model) of 5 km cell size (2,500 hectares each). Considering the requirements for forest management plans in the Brazilian Amazon[3], each stand was divided into 35 annual harvesting units of 71.4 hectares each (notation A_i in the land allocation model). As discussed in the Chapter 2, a cell of 2,500 hectares represents a small concession. Considering

[3] According to the Normative Instruction 05/2006 from IBAMA, a minimum cutting cycle of 35 years is required for harvested forests with a logging intensity of 30 $m^3 ha^{-1}$.

the same requirements for forest management plans, this area would be sufficient to sustain a small mill that consumes 2,100 m^3 $year^{-1}$ (in average terms less than 3 logs per day).

Optimization modeling and solvers. The software used in the analyses was IDE GAMS 22.4 (General Algebraic Modeling System). The unconstrained logging scenario, in which logging was the only land use alternative considered, is a linear programming (LP) problem, and was solved with CPLEX 10 solver. Simulations incorporating other land uses could not be solved through CPLEX, even though it is an efficient algorithm for mixed integer programming problems, which is the case when it was incorporated the binary variable Y_{iu}. Also, due to the non-linearities in the model's objective function, the problem was solved using an algorithm for mixed integer non-linear programming (MINLP) problems, named DICOPT (Discrete and Continuous Optimizer), developed by Viswanathan and Grossmann (1999). DICOPT was chosen because it was proven to be an improvement in robustness and time efficiency over several other solution methods for MINLP problems (Varvarezos et al., 1992).

Simulations Executed

Simulations were conducted with the optimization model to estimate the production possibility frontier (PPF) and investigate the tradeoffs among different land uses in FSF. The first set of simulations considered a fixed weight of each potential stand for alternative land uses (i.e., the variable δ_{iu} in the land allocation model) (Figure 3-3). Then, simulations were executed with an increasing number of stands assigned to livelihood systems and/or biodiversity conservation. Three general scenarios were considered: (i) the unconstrained logging (UL) scenario, as explained before, considering logging as the only land use within Faro; (ii) the multiple use scenario without connectivity concerns; and (iii) the multiple use scenario with connectivity concerns.

In the second set of simulations, the same set of scenarios were investigated considering differentiated weights for potential stands assigned to livelihood systems and biodiversity conservation. In the case of livelihood systems, I arbitrarily assigned for stands in which older forest fires were identified (1996-2002) a weight equal to $^2/_3$ of the weight assigned to stands of recent forest fire (2003-6). I also arbitrarily assigned an increasing gradient of weights (1-5) for potential stands for biodiversity conservation, from the western to eastern portions of FSF, since its eastern portion contains higher biodiversity according to the map from ISA et al. (1999) (Figure 3-3). It is not the scope of this study to discuss how accurate these scores are in representing the relative importance of stands but, rather, to demonstrate the model's capabilities in taking this information into account in the optimization.

In the third set of simulations, I assume that sawmills move to the urban centers located closest to Faro that currently have no sawmills, under the assumption that new mills would be constructed to take advantage of the legal timber supply from FSF[4]. The main impact that such a decision would provoke, considering that the cost of moving a firm can be considered as a fixed cost – and therefore should not influence in the firm's harvesting decision – is a decrease in the transportation cost, allowing logging to be more profitable inside Faro and a larger number of stands to be harvestable[5]. I included 14 cities in this simulation: Barreirinha, Boa Vista do

[4] As discussed in the second chapter, mills located in older frontiers are continuously migrating to newer frontiers, stimulated by the exhaustion of raw material sources in old logging centers. On the one hand, due to the abundance of roundwood in Calha Norte, it is expected that mills will start to migrate to the region in the coming years, even without the establishment of concessions. On the other hand, factors such as the little infra-structure available in the cities closer to FSF (i.e., electric energy, paved roads and specialized services), the difficult access to markets, and the low local availability of specialized labor might discourage the migration of firms for the next few years.

[5] It is also true that the costs to transport the final production to markets would become relatively more expensive. To mitigate this effect I used, in the net returns model for the cities closer to FSF, average prices equal to the prices in mills located in the closest logging centers to these localities.

Ramos, Itapiranga, Maués, Nhamundá, Parintins, Silves, São Sebastião do Uatum, Urucurituba and Urucará, in the State of Amazonas; and Faro, Juruti, Óbidos, and Terra Santa, Pará State.

Benefit-Cost Analyses (BCA) and Sensitivity Analyses

Recalling, the optimization model calculates in the objective function the annual profits for concessions. Harvested volume is calculated on a per-hectare basis, and the total annual harvestable area in each stand was set to 71.4 hectares. In the final set of analyses, annual profits from logging were used in a BCA to calculate the NPV from logging concessions (equation 3-7).

$$NPV = \pi\left(\frac{1-(1+r)^{-n}}{r}\right) - C_{aud}\left(\frac{1-(1+r)^{-n}}{(1+r)^{t}-1}\right) - C_{estab} \qquad (3\text{-}7)$$

Where π is the annual profits from logging calculated in the optimization model, and n represents the length of the concessions contracts – set to 40 years, which is the maximum length allowed by law. The interest rate, r, is equal to 10% year^{-1}, based on the long run interest rates of the Central Brazilian Bank in 2004 (BNDES, 2007).

The second term of the equation calculates the present value of the economic benefits from concessions, and the third term the present value of the audit costs, expressed by C_{aud}. Every three years (time interval represented by the notation t) the law requires that concessions must be audited by independent bodies. Due to the lack of suitable data, audit costs were assumed to be equivalent to current costs for certification audits, which are typically estimated between US$ 0.15 ha^{-1} year^{-1} and US$ 1.00 ha^{-1} year^{-1}, depending on the size of the management units (Mauricio Voivodic, personal communication, May 4th, 2007). In a baseline scenario, I used an estimate of US$ 3,000 stand^{-1} every 3 years (US$ 0.40 ha^{-1} year^{-1}). However, larger concession units may have lower audit costs, with positive impacts in the NPV.

The notation C_{estab} is the establishment costs for implementing forest concessions. The Federal Decree 6,063 (March 20th, 2007) establishes that such costs include forest inventories to set minimum prices, preliminary studies, granting licenses, conducting the competitive proposal and auction processes. Such establishment costs are case-specific and may be very different across countries and regions. However, sufficient information exists to estimate the establishment costs. According to Sabogal et al. (2006), inventory costs for timber production executed by private companies in the Brazilian Amazon typically cost US$ 13.0 - US$ 17.0 ha^{-1}. While larger state forests may have lower costs due to economies of scale, establishment costs will be within an interval of US$ 15.0 - US$ 40.0 ha^{-1}. In a baseline scenario, I applied US$ 20.0 ha^{-1}.

Sensitivity analyses were conducted to investigate the effect of the establishment and the audit costs in the NPV generated by forest concessions within FSF. As mentioned before, a baseline scenario considered establishment costs of US$ 20 ha^{-1} and audit costs of US$ 0.40 ha^{-1} $year^{-1}$. Three additional simulations were performed. In the first, the low cost scenario, such values were assumed to be equal, respectively, to US$ 10 ha^{-1} and US$ 0.20 ha^{-1} $year^{-1}$. In an intermediate scenario, establishment costs were set at US$ 30 ha^{-1} and audit costs at US$ 0.70 ha^{-1} $year^{-1}$. Finally, in the high cost scenario, such values were assumed to be, respectively, equal to US$ 40 ha^{-1} and US$ 1.00 ha^{-1} $year^{-1}$.

Considering the baseline scenario costs, two calculations of NPV were made considering a societal and a loggers' perspective[6]. In the latter, it was assumed that loggers can capture in concessions equivalent profits to logging in private lands, calculated by Veríssimo et al. (2002b)

[6] The private BCA appraises a given project under a firm's perspective, evaluating its effects on revenues and costs and, therefore, in the firm's profits. Wider implications of the project are investigated under the referent groups' perspective, in the social BCA (Campbell and Brown, 2003).

as varying between 10% - 26% over the prices for sawn-wood. In this study it was considered that loggers would capture 10% over the prices in the logging centers. The remaining profits are assumed to be captured by government through minimum prices in the auctions, volume harvested fees or profit fees[7]. Loggers also are assumed to reimburse the government for the establishment costs and pay the tri-annual audits. In both cases, the internal rates of return (IRR) were calculated.

The PPF Between Logging and Other Land Uses

The simulations and sensitivity analyses generated several NPVs according to an increasing number of stands or the cumulative score for land use alternatives other than logging. These values were used to estimate the PPF among land uses, such as logging and livelihood systems, or logging and biodiversity conservation. Then, using the establishment and audit costs of the baseline scenario, I tested the hypothesis that marginal opportunity costs (mOC) involved in these zoning decisions should be increasing when an increasing proportion of FSF is being assigned for land uses other than logging. Such increases in mOC are implicitly shown in the PPF generated to investigate tradeoffs between market and non-market goals in land use planning (e.g., Polasky et al., 2005).

[7] From a theoretical point of view, while private agents are exclusively concerned with costs and revenues that affect the firm's profits, from a social perspective the external costs provoked by a given project must be taken into account. The rationale for the fees and taxes imposed by the government is based on the idea that loggers, the group which will collect direct benefits from concessions, must compensate the rest of society by eventual external costs provoked by logging. This rationale is consistent with the concept of economic efficiency created by Kaldor and Hicks, where those who become better off under a given policy should compensate those who are worse off, leading to a Pareto optimal outcome.

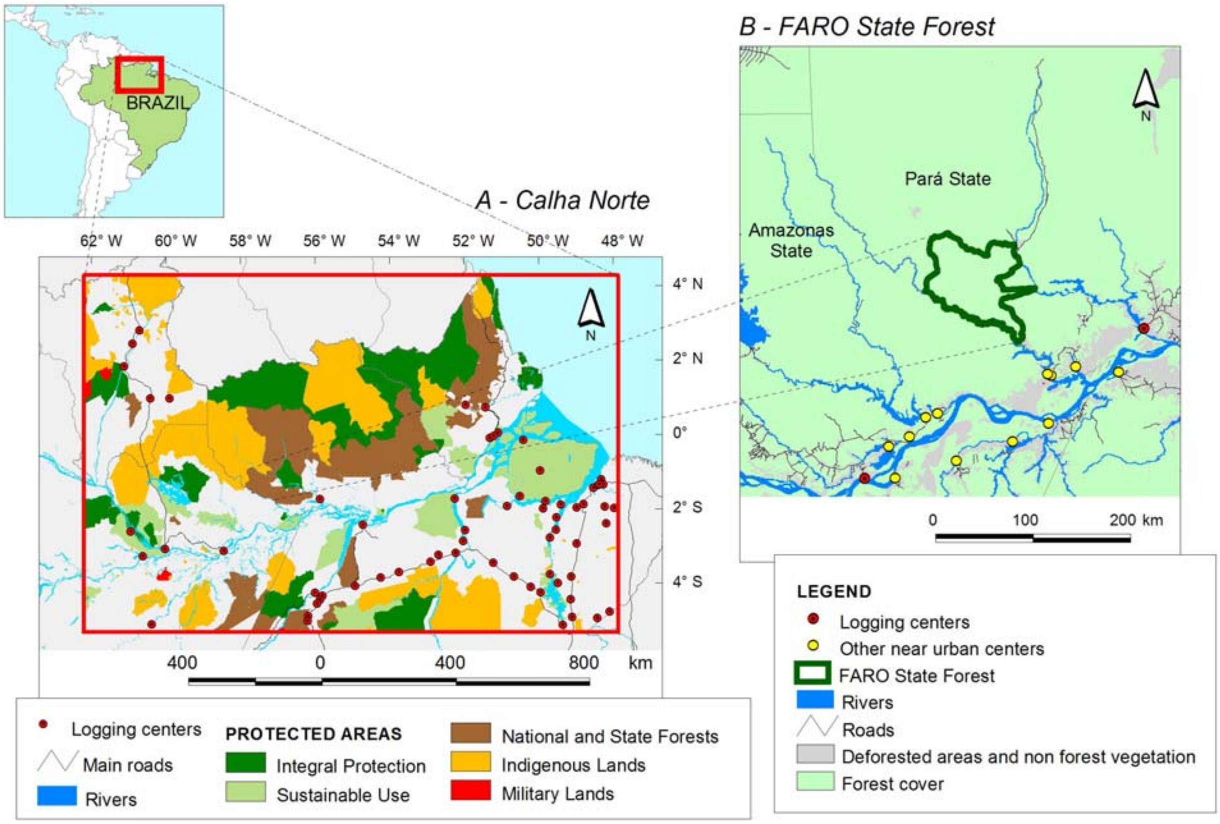

Figure 3-1. View of the Calha Norte region, northern Amazon. A) Map of Calha Norte highlighting the main roads, conservation units, and logging centers. B) Surroundings of the Faro State Forest, highlighting the closer urban centers to the state forest.

