Subsistence needs, non-farm employment and tenure conflicts: predicting land use change in Mexico using dynamic stock-flow modelling techniques

Raffaello Cervigni

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Academic affiliation:
Centre for Social and Economic Research on the Global Environment (CSERGE)
University College London and University of East Anglia

Address for Correspondence:
Room G-6043, The World Bank
1818 H Street, NW, 20433 Washington DC
Tel: 202 473 58 36
Fax: 202 522 32 40
E-mail: RCERVIGNI@WORLDBANK.ORG

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Abstract

Deforestation is the term frequently used to describe several human-induced alterations of the rural environment, potentially responsible for decreased provision of ecological services. However, many studies of deforestation fail to analyse the process of change in the whole spectrum of land uses that determine ecosystem stability. Farm-level decisions causing these changes depend on a complex interplay of the farm’s objectives (often revolving around subsistence goals), the opportunities for land use in the farm’s area of residence made possible by the prevailing tenure system and by the technology available, and the opportunities for salaried work outside the area of residence.

This paper proposes an application of computer based modelling of dynamic systems to original household survey data from a biosphere reserve in the Mexican tropics. The impact on the stocks of primary and secondary forest, agriculture and pasture land of demographic growth, eviction of farmers without land title and intensification of staple crop farming are analysed, under different assumptions about the demand for temporary salaried employment and the technological options available to farms. Using the software Stella, scenarios of land conversion and resource depletion are constructed, for different portions of the study area with different endowments of land types, and allowing for different resource allocation decisions made by different household types. Implications for local level resource management and policy are discussed, as well as direction for further research.
1. Introduction

Deforestation in developing countries is a matter of great concern for its ecological, social and economic impacts; scholars and policy makers often debate on the causes of, and the appropriate policy responses to, deforestation. One explanation for the proliferation of the debate may be semantic: by using the simple term “deforestation”, people in fact refer to i) a wide variety of situations, and hence, ii) to a wide range of effects and causes. The actual processes that may fall within the scope of the term deforestation range from selective logging for timber extraction, to clearance associated to slash and burn agriculture, to clear cutting of wide areas for pasture establishment; the causes of the phenomenon may be very different, depending on whether deforestation is undertaken by landless peasants, small holder farmers, or large timber concessionaires.

Based on case study material in Mexico, this paper proposes to revisit, as a contribution to the clarification of the debate, both the way the problem ought to be defined, and the spatial scale at which the problem may be analyzed.

Deforestation vs. land use change

On the first point (characterization of the issue), it may be argued that casting the problem in terms of “land use change” may be more useful than in terms of “deforestation”. The rural landscape consists of a rich variety of land uses, each one with different degrees of human presence, and different degrees of impact on the preservation of ecosystem characteristics (genetic and species diversity, resilience), and functions (watershed protection, micro-climate regulation, soil conservation). As high impact uses, such as pasture, replace low-impact uses, such as extraction of non-timber forest products, concerns are often expressed that the equilibrium of ecosystem may be disrupted, putting human welfare in jeopardy.

However, both in theory and in practice there are many different ways (and correspondingly, different ecological implications) in which the transition from one configuration of the landscape to another may take place: the same area of forest may be cleared for pasture, converted to agriculture, or to some lower impact uses, such as agroforestry use. In all cases, the vegetation cover is being altered; however, the ecological impacts will be very different, depending on what is the vegetation that was in the area before the change (primary or secondary forest), and what is the type and density of the vegetation that takes over after the change. As suggested by the hydrology literature (Hamilton, 1983; Brujinzeel, 1990), and by the ecological (Barbault & Sastrapradja, 1995) and forestry literature (Lugo, 1988; Lugo, Parrotta et al., 1993), estimating the watershed and biodiversity impacts of a given human induced perturbation of the ecosystem requires detailed information on the uses of land preceding and following that perturbation.

In line with the insight of that literature, it is argued here that changes in human welfare are not a function of changes of land from forested to deforested status, but, more broadly, are a function of changes in the overall composition of the mosaic of land uses, which include a broader range of vegetation cover, such as primary and secondary forest, agroforestry systems, agricultural production, pasture. Accordingly, the model presented in this paper simulates changes over time of the stock of these types of land use for the case study area in Mexico.

Causes of deforestation and scale of analysis

As reviewed in (Brown & Pearce, 1994), a great deal of the deforestation literature applies statistical techniques (mainly multiple regression) to measure the impact of several human factors on changes in forest cover, both over time and across different geographic locations. Most of the studies specify on
plausible a priori assumptions functional relationships between forest cover (and/or forest cover change) indicators, and variables measuring population growth, poverty, income growth, external indebtedness, structural adjustment and other factors.