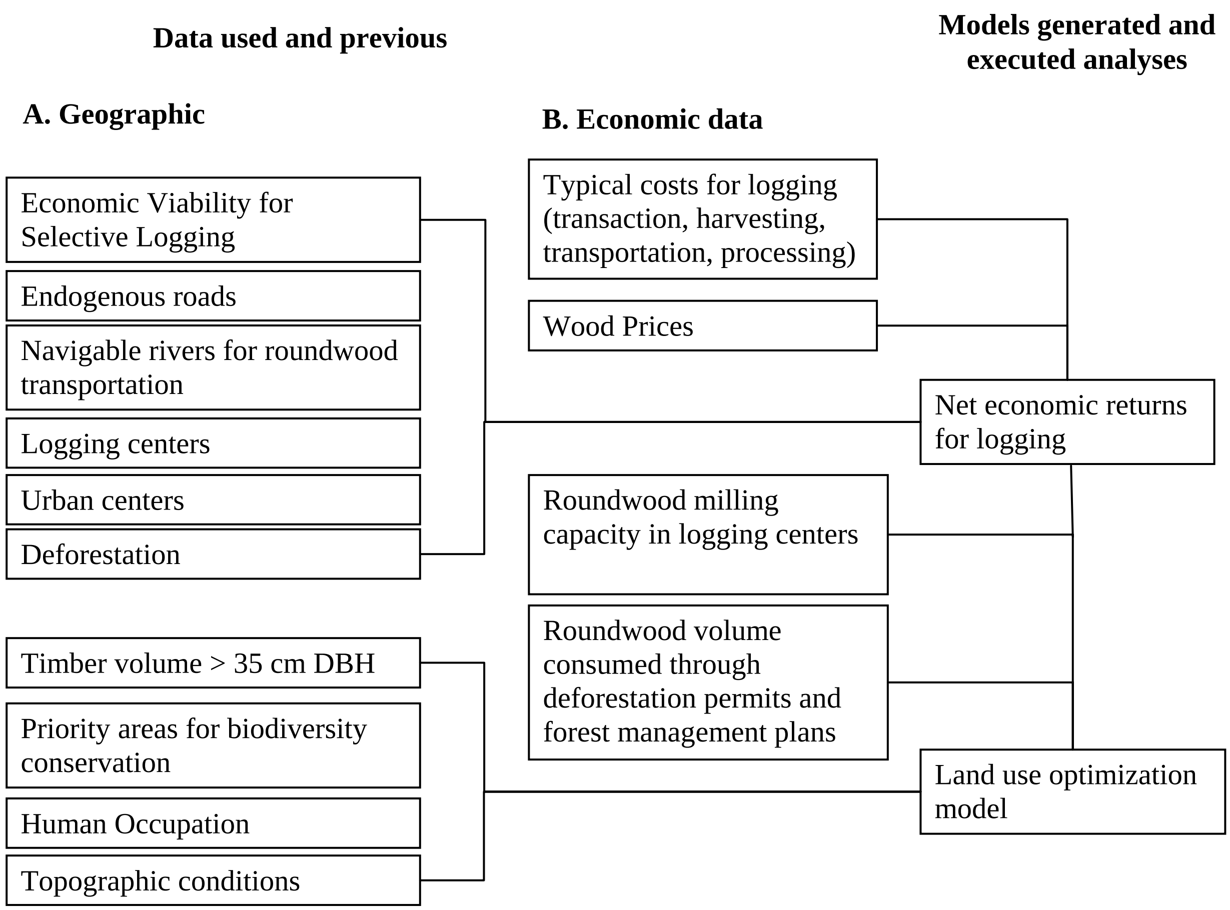

Figure 3-2. Spatially-explicit and economic data used to build the net economic returns and the land use optimization model.

Table 3-1. Sources and year of the analyses of the datasets used in the two models developed in this study.

Data description	Year of the Analyses	Source
Economic viability for selective logging	2004	Lentini et al. (unpublished)
Endogenous roads	2003	(Brandão and Souza, 2006), IMAZON (unpublished)
Navigable rivers for roundwood transportation	1999	IMAZON (unpublished)
Logging centers	1998, 2004	Lentini et al. (2004, 2005)
Urban centers	1991	IBGE (1991)
Deforestation	2004	INPE (2006), compiled by IMAZON (unpublished)
Timber volume > 35 cm DBH	1976	Sales & Souza Jr. (unpublished)
Priority areas for biological conservation	1999	ISA et al. (1999)
Human occupation	2003	Barreto et al. (2006), IMAZON (unpublished)
Topographic conditions	2002	IBGE (2002)
Variable costs in logging activity (harvesting, transaction, transportation and processing)	2004	Stone (1997), Veríssimo et al. (2000), Lentini et al. (2005), IMAZON (unpublished), and Lentini et al. (unpublished).
Sawn-wood prices	2004	Veríssimo et al. (2002), Lentini et al. (2005), and IMAZON (unpublished)
Roundwood production characteristics milling capacity in logging centers	2004	Lentini et al. (2005)
Roundwood volume consumed in the logging centers through deforestation permits and forest management plans	2004	IBAMA (unpublished)

Table 3-2. Costs for roundwood transportation and friction coefficients used in the model of net economic returns for logging.

Access type to forestlands	**Transportation Cost[1] (US$ m^{-3} km^{-1})**	**Friction Coefficient**
River (barges or rafts)	0.03 – 0.05	4
Paved roads	0.07 – 0.14	11
Graveled dirt roads (high quality)	0.15 – 0.18	17
Non-graveled dirt roads (poor quality)	0.21 – 0.24	23
Non-trafficable roads	0.60	60
Construction of new roads through non-forest areas	0.92	92
Construction of new roads through forestlands	1.49	149
Natural obstacles	-	3,000

[1] Source: Veríssimo et al. (2000), Lentini et al. (2005), IMAZON (unpublished), and Lentini et al. (unpublished); and estimates made using data from Veríssimo et al. (1995) and Stone (1997, 1998b).

Table 3-3. Sawn-wood prices and typical costs of the logging activity in the logging centers of the Calha Norte region, 2004[1].

Zone (# of interviews)	Sawn-wood prices (US\$/m^3) per timber value class (s.d.)			Costs per m^3 of sawn-wood (US\$) (s.d.)		
	High value species[2]	**Medium value species[3]**	**Low value species[4]**	**Harvesting[5]**	**Transaction[6]**	**Processing[7]**
Amazonas (129)	225.70 (266.3)	155.60 (179.2)	120.90 (130.0)	28.80 (20.3)	28.20 (22.2)	34.40 (16.5)
Central Para (94)	404.70 (202.2)	189.74 (190.5)	153.30 (184.5)	27.30 (17.52)		
Estuary (204)	342.50 (230.9)	122.98 (132.9)	98.90 (156.6)	23.20 (8.41)		
Western Para (92)	338.10 (285.2)	165.38 (167.3)	104.30 (116.7)	30.90 (18.9)		
Amazonia (680)	303.90 (273.1)	161.23 (175.4)	111.00 (114.1)	27.60 (18.7)		

[1] Source: data from IMAZON (unpublished) and Lentini et al. (2005). [2] High value timber is formed by species such as cedro (*Cedrela spp*.), freijó (*Cordia spp*.), jatobá (*Hymenaea courbaril*), itaúba (*Mezilaurus itauba*), ipê (*Tabebuia spp*.) and cerejeira (*Torresia acreana*). High value species were classified by Lentini et al. (2005) as species which have an average sawn-wood price in the domestic market higher than US\$ 210 m^{-3}. [3] Medium value timbers encompass non-high value species used to produce sawn-wood for civil construction parts, flooring, decking, etc. These species were classified by Lentini et al. (2005) as species which have an average sawn-wood price in the domestic market higher than US\$ 130 m^{-3} and lower than US\$ 210 m^{-3}. [4] Low value timbers encompass species used to produce plywood or low value sawn-wood in regional Amazonian markets. Such timber was classified by Lentini et al. (2005) as species which have an average processed price in the domestic market lower than US\$ 130.0 m^{-3}. [5] Harvesting costs include all operations conducted to extract timber from the forest, as cutting and bucking of trees, and skidding operations until the log decks, as well as loading the logs on trucks. [6] Transaction costs include all related costs to the documentation of the roundwood, including Forest Management Plans, environmental licenses and documents to transport roundwood, etc. [7] Processing costs include operations carried out in the firms to transform roundwood to sawn-wood to be sold in the domestic Brazilian market in medium to large size sawmills in the Brazilian Amazon, which present an average industrial efficiency in converting roundwood to sawn-wood equal to 39% (Lentini et al., 2005).

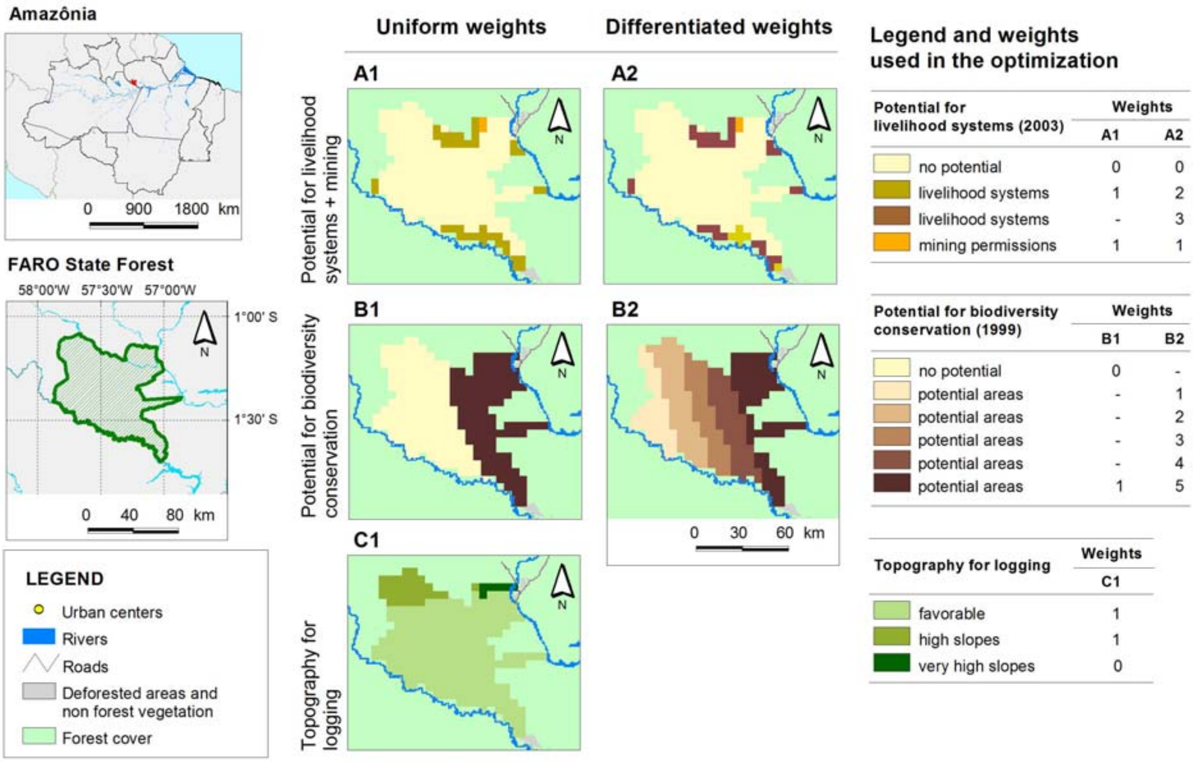

Figure 3-3. Potential for land use alternatives in Faro State Forest and weights used in the simulations. A1) Location of areas with potential for livelihood systems or mining. A2) Differentiated weights for livelihood systems in the second set of simulations (see text). B1) Location of areas with high importance for biodiversity conservation. B2) Gradient of different weights for biodiversity conservation used in the second set of simulations (see text). C1) Topographic conditions within Faro State Forest. Data respectively from Barreto et al. (2006), ISA et al. (1999) and IBGE (2002).

CHAPTER 4
RESULTS

This chapter is organized as follows. First, I will present the results of the net returns from logging model in the Calha Norte region and in Faro State Forest (FSF). Then, using methods described in the previous chapter, I will present the estimated supply and the milling capacity for roundwood from Faro. Results from the optimization model will be presented next, focusing on the timber supply problem for Faro. Results from the simulations will then be presented, showing different landscape mosaic alternatives in Faro as a consequence of the intended number of stands or the cumulative score pursued for livelihood systems or biodiversity conservation. The variation in the annual profits from logging due to such choices will then be reported. The last section will present the production possibility frontier (PPF) for logging and other alternative land uses and investigate the tradeoffs between the NPV from logging and the provision of alternative land uses within Faro.

Estimated Net Returns from Logging in Calha Norte

Figure 4-1 shows how net returns from logging vary in the Calha Norte region, including FSF. Table 4-1 shows the expected net returns from logging in Calha Norte forests for each timber value class. Considering only the forested lands in Calha Norte (80% of the region), approximately 20% of these forestlands are unviable for logging of high value species (i.e., negative returns from logging). One quarter of these forests have economic returns between US$ 70 and US$ 100 m^{-3} for high value species. Almost 10% have returns higher than US$ 100 m^{-3}. The more profitable forestlands are actually located in the center of Calha Norte, within proximity of the Transamazon highway and close to important logging centers such as Altamira, Uruará and Pacajá. Some logging centers can access roundwood of high value species at distances greater than 300 km.

On the other hand, the harvesting of medium value species is viable in only 42% of the region, while the maximum harvestable distances from these logging centers decreases to a maximum of 100 km. Only 11% of the region indicates net returns from logging of medium value species above US\$ 40 m^{-3}. Finally, only 16% of the forestlands in the region are viable for logging low value species, since the maximum harvestable distance from the logging centers decreases to less than 50 km.

Net returns within FSF. The most profitable stands for logging within Faro are located adjacent to its southern and eastern borders, in the proximities of rivers and the few existing roads. All stands within Faro are viable for logging of high value species, and almost 30% of its stands have net returns greater than US\$ 70 m^{-3} for high value species (Table 4-2). However, only 22% of Faro's stands are viable for logging medium value species and no stands are viable for the harvesting of low value species. If the industry moves to cities closer to FSF, 32% of its stands become feasible for logging of medium value species and 7% for low value species (Table 4-2).

Estimated Timber Supply within Faro State Forest

According to the map of timber species volume provided by Sales & Souza Jr. (unpublished), the stands within FSF present, on average, 119 m^3 of roundwood ha^{-1} (total stock of ~ 3,000 m^3 $stand^{-1}$). As expected, the variation among stands is very small (standard deviation of 4.0), since the original map was generated in a coarse scale for the entire Amazon. Most stands with higher timber volumes (> 120 m^3 ha^{-1}) are located in the central-southern portion of FSF. As discussed in the last chapter, I estimated from this map the total merchantable timber inventory volume (> 50 cm DBH), which is on average, 49.1 m^3 ha^{-1}. From this volume, 2.9 m^3 is assumed to be available from high value species, 18.1 m^3 from medium value species, and 8.9 m^3 from low value species (Table 4-3).

Milling Capacity for Roundwood from Public Forests in Calha Norte

The total roundwood consumption from the 17 logging centers within the region was equal to 1.6 million m^3 in 2004 – equivalent to 7% of the total demand in the Brazilian Amazon (Lentini *et al*., 2005). Of this amount, at least 700,000 m^3 was supplied from areas having forest management plans (FMP) and deforestation permits granted by IBAMA. Therefore, around 0.9 million m^3 was supplied by other sources (Table 4-4), which could include legal sources (e.g., FMP and legal deforestation) located outside the region, or illegal harvesting and illegal deforestation within the region. As discussed in the last chapter, assuming that the total milling capacity will remain constant in the region after the establishment of concessions, the proportion of the consumption currently supplied by other sources is assumed to be the milling capacity of roundwood from public lands.

The Timber Supply Problem

The unconstrained logging (UL) scenario. Without considering any other alternative land uses within FSF, 250 stands – 98% of Faro – would be logged by the logging centers (Figure 4-2). The few unlogged stands are located at the northeastern portion of Faro, in which the existence of high slopes forbids harvesting activities. Forty four stands (17% of Faro) would have more than 70% of the volume logged from both medium and high value species. In the remaining area, only high value species would be logged. Total harvested volume would be equal to approximately 109,000 m^3 – equivalent to 12% of the total milling capacity of timber from public forests in Calha Norte. Logging companies would generate annual profits from logging of US$ 3.2 million (see the first bar in the Figures 4-3A and C). Logging would be carried out only by companies located in 3 logging centers: Oriximiná, Santarém and Uruará (Figure 4-4C).

As expected, Faro would become relatively more important for logging in the region if the industry moves to closer cities. In this scenario, the same 250 stands would be logged, but 63 stands (25% of Faro) would have all the high and medium value species logged, and 18 stands (7% of Faro) would have all of the available timber harvested (Figure 4-2). Total volume harvested within Faro would rise to 168,519 m^3, supplying 18% of the total milling capacity (first bar of the Figures 4-3BD and 4-4D). Annual profits from logging would increase to US$ 4 million. From all the closer cities considered in this scenario, harvesting would be performed mainly by three urban centers: Faro, Nhamundá and Óbidos.

Interaction of logging and other land uses. Obviously, as the number of stands assigned for alternative land uses such as mining, biodiversity conservation and livelihood systems is increased, there is a decrease in the number of stands logged, timber volume harvested, and profits from logging. Figure 4-3 shows what happens to the number of stands assigned for logging and harvested volume when logging is performed by firms located in the current logging centers (Figure 4-3A and C) and in closer cities (Figure 4-3B and D). It is interesting to note that, in the case of the logging centers, the proportion of stands in which high and medium value species are harvested is always lower than 17% of the stands; in the second case (closer cities), always above 20% of the stands. In the case where 48% of stands is under other land uses, only 133 stands are logged, and only 44% of the original available volume is harvested by the logging centers and 48% by closer cities. As will be discussed later, in this situation, annual profits would decrease to 46% and 47% of the UL scenario, respectively.

Roundwood supply within FSF. In the UL scenario, with logging centers performing the harvests, only 20% of Faro's total merchantable timber inventory would be logged. This proportion decreases to 9% of the merchantable timber inventory when 122 stands are assigned to other land uses (48% of stands in other land uses). However, it is important to note that the timber stocks within the state forest are not logged uniformly – 98% of the high value timber supply is logged in the UL scenario while only 17% of the medium value timber available is logged and 0% of the low value timber. Possible implications of such findings will be discussed in greater details the final chapter. Considering logging by closer cities, 31% of Faro's total merchantable timber inventory is harvested in the UL scenario, depleting 98% of the available timber inventory of high value species. However, logging performed by closer cities also resulted in a higher usage of medium value species (32% of the available inventory) and low value species (7% of the available inventory) (Figure 4-4A and B).

Regional roundwood milling capacity. As discussed before, in the UL scenario with logging centers performing the harvests, only 12% of the regional milling capacity can be satisfied by Faro. This proportion falls to 5% in the extreme opposite situation in which 122 stands are assigned to other uses (Figure 4-4C). Interestingly, the establishment of concessions within Faro would be very important for Oriximiná, a small timber processing center (~ 9,500 m^3 $year^{-1}$), which would be fully supplied by concessions in FSF. Other logging centers such as Santarém and Uruará would also be able to satisfy a large share of their capacity with roundwood from Faro. If the industry moves to closer cities, Faro could satisfy 18% of the total milling capacity if the companies concentrate in the cities of Faro, Nhamundá and Óbidos. In this situation, the city of Faro would be able to process between 75% and 93% of the roundwood harvested within FSF, depending on the number of stands assigned to other uses (Figure 4-4D).

Landscape Patterns Formed by the Optimization Model

Simulations shown in Figure 4-5 assumes each stand is weighted equally with respect to its contribution to the provision of an alternative land use (for stands with potential for providing the alternative land use). As such, the simulations performed gradually assigned an increasing number of stands for livelihood systems and biodiversity in the least cost manner. The model attempts to avoid stands for conversion that have the highest logging profits. For livelihood systems, this later task becomes quickly difficult, since a large part of the areas with potential for livelihood systems are located near rivers and Faro's borders, stands which also have naturally high logging profits. Stands for biodiversity conservation can only be assigned on the eastern side of FSF (i.e., stands with potential for biodiversity conservation according to the map from ISA et al., 1999), and in the final simulations they also occupy highly profitable stands for logging.

Figure 4-5 compares landscape patterns generated by the optimization model developed both with and without connectivity constraints, considering harvesting as being performed from the current logging centers. Without connectivity constraints, individual patches for livelihood systems and biodiversity conservation tend to be smaller, more so for livelihood systems, which also implies that a larger number of patches will be created for a given number of stands assigned for these alternative land uses. With respect to number of patches, for livelihood systems, there were on average 3.5 patches created versus 4.5 without the constraint, and for biodiversity conservation, 1.5 versus 2.3 patches. With respect to patch size, livelihood systems average size was 3.9 stands without the constraint versus 5.3 stands with it. For biodiversity conservation, average patch size was 29.4 and 32.5 stands, respectively. Surprisingly, a very small decrease in the objective function value (annual profits from logging) resulted from the constraint, varying from a 0.6% to 3.5%. Due to the assumed importance of landscape connectivity for planning purposes and due to the low decrease in the objective function generated by the constraint, the remaining results reported in this chapter include connectivity constraints.

Figure 4-6 presents landscape patterns within Faro under increasing cumulative scores for livelihood systems and biodiversity conservation. Stands are weighted differentially within each use. In the case of scores for livelihood systems, the model first avoids to use more profitable stands for logging, as well as the stands with lower potential for this land use. As the score constraint becomes larger, almost all potential stands are converted. The same logic is valid in the case of biodiversity, but there is more flexibility in the assignment of stands with priority given to converting stands on the eastern side of Faro to achieve a given score.

Annual Profits from Logging and Government Revenues

As discussed in the beginning of this chapter, without alternative land uses within Faro, the total annual profits generated by logging performed from the surrounding logging centers would be equal to US$ 3.2 million. Such profits would naturally decrease if the social planner decides to allow other land uses within FSF. Then, in the opposite extreme, profits would decrease to US$ 1.5 million if 48% of Faro's stands are converted to alternative land uses (assuming equal stand weights). A second question that could be raised by the social planner refers to how much of the logging profits could be taxed by the government through, for example, royalties, logging fees or profit taxes and still leave the loggers in a profitable position. As discussed in the methods, one assumption is to tax loggers only enough such that they still earn a normal profit (i.e., equivalent to profits earned by loggers on private lands).

Figure 4-7 shows the share of the profits for loggers and government under this assumption. Government would be able to extract around 31% to 38% of the annual profits from logging if it is being performed by firms located in the surrounding logging centers (Figure 4-7A). Given total annual profits of US$ 3.2 million in the UL scenario, US$ 2.3 million would be considered as normal profits for loggers and US$ 0.9 million would be paid to government (Figure 4-7A). Figure 4-7B shows the same share if harvesting is performed by firms that moved to cities closer to Faro. In this second scenario, government would be able to extract 31% to 32% of the total annual profits, which would be equivalent to US$ 1.2 million of the US$ 4 million generated if logging is the only land use considered within Faro.

Figures 4-7C and D show the annual profits from logging under increasing scores for livelihood systems and biodiversity conservation, respectively. Both consider harvesting has been performed from the surrounding logging centers. The government's share of the annual profits under increasing scores for livelihood varies between 28% and 29% and, under increasing scores for biodiversity conservation, between 26% and 29%.

The base case UL scenario was used to investigate the spatial behavior of the annual profits from logging within Faro (Figure 4-8). Considering logging performed by firms in the current logging centers, on average, each stand has an annual profit of US$ 12,619. This value increases to US$ 15,744 when the harvests are performed by firms located in cities closer to the state forest. In both scenarios, the most profitable stands are located in Faro's southern and eastern portions. The highest profit achieved by an individual stand, in the first case, was close to US$ 40,358, and in the second case, US$ 54,502.

Logging NPVs and IRRs under Increasing Conversion to Alternative Land Uses

Tables 4-5 and 4-6 show NPVs from a society and loggers' perspective under increasing areas assigned to alternative land uses, with harvesting performed by logging centers and closer cities. Again, in the UL scenario, annual profits are US$ 3.2 million. Assuming the baseline scenario for the establishment and audit costs (respectively US$ 20 ha^{-1} and tri-annual audits of US$ 3,000 $stand^{-1}$), this would generate a NPV of US$ 16.8 million from a societal perspective (i.e., considering all annual profits from logging). This base case NPV declines as stands are converted to alternative land uses. With 48% converted, the societal NPV declines to US$ 6.7 million. From the loggers' perspective, in which these agents would receive a normal profit over the sawn-wood price while paying the government for the establishment costs, the excess profits and the audit costs, the NPV in the UL scenario would be equal to US$ 7.7 million. This would decline to US$ 2.6 million when 48% of stands are converted to other land uses. Internal rates of return (IRR) from the investments in logging from the loggers' perspective are between 14% and 17%.

Table 4-6 shows the same information, assuming that logging would be done by industry after migrating to cities closer to Faro. In the UL scenario and in the baseline establishment and audit costs scenario, the societal NPV would increase to US$ 24.6, and the loggers' NPV would increase to US$ 12.5 million (IRR of 20.6%). It is also important to note that the share of the total economic benefits that could be captured by the government would rise to between 30.7% and 32.3% of the societal NPV. This is an expected finding since loggers will continue to capture the same normal profits as in the original situation, but total economic benefits would increase. However, loggers would also have benefits from moving to closer cities since a higher number of species would become profitable within the state forest and, as discussed before, they would be able to supply a larger share of their demand for roundwood from harvesting operations inside FSF.

The Production Possibility Frontier

As discussed before, PPF curves are valuable for social planners because they express efficient uses in the state forest, in the sense that any zoning alternative below the PPF is suboptimal (i.e., it would be possible to increase the production of one of the outputs without decreasing the other). Figure 4-9 shows PPFs examining tradeoffs between economic (NPV) and non-market objectives in Faro (i.e., livelihood systems or biodiversity conservation), assuming that harvests are performed from current logging centers and varying the establishment and audit costs for concessions. In Figures 4-9A and B, potential stands for livelihood systems and biodiversity conservation are assigned equal weights within uses. In both cases, the maximum economic value that can be reached lies under the UL scenario, generating a NPV of US$ 16.8 million in the baseline scenario. Lower establishment and audit costs would evidently generate higher NPVs, and higher costs (such as establishment costs of US$ 40 ha^{-1} and audit costs of US$ 1.0 ha^{-1} $year^{-1}$) would generate very low or even negative NPVs. In Figure 4-9A, NPV would decrease with an increase in number of stands in livelihood systems. When 30 stands (12% of Faro) are in livelihood systems, the NPV in the baseline scenario drops to US$ 12.6 million. In Figure 4-9B, a NPV of US$ 8.0 million in the baseline scenario would be generated when 110 stands (43% of FSF) are assigned to biodiversity conservation. Figures 4-9C and D shows basically the same frontiers assuming stands not weighted equally.