In several cases, econometric analysis is used to assess the comparative merits of competing theories. Income, for example, can in theory be expected to have either a positive correlation with deforestation (via increasing demand of goods that require land clearance for their production) or a negative one (if the demand for environmental quality grows with income). Once specified on theoretical grounds, the relationships between deforestation and explanatory variables are tested using fairly aggregated, national level data, with the objective of providing decision makers with indications about the policy interventions that would be most effective to mitigate deforestation. This approach may arguably face methodological challenges, and runs the risk of resulting in policy recommendations that are either unviable or irrelevant.

On the first point (methodology), it can be argued that several econometric studies of deforestation analyze statistical correspondences between changes in forest cover and broad explanatory variables. Inferring cause-effect links from the conclusion of these studies is problematic in the absence of explicit micro-economic foundation, i.e. one that traces land use change activities back to the motivations underlying the individual agent’s (e.g., farm household, logging company) decision making process.

The second point concerns the issue of the appropriate target audience of policy recommendations. Demographic and poverty alleviation policies are typically controlled by national policy makers, for whom deforestation, and natural resources conservation in general, is often not a high priority. Local decision makers, such as protected area managers, and local stakeholders, such as communities and NGOs, are likely to have much more interest in the conservation of the forest cover, and yet a much more limited ability to control demographic pressure or promote national or sub-national income support programs.

To be sure, the lack of micro-economic foundations in the analysis of deforestation is recently being addressed by the literature. An ambitious research program is currently under way (results are not yet available) (Vosti & Witcover, 1996), which seeks to improve the understanding of the forces leading to deforestation at the agricultural frontier via a three pronged approach: micro (farm), meso (region), and macro (country). The micro approach consists of a multi-period optimisation model of archetypical farms in the western Brazilian Amazon.

(Deininger & Minten, 1996) use disaggregated, municipality-level data to estimate the demand for land clearance in Mexico on the basis of an agricultural household-type model. They find that physiogeographic factors, poverty, and government policies have distinct effects on deforestation. On the last two variables, they also argue that the recently adopted, NAFTA-induced, package of trade liberalisation and elimination of government interventions in agriculture, may result in increasing poverty of marginal farmers, who may not be able to benefit in the short run from increased opportunities coming linked to more open export markets, and are therefore likely to put additional pressure on forest and natural resources in rural areas.

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1 Population growth is normally believed to have unambiguous positive links with deforestation. However, as observed by (Meyer & Turner, 1992), quoted by (McNeely, Gadgil et al., 1995), the connection between population and land cover change become weaker at increasingly smaller spatial scales because of the importance of other variables that affect demand, or spatially deflect its impact. For example, technological improvements may be able to reduce the land intensity of agriculture expansions that would be propelled by demographic growth.
Another recent study on deforestation in Mexico reaches similar conclusions. (Barbier & Burgess, 1996) estimate the increase in agricultural area and livestock numbers (a plausible proxy for deforestation) as a function of a range of price, income and policy variables. Barbier and Burgess argue that ongoing removal of input and output subsidies in agriculture may, on the one hand reduce incentives for conversion, but, on the other hand, it may make poorer farmers worse off and induce them to migrate to the agricultural frontier. In order to mitigate pressure on forests the authors therefore suggest to complement the broader liberalisation policies with a program of investments in land improvement for existing cultivation on rainfed areas.

This paper further develops these recent “micro” approaches to deforestation, by constructing projections of land use at the community level, based on a farm-level model of resource allocation (Cervigni, 1997, summarized in section 3 below).

2. The study area

The Sierra de Santa Marta (SSM) lies on the Gulf of Mexico, about 150 kilometers to the southeast of the Port of Veracruz, in the western foothills of Lake Catemaco, and about 40 kilometers to the northwest of the cities of Coatzacoalcos and Minatitlán. Administratively, it belongs to the municipalities of Catemaco, Mecayapan, Soteapan, and Pajapan (see Figure 1). Sierra de Santa Marta is the southern part of a broader area known as Los Tuxtlas.