Opportunity Costs for Alternative Land Uses

Until now, I demonstrated how the net returns from logging can generate useful information to investigate the tradeoffs between revenue generation through logging and other alternative land uses that also are part of the management objectives in state forests. Hence, each zoning decision in public forests, assuming that logging is the activity that most efficiently generates economic development, will involve some opportunity cost measurable in the decrease in NPVs for logging. However, as discussed in the last chapter, economic theory would say that such opportunity costs may not be uniform across every management decision that social planners could take. For example, it was discussed how the first stands assigned to an alternative land use will likely be stands with low opportunity costs in terms of lost NPV. While the social planner is increasing the proportion of the public forest in alternative uses, more profitable stands are assigned. If this is true, two main hypotheses can be made about the opportunity costs: (i) they should vary across the landscape, depending on the location of each state forest, since they influence the potential of the public land for possible land uses within its boundaries; (ii) they should be increasing at the margin as a larger share of the public forest area is being assigned to alternative land uses.

Figure 4-10 presents the behavior of four marginal opportunity costs (mOC) curves within FSF considering the baseline scenario of establishment and audit costs (respectively, US$ 20 ha^{-1} and US$ 0.4 ha^{-1} $year^{-1}$). All these curves were estimated using the final optimization model with connectivity constraints and harvesting being performed from the surrounding logging centers. Figures 4-10A and C investigate mOC as more stands are assigned to livelihood systems, assuming uniform stand weights and differentiated stand weights, respectively. Figures 4-10B and D shows the same results for areas assigned to biodiversity conservation.

Comparisons between A and B or C and D reveal that the mOC and average opportunity costs for stands assigned to livelihood systems is considerably higher than the opportunity costs for biodiversity conservation. This is an expected finding because, as discussed earlier, most stands with potential for livelihood systems are located in areas with high logging profits. Therefore, Figure 4-10A shows that mOC are around US$ 10,000 when few stands are assigned for livelihood systems and increase to US$ 270,000 when 30 stands are being assigned for this land use. Then, mOC for biodiversity conservation start around US$ 10,000 and can increase to US$ 170,000 when 43% of Faro is being assigned for this land use. Figures 4-10C and D depicts the same costs for an added unit score of livelihood systems and biodiversity conservation.

These results confirm the proposed hypothesis about the opportunity costs for alternative land uses. Social planners have to take into account, in the public forests zoning, that opportunity costs involved in the production of non-market goods will vary spatially and also as a function of the proportion of a given area that is being assigned for such uses. Implications of such findings for the planning of public forests use will be discussed in the next chapter.

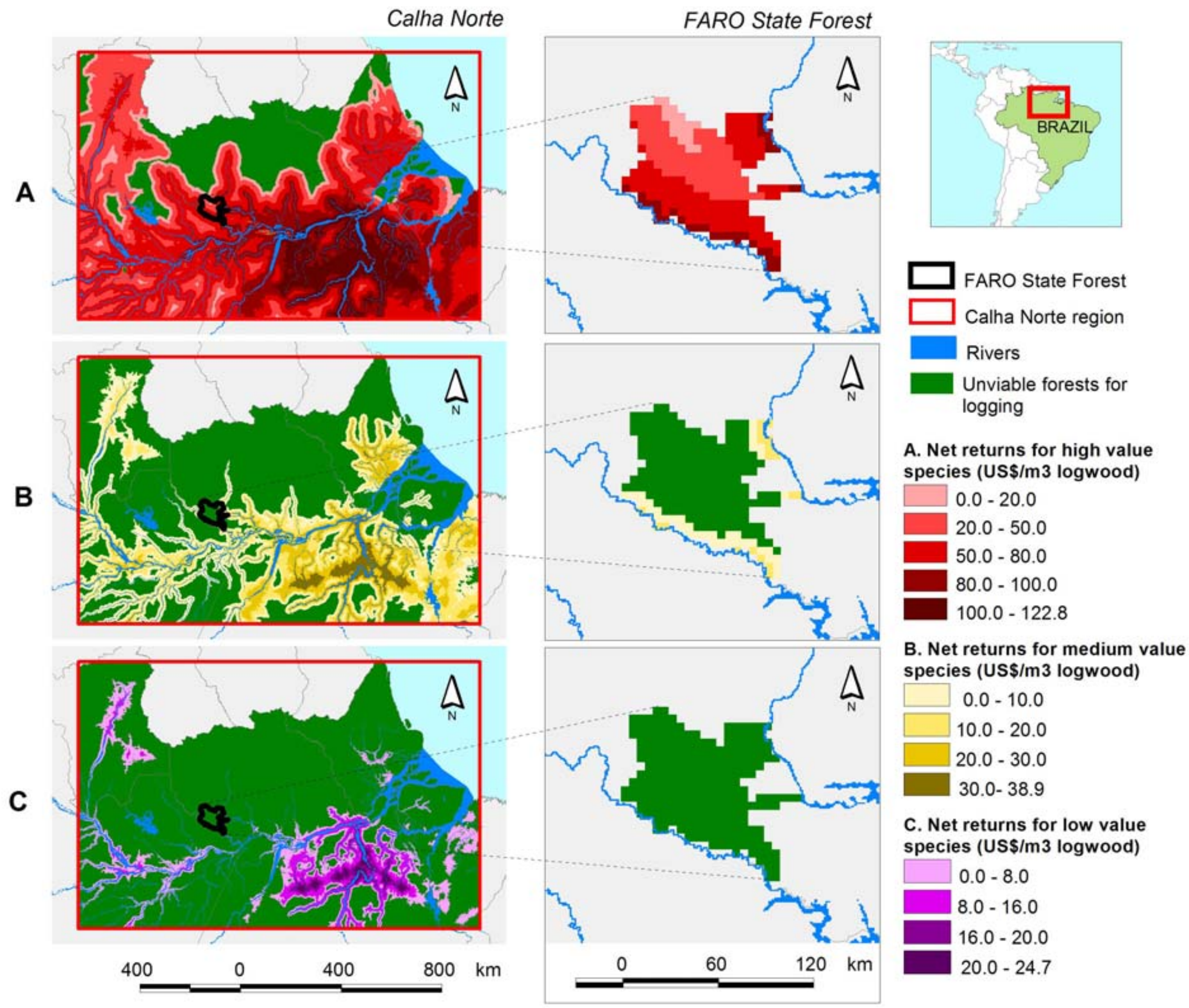

Figure 4-1. Net economic returns for logging in Calha Norte and within Faro State Forest, 2004. A) Net returns from the logging of high value species. B) Net returns from the logging of medium value species. C) Net returns from the logging of low value species.

Table 4-1. Net economic returns from logging in the Calha Norte, 2004.

Net returns for logging ($US\$/m^3$)	**Proportion (%) of the forests in *Calha Norte***		
	High value species	**Medium value species**	**Low value species**
Unviable for logging (negative returns)	18.9	58.1	83.7
0.00 – 20.00	5.9	31.2	15.7
20.00 – 40.00	10.3	10.7	0.6
40.00 – 70.00	30.1	-	-
70.00 – 100.00	25.3	-	-
> 100.00	9.5	-	-

[1] The region (131,757,900 hectares) in 2004 was 78.3% forested, 17.1% deforested, and 4.6% occupied by rivers and other water bodies.

Table 4-2. Net returns from logging in Faro State Forest, 2004.

Net returns for logging ($US\$/m^3$)	**Proportion (%) of Faro State Forest**					
	Harvesting from the logging centers			**Harvesting from closer cities**		
	High value species	**Medium value species**	**Low value species**	**High value species**	**Medium value species**	**Low value species**
Unviable for logging (negative returns)	0.0	78.1	100	0.1	67.6	93.3
0.00 – 20.00	6.8	21.9	-	7.1	30.0	6.7
20.00 – 40.00	22.3	-	-	22.8	2.3	-
40.00 – 70.00	41.8	-	-	41.3	-	-
70.00 – 100.00	29.1	-	-	28.7	-	-

Table 4-3. Total timber volume and estimated roundwood supply (in $m^3\ ha^{-1}$) of merchantable species by timber value class in the stands within Faro State Forest in 1976.

	Total volume from trees > 35 cm DBH	**Total volume from trees > 50 cm DBH**	**Total volume from trees > 50 cm DBH assigned for harvesting**		
			High value species	**Medium value species**	**Low value Species**
Mean	119.3	49.1	2.9	18.1	8.9
Std deviation	4.06	1.67	0.10	0.07	0.03
Minimum	106.9	43.9	2.6	18.0	8.9
Maximum	125.9	51.7	3.1	18.3	9.0

Table 4-4. Milling capacity by logging center within Calha Norte, 2004.

Logging Center	**Logging Zone**	**Milling capacity of roundwood in 2004 (m^3)**			
		Total	**Supplied through FMP**[1]	**Supplied through Deforestation**[2]	**Demand from public forests**[3]
Altamira	central Pará	172,316	0	0	172,316
Anapu	central Pará	53,681	46,137	6,186	1,358
Itacoatiara	Amazonas	200,000	14,526	301	185,173
Itaituba	western Pará	88,462	0	420	88,042
Manacapuru	Amazonas	28,598	0	30	28,568
Manaus	Amazonas	126,441	0	978	125,463
Medicilândia	central Pará	27,684	0	0	27,684
Novo Aripuanã	Amazonas	6,327	222,888	12,787	0
Oriximiná	western Pará	22,401	0	12,854	9,547
Placas	central Pará	71,477	11,982	6,610	52,885
Porto de Moz	estuary Pará	110,000	95,844	0	14,156
Rurópolis	western Pará	43,989	42,523	351	1,114
Santarém	western Pará	167,599	107,290	4,829	55,480
Sen. José Porfírio	central Pará	130,000	0	0	130,000
Trairão	western Pará	197,952	96,921	0	101,031
Uruará	central Pará	168,523	14,124	240	154,159
Vila Km 30	western Pará	19,597	0	0	19,597
Calha Norte **region**	**-**	**1,635,047**	**652,236**	**45,586**	**1,166,574**

[1] Refers to roundwood authorized for logging through forest management plans.
[2] Refers to roundwood legally generated though deforestation permits from IBAMA.
[3] Defined as the difference between the total milling capacity and the volume authorized by IBAMA through forest management plans and deforestation permits.

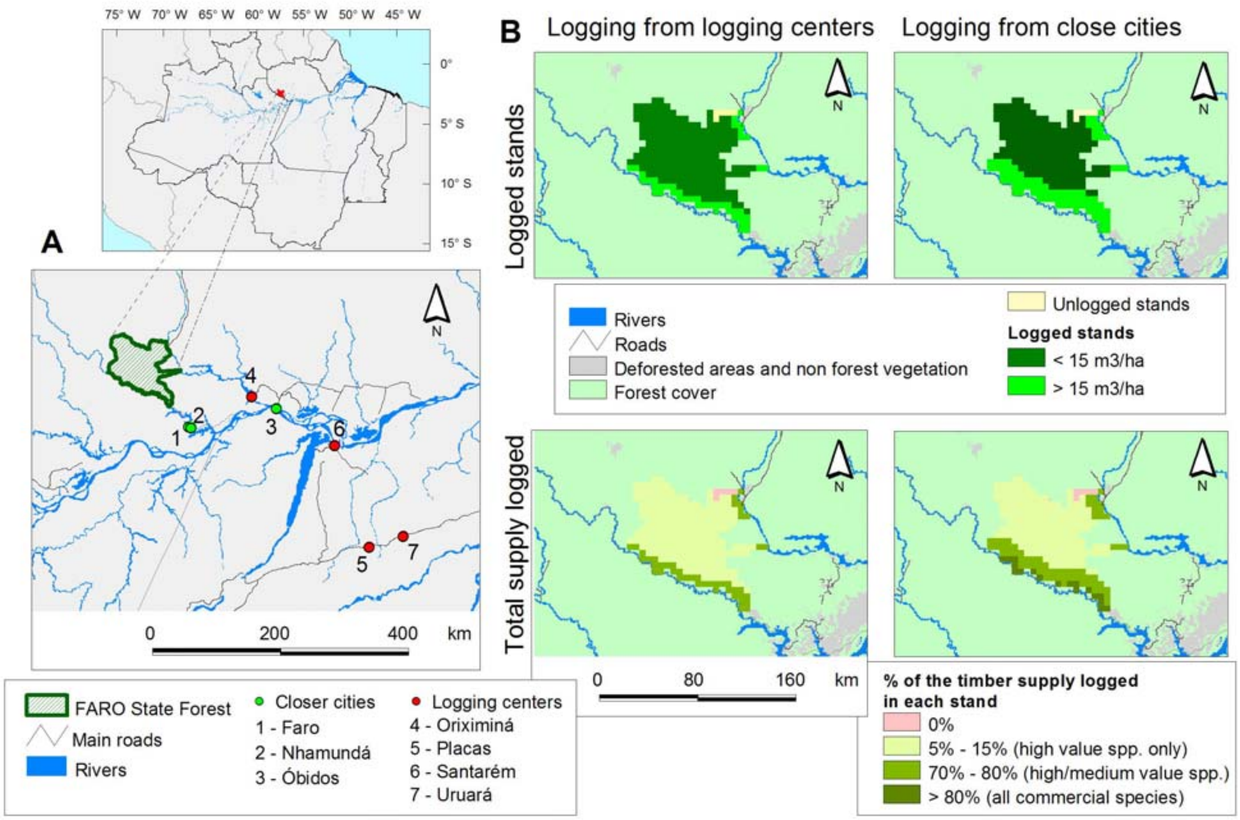

Figure 4-2. Results from the unconstrained logging scenario. A) Location of the current logging centers potentially consuming roundwood from the Faro State Forest, and B) Location of the harvested stands and proportion of the total available timber volume in each stand logged from current logging centers and from urban centers (cities).

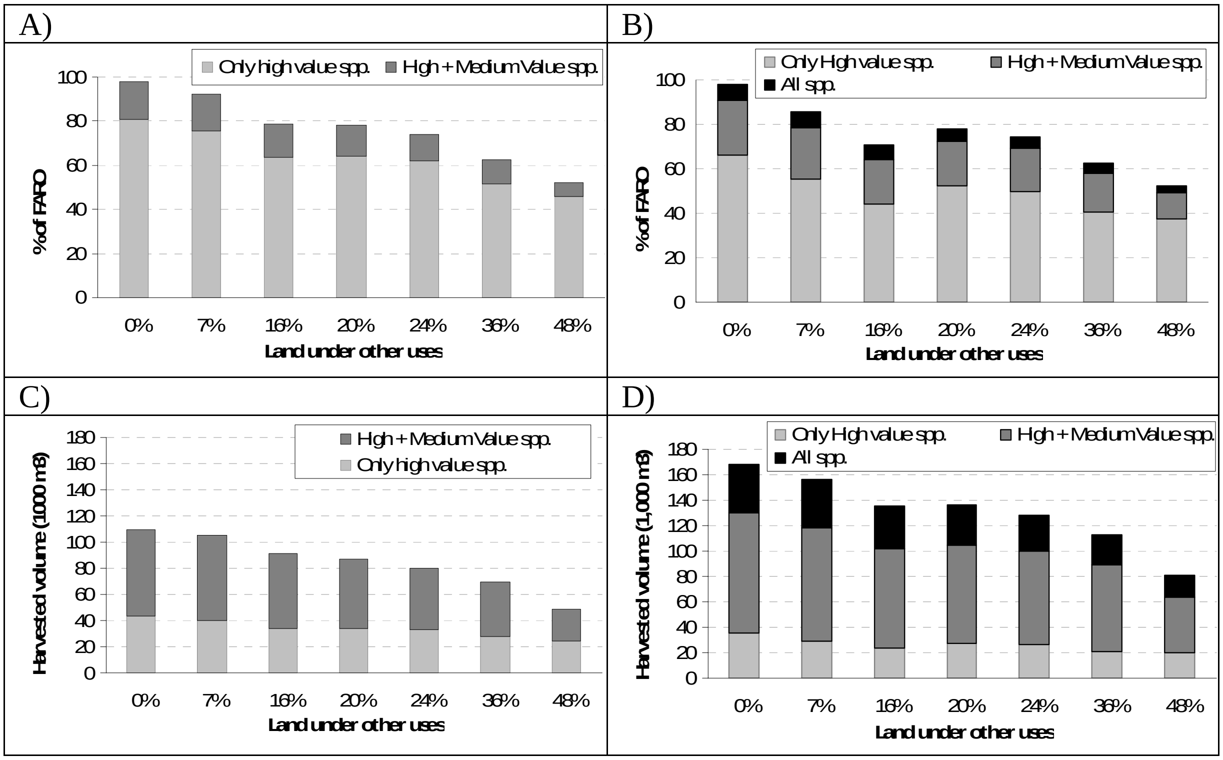

Figure 4-3. Variation in the number of stands and volume logged within Faro State Forest under increasing number of stands converted to other land uses (biodiversity and livelihood systems). A) Proportion of stands logged by species value class from current logging centers. B) Proportion of stands logged by species value class from closer urban centers. C) Volume harvested by species value class from current logging centers. D) Volume harvested by species value class from closer urban centers. All results include connectivity constraints.

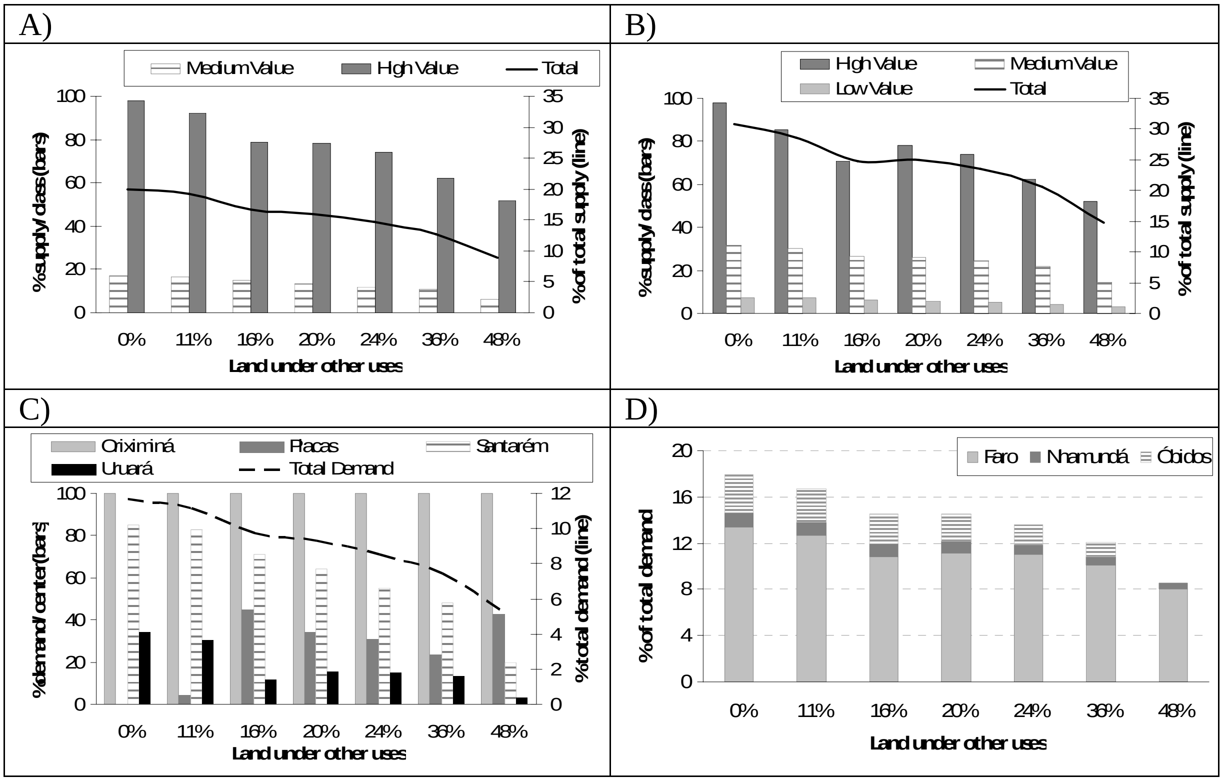

Figure 4-4. Variation in the proportion of the available merchantable timber harvested (supply), and in the proportion of the regional milling capacity met by Faro harvests, under increasing conversion of stands to other land uses (biodiversity and livelihood systems). A) Proportion of timber volume harvested (total and by timber value class) from current logging centers. B) Proportion of timber volume harvested (total and by timber value class) from closer urban centers. C) Proportion of the regional milling capacity being supplied by Faro to current logging centers. D) Proportion of the regional milling capacity being supplied by Faro if the industry moves to closer urban centers. All results include connectivity constraints.

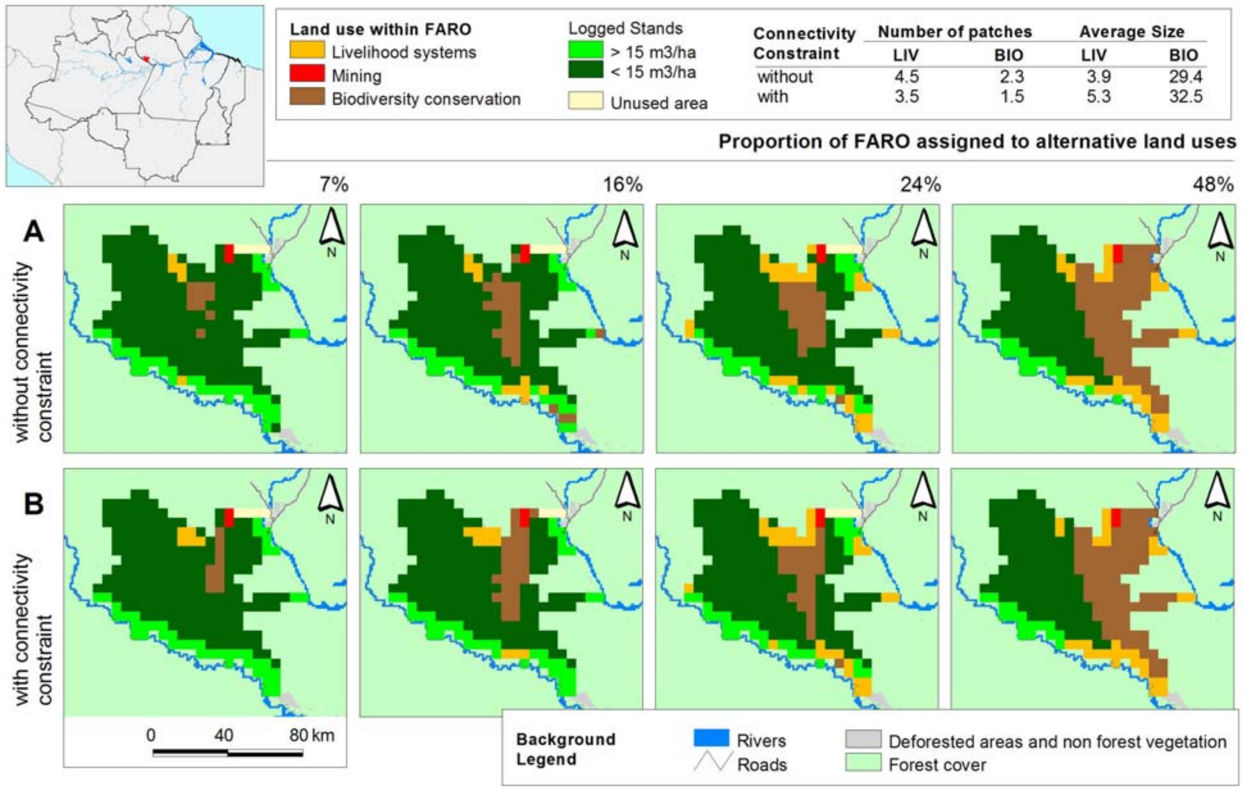

Figure 4-5. Landscape patterns formed by the optimization model for increasing number of stands converted to alternative land uses (A) with and (B) without the connectivity constraint. These simulations assume that each stand contributes equally within either biodiversity conservation or livelihood systems (for those stands with potential for these uses). Logging is performed by current logging centers.