Figure 1: Location of the study area (Source: PSSM, 1995)

The area covers 135,912 hectares, of which 82,300 hectares were declared a protected forest and wildlife refuge zone under the decree of April 28, 1980. In 1988 it was reclassified as a special biosphere reserve. The boundaries of the present study area were defined by combining criteria related to land tenure, and the need for a territorial and hydrographic continuum. The zone contains 90 land...
units, including communities, ejidos, and private properties; among towns, villages and other forms of human settlements, the total number of centers of residence is 110.

Sources of information
Data on land areas, land use and vegetation cover was obtained from a local Geographical Information System. Information on the demographic structure of the region’s population was obtained from census data. Farm-level information on cropping patterns, off-farm labor use and household composition come from field surveys. Data on production technology (input coefficient, yields) comes from technical monographies (Buckles & Erenstein, 1996; Chevallier & Buckles, 1995; Pare, 1993) and from consultation with experts in the field, as summarized in (Cervigni & Ramirez, 1996).

Zoning
Based on ecological, geographical and land tenure considerations, a zoning of the study area (Pare, 1993) was developed in the early 90s. In accordance with broad UNESCO principles on biosphere reserves, three basic zones are identified: (i) a nucleus or core zone, (ii) a buffer zone, and (iii) a zone of influence. The degree of conservation of pristine ecosystems decreases as one moves from the core to the buffer and influence zones, while the range of recommended land uses increases.

By overlaying the ecological zoning with the administrative one (based on the four municipal jurisdictions comprised in the study area), one obtains a clustering of the communities of the Sierra in seven Zoning and Administrative Units (ZAUs). The ZAUs enable the analysis to take into account not only ecological considerations, but also political and institutional constraints and opportunities to natural resource management in the region. They are therefore used in the rest of the paper as the basic spatial unit of analysis.

Population and land tenure
According to official census data, in 1995 in the study area lived a total of 57,804 people, distributed in 72 land tenure units (ejidos, ranching colonies, agrarian communities and private properties), belonging to four municipalities (Catemaco, Mecayapan, Pajapan and Soteapan). Between 1990 and 1995 an average demographic growth rate of 5.3% was recorded, which is more than twice the national rate (2.5%). The population is composed for the most part of indigenous people (80%) of the ethnic groups “nahua” and “zoque-popoluca”. The rest corresponds to “mestizo” populations of different origins.

The Mexican Constitution allows for three types of property: ejidos, small property, and communal property (comunidades). Ejidos constitute a land grant for usufruct to a population group, and until a major constitutional reform in 1992, ejido land essentially belonged to the state and could not be sold.

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2 This the Geographic Information System of the Proyecto Sierra de Santa Marta, a local non-governmental organization (PSSM, 1995). The GIS is based on maps at the 1:50,000 scale. Maps have been digitalized using with a grid of 200 metres -per side boxes (equivalent to 4 has per box). Land use data are based on interpretation of 1990 aerial photography and satellite images, and validated through ground truthing exercises. For further details, see (Pare, 1993).

3 Field work was part of a study funded by the Global Environment Facility in the region; for a summary, see (Cervigni & Ramirez, 1996). In the context of that study, two types of surveys were undertaken during August and September of 1995. The first survey consisted of interviews with 531 heads of household in 47 communities. The questionnaire comprised questions on household composition, agriculture, forest and livestock activities, as well as fishing, hunting, live animals trapping, and sources of off-farm income. The other type of survey was administered to 74 key informants in 41 communities. In this survey, community-level information was sought on land tenure, land inheritance and parceling modalities, availability of, and access to, rural services and infrastructure.

4 In the intentions of its developers, the zoning should also be instrumental to the implementation of the protected status of the region, formally decreed in the 1980s but never enforced in practice.
Following NAFTA - induced constitutional reforms, community members are now allowed to gain title over land. Subject to some limitations spelled out in the new agrarian law, ejidatarios are permitted to sell and rent their land, pledge it as collateral and form association with private investors.

In order to implement the constitutional and legislative reform, a major nation wide land titling program has been launched in 1993: the PROCEDE (Programa de Certificación de Derechos Ejidales y Titulación de Solares Urbanos, i.e. Program for Certification of Ejido Rights). According to the World Bank, as of April 1995 only 20% of the ejidos included in PROCEDE’s workplan obtained community level titles, and few individual private land titles had been granted.

One of the key social issues that have been raised on the program concerns its impact on the different tenure arrangements (including formal and informal ones) that have been developing since the beginning of the post-revolution land distribution process. Both in private and communal land units, formal land rights holder (“propietarios” in the former case and “ejidatarios” or “comuneros” in the latter) are by no means the only type of land dwellers. Along with genuinely landless salaried agricultural laborers, there is a significant proportion of the rural population who does not possess neither private nor community land titles, and yet farms individual parcels of land by entering in contractual or informal arrangements (land rental, borrowing or sharecropping) with either private landlords or ejidos.