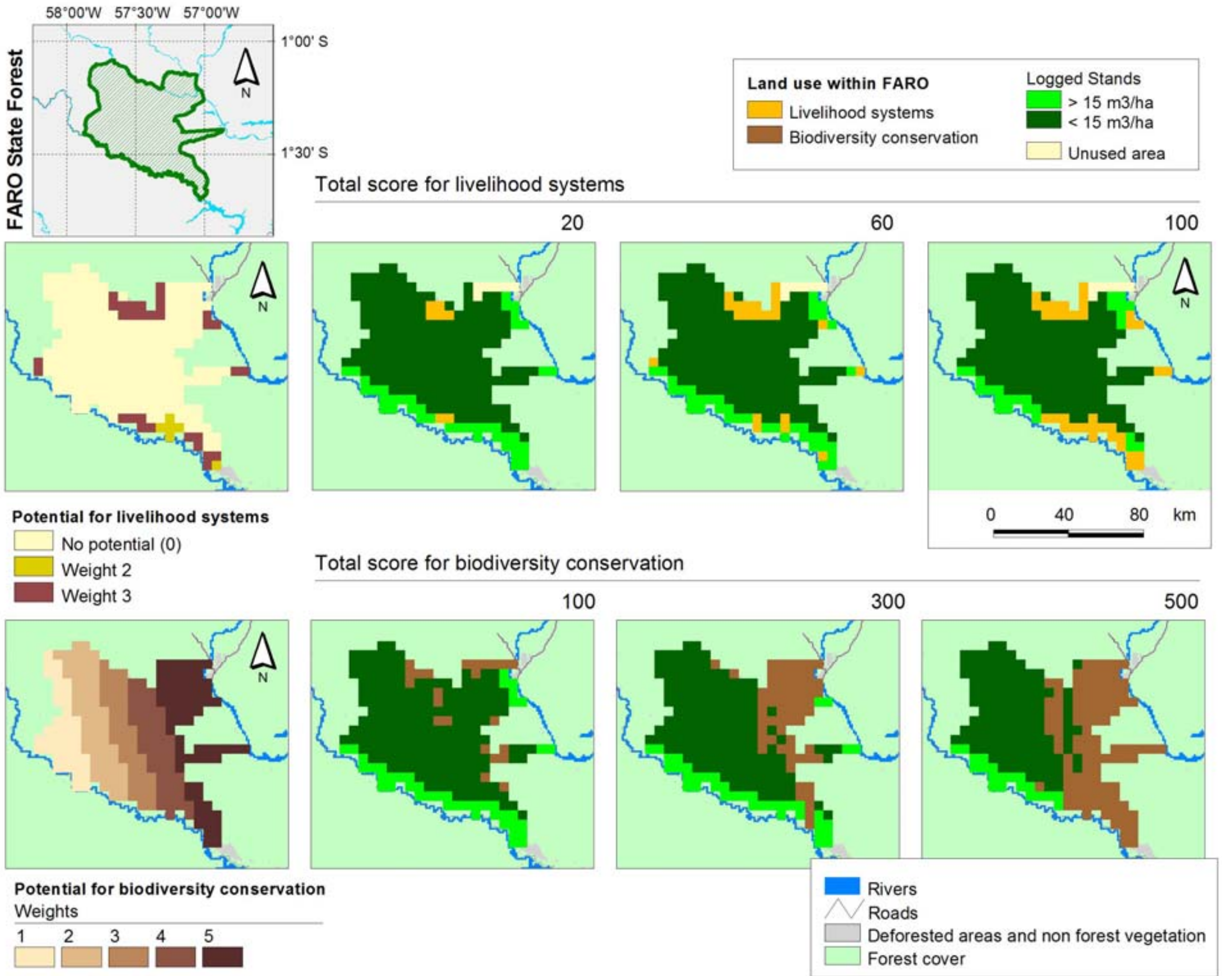

Figure 4-6. Landscape patterns formed by the final optimization model for increasing cumulative scores for livelihood systems and biodiversity conservation. Stands are weighted differently within each use. All results include connectivity constraints. Logging is performed by current logging centers.

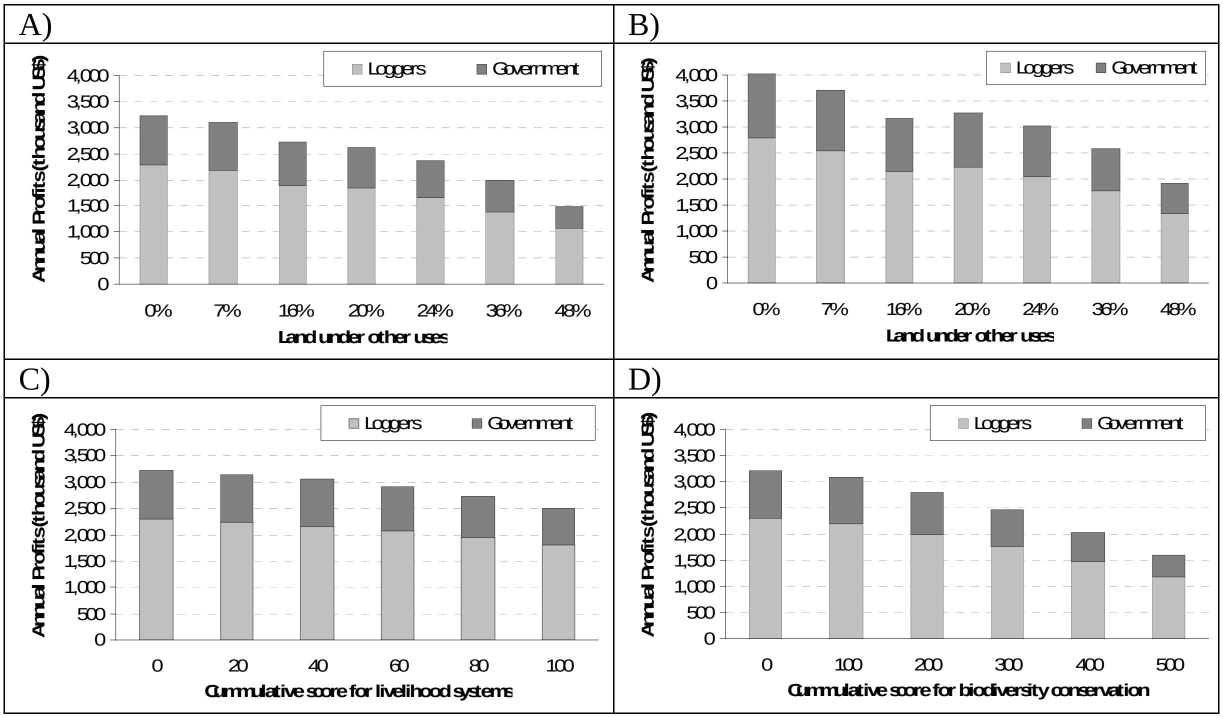

Figure 4-7. Annual profits from logging in Faro for government and loggers under increasing stand conversion to alternative land uses. A) Increasing stand conversion assuming stands weighted equally and logged by current logging centers. B) Increasing stand conversion assuming stands weighted equally and logged from closer cities. C) Increasing stand conversion to livelihood systems assuming stands weighted differentially and logged by current logging centers. D) Increasing stand conversion to biodiversity conservation assuming stands weighted differentially and logged by current logging centers. All results include connectivity constraints.

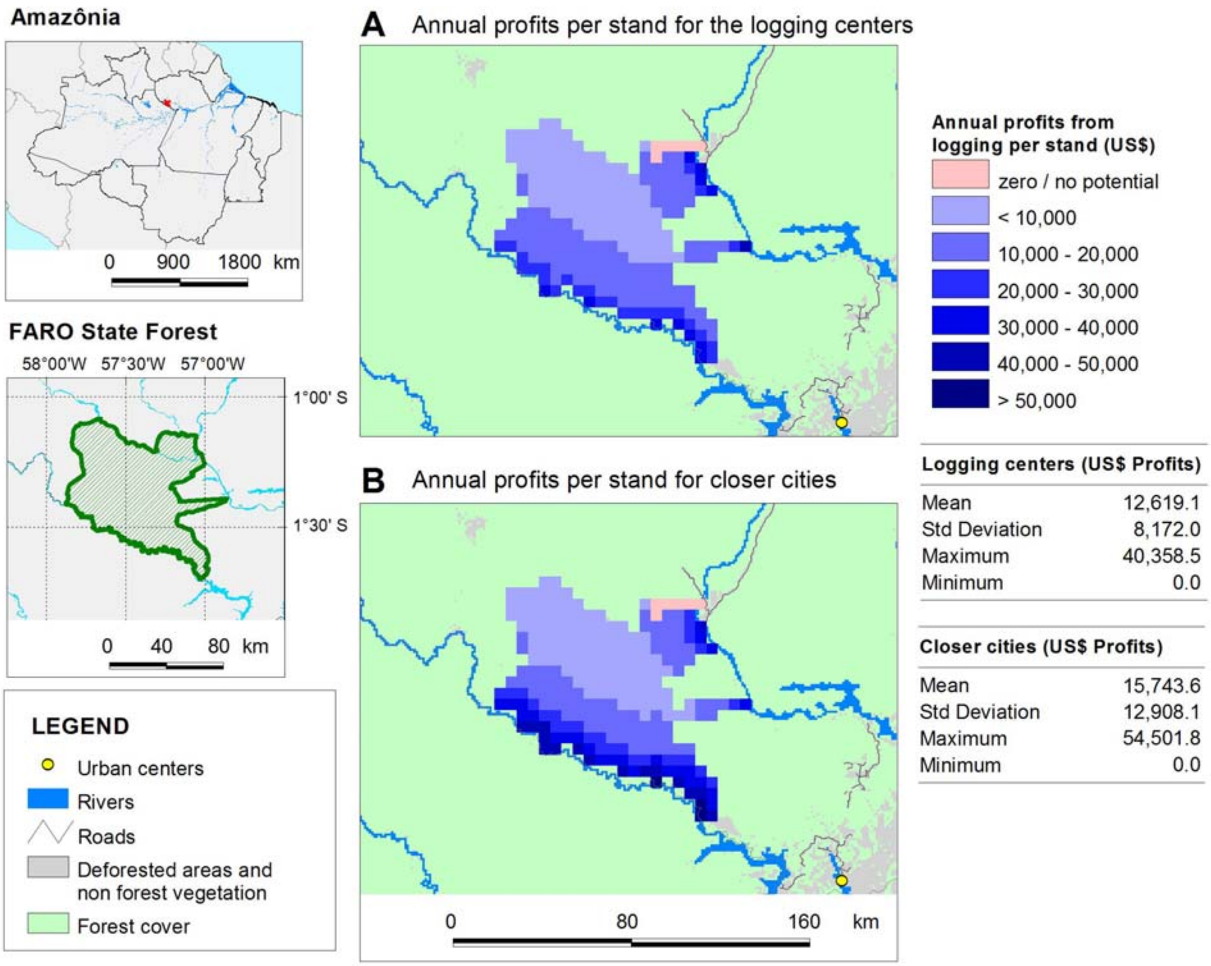

Figure 4-8. Spatial distribution of annual profits from logging in the unconstrained logging scenario, with harvests performed from the (A) logging centers, and (B) closer urban centers. Zero values represent stands in which logging is forbidden due to the occurrence of high slopes.

Table 4-5. NPVs and IRRs for logging within Faro State Forest from the logging centers, from the society and loggers perspectives[1], under decreasing number of stands used for concessions.

Proportion of Faro logged	Annual Profits from logging (thousand US$)	Concession costs and fees		Societal perspective		Private perspective	
		Establishment costs (thousand US$)	Royalties and fees	NPV (thousand US$)	IRR	NPV (thousand US$)	IRR
98.0%	3,217.7	12,500.0	28.8%	16,755.2	24.2%	7,699.9	16.6%
92.2%	3,096.4	11,750.0	29.7%	16,451.5	24.8%	7,448.6	16.8%
78.4%	2,725.3	10,000.0	30.6%	14,882.4	25.7%	6,726.7	17.2%
78.0%	2,618.0	9,950.0	29.4%	13,891.5	24.7%	6,364.1	16.8%
74.1%	2,374.3	9,450.0	30.0%	12,097.2	23.5%	5,137.0	15.8%
62.4%	1,994.6	7,950.0	30.2%	10,149.2	23.5%	4,255.5	15.7%
52.2%	1,482.9	6,650.0	28.0%	6,674.8	20.6%	2,614.5	14.2%

[1] The societal perspective includes the total annual profits from logging in the calculations. The logger's perspective discounts the values paid to government in royalties and fees (4th column).

Table 4-6. NPVs and IRRs for logging within Faro State Forest from closer urban centers, from the society and loggers perspectives[1], under decreasing number of stands used for concessions.

Proportion of Faro logged	Annual Profits from logging (thousand US$)	Concession costs and fees		Societal perspective		Private perspective	
		Establishment costs (thousand US$)	Royalties and fees	NPV (thousand US$)	IRR	NPV (thousand US$)	IRR
98.0%	4,024.2	12,500.0	30.9%	24,641.6	30.7%	12,492.8	20.6%
85.5%	3,709.6	10,900.0	31.7%	23,448.9	32.6%	11,953.8	21.6%
70.6%	3,165.5	9,000.0	32.3%	20,363.8	33.7%	10,354.1	22.2%
78.0%	3,268.2	9,950.0	31.8%	20,249.8	31.4%	10,076.2	20.7%
74.1%	3,022.7	9,450.0	32.3%	18,438.2	30.5%	8,895.2	20.0%
62.4%	2,585.5	7,950.0	31.6%	15,927.6	31.0%	7,947.0	20.6%
52.2%	1,909.2	6,650.0	30.7%	10,843.8	27.2%	5,113.9	18.2%

[1] The societal perspective includes the total annual profits from logging in the calculations. The logger's perspective discounts the values paid to government in royalties and fees (4th column).

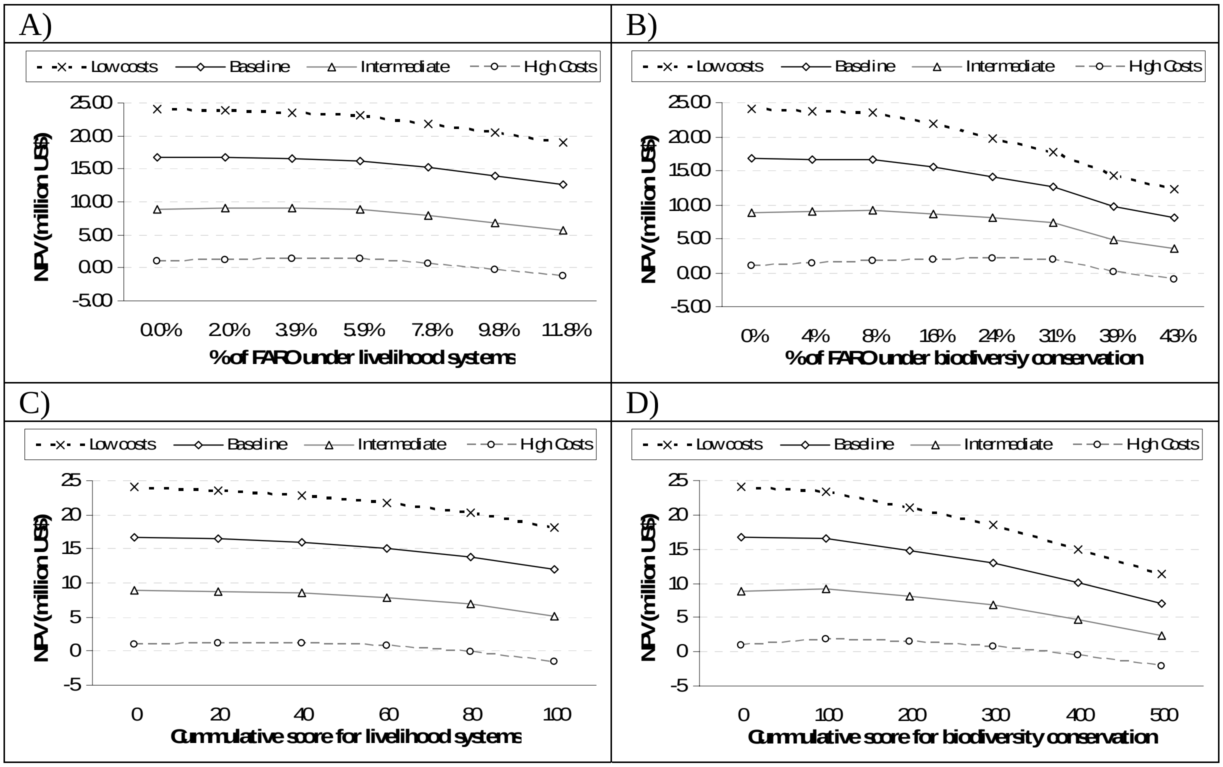

Figure 4-9. Production possibility frontiers (PPF) for competing land uses within Faro State Forest with logging being performed by firms located in the logging centers and different costs for establishing and auditing concessions. The low cost simulation considers establishment costs of US$ 10 ha^{-1} and audit costs of US$ 0.2 ha^{-1} $year^{-1}$. The baseline simulation considers, respectively, US$ 20 ha^{-1} and US$ 0.4 ha^{-1} $year^{-1}$. The intermediate simulation considers, respectively, US$ 30 ha^{-1} and US$ 0.7 ha^{-1} $year^{-1}$. The high costs simulation considers, respectively, US$ 40 ha^{-1} and US$ 1.0 ha^{-1} $year^{-1}$. A) NPVs generated by logging and livelihood systems, assuming stands weighted equally for livelihood systems. B) NPVs generated by logging and biodiversity conservation, assuming stands weighted equally for biodiversity conservation. C) NPVs generated by logging and livelihood systems, assuming differential weights for livelihood systems. D) NPVs generated by logging and biodiversity conservation, assuming differential weights for biodiversity conservation. All results include connectivity constraints.

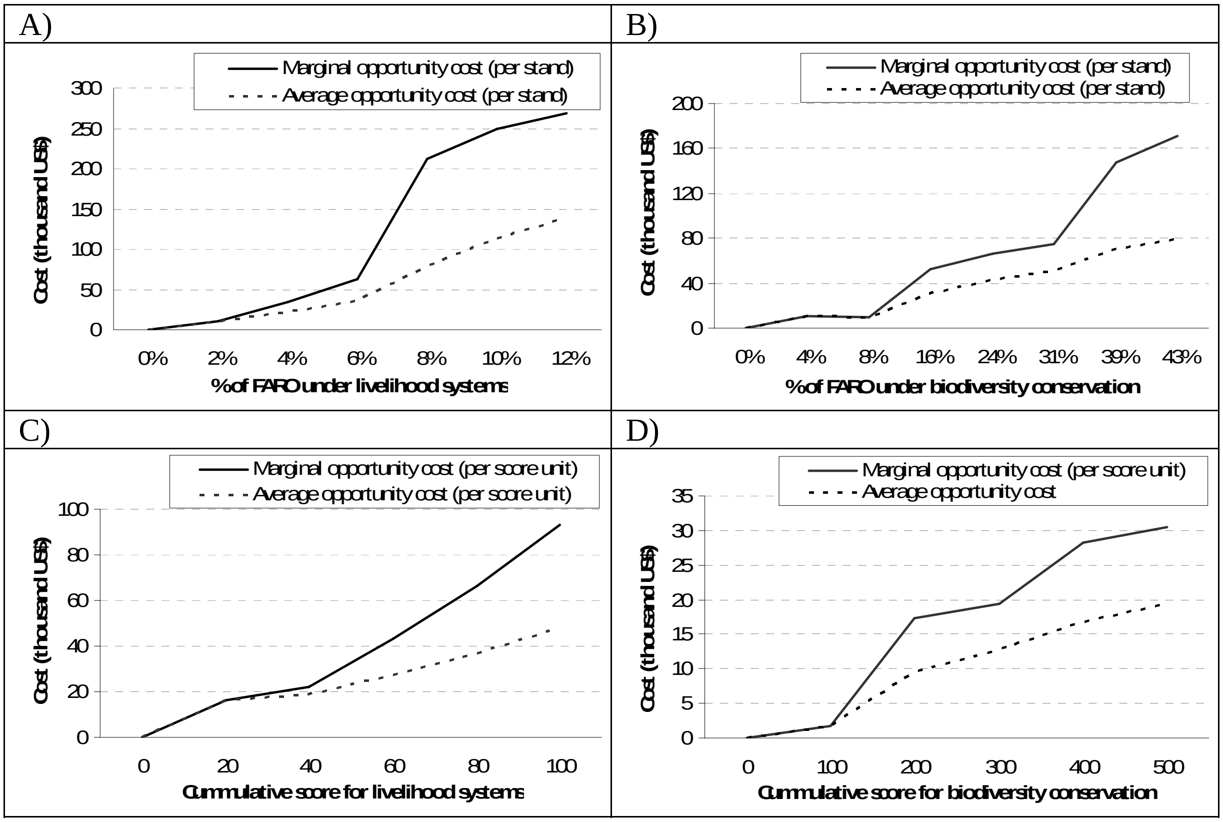

Figure 4-10. Marginal and average opportunity costs for livelihood systems and biodiversity conservation in Faro State Forest, assuming harvests are performed by firms located in the logging centers. A) Opportunity costs under increasing number of stands assigned to livelihood systems, assuming uniform stand weights. B) Opportunity costs under increasing number of stands assigned to biodiversity conservation, assuming stand uniform weights. C) Opportunity costs under increasing cumulative score for livelihood systems, assuming differentiated stand weights. D) Opportunity costs under increasing cumulative scores for biodiversity conservation, assuming differentiated stand weights. All results include connectivity constraints.

CHAPTER 5
DISCUSSION AND FINAL REMARKS

Importance of Land Use Modeling in the Large-Scale Planning of Public Forest Use

The models developed in this study proved useful for Amazonian public forest land use planning. First, based on wood prices and typical variable logging costs, a spatially-explicit model was built to estimate net economic returns. Such estimates represent, in areas within public forests designated for logging, the resource rent plus the normal private profits that can potentially be generated. The net returns from logging are also a proxy for the opportunity costs associated with allocating to other land uses, including the production of non market goods and services, such as biodiversity conservation or livelihood systems.

Second, an optimization model was developed to guide decisions regarding the desirable level of profits that should be raised through concessions in a public forest, subject to a minimum area or a minimum subjective score to which non-commodity uses are assigned. Then, the compromises between competitive land uses can be determined through the production possibility frontier (PPF), since it reveals efficient alternatives for land allocation.

One of the key findings of this study is that marginal opportunity costs for non-commodity uses in Faro State Forest (FSF) are increasing when a larger proportion of the area is assigned for such uses. Social planners need to take into account in public forest zoning that opportunity costs vary across the landscape, and also within the same area, depending on the zoning alternative chosen.

Regulations establish that each public forest will have a supervisory committee responsible for making land use planning decisions, guided by an overarching forest-level management plan (Federal Decree 4340/2002). Management plans will be generated based on accurate surveys in each public forest, including forest inventories, important sites for biological conservation and tourism, and location and needs of the traditional communities dwelling in these forests. The models developed in this study do not aim to replace these surveys to establish the management plans. Instead, the models can be improved by incorporating the data generated during these surveys, improving their utility to decision-makers.

It is expected that social planners will often not be able to decide about land use in a specific public forest, since this zoning configuration will be generated in negotiation processes among several stakeholders. Models are still useful in this situation to evaluate zoning alternatives in relation to land allocation efficiency within the public forest, as demonstrated in this study. Such models become even more important in the Amazonian context considering that, frequently, planners are located in capital cities thousands of kilometers from the forests they are planning and they have very scarce information about the economic potential of such lands.

At the landscape level, these models can help to determine the optimum level of timber production from public lands in a given region, considering future production trends of the logging industry and, at the same time, maximize societal benefits from public forests. In the example used in this study, the Calha Norte region (~ 130 million hectares) encompasses 20 million hectares of public forests that will be partially used to supply approximately 1.2 million of m^3 of roundwood to the regional timber industry. In one extreme scenario, Faro (only 4.4% of the public forests in the study area) would be able to supply 18% of the regional milling capacity if the regional industry moved to cities close to the state forest. However, this milling capacity may increase in the study area if, due to the establishment of concessions, more companies are attracted to migrate due to the local stocks of raw material.

Concessions may have a major role in stabilizing logging frontiers in regions where most roundwood is potentially harvested illegally, as in Calha Norte. However, if monitor and control systems are not well implemented, concessions could have the perverse effect of creating a trap for the current protected areas. In this study, it was discussed how concessions could increase economic returns from logging by promoting the migration of mills to urban centers closer to FSF. This also implies that large extents of protected forests such as indigenous lands and conservation units near Faro also would become more profitable for illegal logging if the industry relocated to closer cities.

Model Assumptions

The first important assumption of the optimization model is related to land use specialization. Each stand within a given public forest is assumed to have an exclusive land use, which is a strong assumption, given that many areas can feasibly have overlapping uses. Tourism, for example, is described in some regulations for forest concessions (e.g., Federal Decree 6,063, from March 20th, 2007) as a land use that is permitted within harvesting areas. However, this study assumes that management efforts in each public forest stand will be more efficiently allocated if these stands have a unique use, decreasing the likelihood of conflicts among different management beneficiaries. Multiple use is then a concept applied at the landscape-level. According to Vincent and Binkley (1993), an exclusive use at the stand-level typically can prevail in terms of economic efficiency over multiple stand level uses, mainly due to diminishing returns from the management effort for different activities within the same stand.

The second important assumption of the model is non-declining timber stocks in the stands over time. Conveniently, since the model of this study is static, it was considered a time length of 40 years (equal to the maximum length for concession contracts) and harvest cycles of 35 years. Even if this assumption is wrong, it would cause only small impacts in the NPV calculated because only $^{1}/_{7}$ of the harvested area would be used for a second cycle and the potential impacts would be discounted far in the future.

However, there is a large literature discussing how the forest structure and the composition of merchantable species can change over time under logging, even using RIL practices (Putz et al., 2001; Phillips et al., 2004; Zarin et al., in press). This is an important concern considering that this study found that, in the more optimistic scenario, at least 70% of the stands in FSF would be harvested only for the extraction of high value timber – a logging pattern described in economic literature as high grading (Repetto and Gillis, 1988; Hyde and Sedjo, 1992). High grading is generally undesirable because it leads to degradation of the forest conditions, since these species can require specific post-logging silvicultural practices to regenerate (Schulze et al., 2005; Zarin et al., in press). It is also possible that some of these species would require larger disturbances provoked by more intensive harvesting to regenerate (F.E. Putz, personal communication, April 12th, 2007). Some improvements in the optimization model that could better address these issues will be further discussed.

A third important assumption is that prices were considered static during the time length of the analyses. As mentioned before, wood prices used are equal to the average prices for sawn-wood at the mills' gate for the Brazilian domestic market in 2004. In this way, the map of net economic returns can change if more firms in Calha Norte start to export due to the larger proportion of roundwood legally harvested under concessions. Currently, these firms have difficulties in exporting because they cannot prove the legal origin of the roundwood. Second, wood markets may be affected if large extents of public forests will be conceded to timber firms in the short run, since changes in roundwood prices as an input to timber firms will have an effect in the equilibrium price and quantity sold for wood products (a mathematical demonstration of such effects can be seeing in Appendix A).

Model Limitations

The main limitation of the analyses presented in this study is related to the coarse scale of the data used in the optimization model. As mentioned earlier, due to the lack of site specific forest inventory data for FSF, I used a timber volume map in a coarse scale (cells of 1 km wide) to estimate the exploitable roundwood volume within Faro. I also used coarse scale maps to identify areas within FSF with potential for biodiversity conservation or with evidences of human occupation. It is important to highlight that accurate site specific information will be collected by the government to generate the FMP for the public forests before the establishment of concessions and other land uses. Forest inventories, for example, are critical steps to be executed before the establishment of concessions to guide government in the best decisions regarding minimum prices and acceptable harvesting intensity. Therefore, the optimization model developed in this study can be used by social planners to identify critical gaps of information to be collected for the generation of the FMP. Clearly, the model's capabilities will be further enhanced with more accurate and site specific information collected.

Economic Efficiency, Government Revenues and Distributional Issues

This study presented an estimate of the share of the profits from concessions that could be captured by the government as resource rent, considering that loggers could raise normal profits over the wood prices as they usually have in private managed forests. Concessions could indeed represent an important source of funds for public agencies considering their current budgets. For example, in an extreme scenario modeled, rents captured by government could be equivalent to US$ 1.24 million year^{-1} in FSF. If other public forests in Calha Norte were able to generate the same rents per unit of area, Brazilian government could generate US$ 28 million year^{-1} from concessions in Calha Norte region. Intuitively, this amount is also a rough estimate of the excess profits that loggers could potentially raise from illegal logging in a scenario in which these lands continue to be uncontrolled by government. For comparison reasons, the budget for the SFB in 2007 is estimated in approximately US$ 13 million (Schulze et al., in press).

Such estimates consider that government would be able to entirely capture resource rents applicable to logging in public forests. Experiences in other countries show that this assumption can be too optimistic, since governments have captured a small proportion of the total rents (Repetto and Gillis, 1988; Vincent, 1990). Lower pricing policies in such countries created several negative impacts in the past, such as reduced governmental revenues, excessive expansion of the forest sector and forest damages provoked by logging (Repetto and Gillis, 1988; Vincent, 1990). These governments' failures, associated with several cases of economic subsidies given to concessions in public lands, generated doubts about the Brazilian government's capacity to successfully implement a forest concession system (Merry et al., 2003; Barreto, 2004a; Barreto, 2004b).

The economic literature contains many studies discussing the best strategies to maximize rent capture according to political settings and institutional arrangements. The main goal, as explained by Vincent (1990), is to convert as much of the resource rent as possible into royalty revenue, while minimizing the excess profits for loggers and excessive damages or timber left in the harvesting sites. Efficiency, then, can be measure in terms of the proportion of the rent that is converted to royalties (Vincent, 1990). In weak institutional and organizational environments like Brazil, the association of a lump sum tax (charged over the overall concession) and a harvest ad valorem tax (charged over every m^3 or value extracted) can be the best setting to capture rents, reducing high grading and improving forest condition (Hyde and Sedjo, 1992; Amacher, 1999; Amacher et al., 2001).

Distribution is an issue that also deserves some attention. It is assumed in this study that the government is the best destination for resources that otherwise would be excess profits for loggers. This does not necessarily need to be true. If government permitted excess profits, some interesting questions that can be raised are related to what amount of such resources would be reinvested locally, or would be transferred to regional households (Hyde and Sedjo, 1992)[1]. This is a relevant question considering the historical fragility and corruption of government forest agencies in the Brazilian Amazon.

Another point that deserves some attention regarding distributional issues is related to the size of firms acquiring forest concessions in the Brazilian Amazon. Brazilian regulations require that different sizes of concession units will be offered, as mentioned earlier in this study (MMA, 2005). The government must decide the best way to distribute overall benefits from logging on public lands. In one model, forests can be conceded to small loggers and traditional community associations, which can have direct benefits from logging. Such an idea is strongly suggested by community forest management advocates (Lima et al., 2003; Merry et al., 2003). In a second model, harvest rights can be granted to more capitalized and economically efficient firms, which would generate higher revenues that could be raised for the Forestry Fund (FNDF), and indirectly could be used to foment small-scale forestry in the Brazilian Amazon.

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[1] In addition, in a competitive concessions market, higher profits must drive concession prices higher, such that governments should be able to capture opportunistic rents (J. Alavalapati, personal communication, July 3, 2007).

Public Forests Sustainability and the Spatial and Temporal Zoning

As any forestry law in different parts of the world, the Brazilian Management of Public Forests Law was created to utilize Amazonian public forests in a sustainable way. Then, a question that is posed to society is what “sustainable” means. Zarin et al. (in press) propose that harvesting carried out on any public land > 10,000 hectares should be able to maintain the volume production at the level of the individual species logged. As mentioned before, for FSF, as well as probably many other Amazonian public lands, this goal is certainly challenging considering that large extents of these lands would only be harvested for the extraction of high value species. Furthermore, recent computer simulations, executed with data from harvested study sites in the Brazilian Amazon, show that this sustainability goal in harvesting areas may be impossible without specific silvicultural measures to improve natural regeneration (Favrichon, 1998; Sist et al., 2003; van Gardingen et al., 2006; Keller et al., 2007; Valle et al., 2007). The national forestry fund could be used to subsidize the adoption of silvicultural treatments in harvested stands in public forests, guaranteeing species level sustainability.

At the landscape-level, sustainability goals are intuitively related to the idea of spatial zoning. During the last decade, state governments in the Brazilian Amazon have performed macro-scale economic and ecological zoning in consultation with several stakeholders. A main thrust of these efforts is to identify areas that would be exclusively reserved for production of market and non-market goods based on their potential and societal preferences about such uses. However, this is not the only possible zoning configuration in public lands. A novel idea would be to implement temporal zoning. For example, taking Faro as an example, a given number of stands can be assigned for logging in the first cycle of the contracts (40 years), and can be afterwards reserved for biodiversity conservation. At the long run, this zoning could achieve the sustainability goals as proposed by Zarin et al. (in press). Under this idea, government could even consider investing intensively in harvesting concessions during the first cycle of the contracts and generate an endowment for the national forestry fund, reserving logged stands for biodiversity conservation in further cycles. Thus, the fund could be used to establish silvicultural treatments in logged forest units in which natural regeneration may not provide full recovery at the species-level (D. Zarin, personal communication, July 3rd, 2007).

Further Research

Further research could investigate what can happen to profits and harvested volumes in public forests over further cycles, using dynamic optimization models. Data predicting the variation in timber stocks after logging could be extracted from studies modeling the post harvest timber species volume through time (Alder and Silva, 2000; Phillips et al., 2004; Macpherson et al. forthcoming). Second, further research could deal with different spatial configurations and sizes for stands destined for concessions, satisfying, for a given public forest, legal requirements regarding different types of timber firms as holders of concessions contracts. The optimization model developed can be improved with more accurate estimates of concession establishment costs, transaction costs generated by the licensing of forest management plans and audit costs.

APPENDIX A
HOW CHANGES IN AN INPUT PRICE CAN AFFECT SUPPLY IN A PARTIAL EQUILIBRIUM MODEL: A MATHEMATICAL DEMONSTRATION

Given the following general equations relating the supply and the demand for wood products:

$$Q_W^S = f\,(P_W^S, w, v, r)$$
$$Q_W^D = f\,(P_W^D, I, P_S)$$

Where Q_W^S represents the supply quantity of wood been produced, P_W^S is the wood price in the supply side, *w* is the wage rate, *v* is the capital price and *r* is the roundwood price. First equation describes how the quantity in the supply side is function of the prices for such inputs. As the same way, the second equation expresses how the demand quantity Q_W^S is a function of the prices in the demand side P_W^D, the income *I* and the prices of substitute goods P_S. Then, in the equilibrium point, the following conditions need to be true:

$$Q_W^S = Q_W^D = Q_W^e \text{ and } P_W^S = P_W^D = P_W^e$$

In words, the demand quantity should be equal to the supply quantity and therefore they should equal the equilibrium. The same is valid for prices. Then, we can proceed with the total differentiation of our first equations.

$$dQ_W^S = \frac{\partial Q_W^S}{\partial P_W^S}.dP_W^S + \frac{\partial Q_W^S}{\partial w}.dw + \frac{\partial Q_W^S}{\partial v}.dv + \frac{\partial Q_W^S}{\partial r}.dr$$
$$dQ_W^D = \frac{\partial Q_W^D}{\partial P_W^D}.dP_W^D + \frac{\partial Q_W^D}{\partial I}.dI + \frac{\partial Q_W^D}{\partial P_S}.dP_S$$

As discussed before, since $Q_W^S = Q_W^D = Q_W^e$ and $P_W^S = P_W^D = P_W^e$, the differentiations above may assume the following notation in the equilibrium point:

$$dQ_W^e = \frac{\partial Q_W^S}{\partial P_W^S}.dP_W^e + \frac{\partial Q_W^S}{\partial w}.dw + \frac{\partial Q_W^S}{\partial v}.dv + \frac{\partial Q_W^S}{\partial r}.dr$$

$$dQ_W^e = \frac{\partial Q_W^D}{\partial P_W^D}.dP_W^e + \frac{\partial Q_W^D}{\partial I}.dI + \frac{\partial Q_W^D}{\partial P_S}.dP_S$$

Now, it is possible to investigate the effect that changes in the input price *r* will provoke in the supply of wood products. Evidently, demand will not be affected. Then, if $dw = dv = dI = dP_S = 0$, using the ceteris paribus assumption, and therefore $dr \neq 0$,

$$\frac{dQ_W^e}{dr} - \frac{\partial Q_W^S}{\partial P_W^S}.\frac{dP_W^e}{dr} = \frac{\partial Q_W^S}{\partial r}$$

$$\frac{dQ_W^e}{dr} - \frac{\partial Q_W^D}{\partial P_W^D}.\frac{dP_W^e}{dr} = 0$$

To solve such equations, they can be expressed in matrix form, which can be later solved through the Cramer's rule:

$$\begin{pmatrix} 1 & -\dfrac{\partial Q_W^S}{\partial P_W^S} \\ 1 & -\dfrac{\partial Q_W^D}{\partial P_W^D} \end{pmatrix} \begin{pmatrix} \dfrac{dQ_W^e}{dr} \\ \dfrac{dP_W^e}{dr} \end{pmatrix} = \begin{pmatrix} \dfrac{\partial Q_W^S}{\partial r} \\ 0 \end{pmatrix}$$

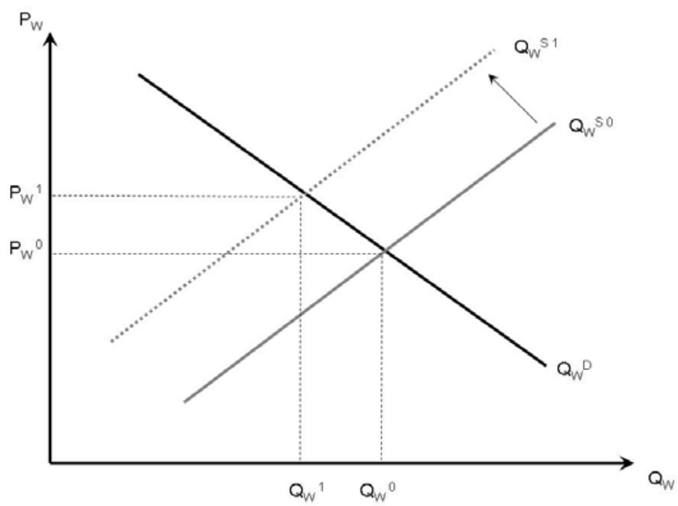
First, Cramer's rule is used to investigate the changes in the equilibrium quantity when there is a shock represented by the change in the roundwood input price. As we can see, both will interact in an opposite way. In other words, this is a mathematical demonstration that, when the input price rise, the equilibrium quantity will drop, and vice-versa.

$$\frac{dQ_W^e}{dr} = \frac{\left(\dfrac{\partial Q_W^S}{\partial r}\right)\left(-\dfrac{\partial Q_W^D}{\partial P_W^D}\right)}{\left(-\dfrac{\partial Q_W^D}{\partial P_W^D}\right) + \left(\dfrac{\partial Q_W^S}{\partial P_W^S}\right)} = \frac{<0}{>0} = <0$$

And, at the same way, it is possible to demonstrate that, when the input price rises, the output equilibrium price will also rise:

$$\frac{dP_W^e}{dr} = \frac{-\left(\dfrac{\partial Q_W^S}{\partial r}\right)}{\left(-\dfrac{\partial Q_W^D}{\partial P_W^D}\right)+\left(\dfrac{\partial Q_W^S}{\partial P_W^S}\right)} = > 0$$

So, ceteris paribus, changes in the roundwood input prices will provoke a shift in the supply curve and changes in the equilibrium quantity and output prices. The magnitude of the final effect on the supply will depend upon the elasticities.



Shift in the supply curve assuming rising roundwood input prices.

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BIOGRAPHICAL SKETCH

Marco A. W. Lentini was born in São Paulo, the largest Brazilian city, in southeastern Brazil. From 1995-1999, he completed his undergraduate studies in Forestry at ESALQ, the Agriculture School of the University of São Paulo, in Piracicaba. During his undergraduate experience, he participated in research projects relating to the ecology and recovery of forest fragments in dry Atlantic forests in São Paulo State. In 2000, he moved to the Brazilian Amazon to work as an assistant researcher at the Amazon Institute for the People and the Environment (IMAZON), an independent research institute located in Belém, in the State of Pará (www.imazon.org.br). The bulk of his work at IMAZON relates to economics and policies focused on timber logging and forest certification. In 2004, Marco served as the field coordinator of a wide survey of the timber industry, in which 680 mill owners and managers, located in 82 logging centers of the Brazilian Amazon, were interviewed. Another of his primary assignments at IMAZON was carried out in 2004-5, when he worked as Executive Secretary of the Certified Forest Producers Association (PFCA, www.pfca.org.br). Marco moved to the United States in August 2005 to pursue a Master of Science degree at the University of Florida, as a scholar in the Amazon Conservation Leadership Initiative (ACLI) program, supported by the Gordon and Betty Moore Foundation.