It is fair to expect that the overall social and economic impact of PROCEDE will depend on the way its implementation will affect the various situations of “de-facto” land use that can be encountered in rural Mexico. A strict application of the program, disregardful of informal tenure arrangements, may result in eviction of avencidados on a significant scale. This opens up a number of issues related to the social and economic costs of the likely resulting migration to urban areas, as well as questions about the capacity of some stagnant segments of the industry and services sector of absorbing the incremental supply of unskilled labor. From the environmental point of view, one reason for concern may be that, as a result of PROCEDE, evicted peasants unwilling or unable to migrate to urban areas may be forced to clear, for subsistence agriculture, marginal forested land, currently not subject to parceling processes under the agrarian law.

In the study area, communal arrangements (Ejidos and agrarian communities) are largely prevalent, amounting to over 70% of the area’s size and to nearly 80% in terms of land tenure units. Out of the 41 communities surveyed, approximately two thirds have still communal land, either because the parceling process has not been completed (30% of the cases), or because it has not yet started (37% of the communities surveyed).

Land use
Recent GIS analysis (PSSM, 1995) of the study area indicate that agricultural uses (which include croplands and pasture) predominate in the Sierra, amounting to about 60% for the entire region, with a range of 2% to 71% moving from the nucleus to the influence zone. Total land with significant vegetation cover (including undisturbed forest, second growth, degraded forests and forest fragments) accounts for about 36% of the study area.

Historically, the land use pattern that prevailed up to the mid-1950s was linked to a production system composed of three complementary activities: (a) agriculture (mainly staple crops), (b) hunting and gathering, and (c) small scale livestock (mainly hogs and poultry). In spatial terms, the system was based on tradition- and community-rulled access to four agro-ecological sub-systems: the primary forest (monte), the second growth forest - fallow land (acahual), the cropping area (milpa), and the farm
orchard (*solar*). The main feature of that system was that none of the activities demanded exclusion of the others to operate.\(^5\)

The traditional production system was dramatically altered by the adoption of extensive cattle ranching, which had been little practised until that time and in any case only for on-farm consumption or saving purposes. Supported by different waves, between the 1950s and late 1908s, of land parceling, enclosures of communal areas, and government-subsidized credit, extensive cattle ranching farming moved into the primary forest and into areas used for farming and regeneration (*acahual*). The impact of enclosures and credit policies became visible by the mid-1970s. The forested area shrank from 96,640 hectares in 1967 to 60,857 hectares in 1976, i.e. 35,788 hectares of forests and jungle were lost in nine years (Ramirez, 1984). By 1991, 59,276 hectares of jungles and forests had disappeared out of an original area under wild vegetation in 1967 (61.3%).

**Biodiversity and protected status**

Los Tuxtlas and Sierra de Santa Marta are regarded as the northernmost patch of tropical rain forest in the American continent (Dirzo & Garcia, 1992). A recent assessment of the conservation priorities for the Latin American and Caribbean region classifies the moist jungles of the Sierra, together with those in other parts of Mesoamerica (broad-leaved humid jungle ecoregion of Tehuantepec) as outstanding on the bioregional level (Central America) or level 1, which is an ecoregion of top regional priority (Dinerstein, 1995).

The processes of dramatic land use change described above are putting much of the region’s biodiversity in jeopardy. The most highly endangered ecosystems are those that have been most heavily deforested, and are generally found in low-lying and mid-mountainous areas. They include the moist jungles in low-lying zones (high and medium perennial jungles), mid-mountain mesophiliic forests (virtually supplanted by coffee fields and pastures), the mangrove swamps, and the warm climate oak. Fires continue to be a threat to the remaining forested areas.

**Off-site employment and migration patterns**

The region has traditionally been a significant provider of workforce to the industrial triangle of Coatzacoalcos, Minatitlán, and Cosoleacaque, one of the most important petrochemical zone in Veracruz and in fact in the whole of Mexico.

In the past, the income of many families of the Sierra used to depend on the level of economic activity of the oil district. For example, during the second half of the past decade, 44% of the salaried population of Pajapan were employed in the cities of the district: 29% in the construction and 15% in rural and urban services (Buckles, 1987).

Following a period in the 1980s of reduced activity of Veracruz’s oil industry, measures of sectoral restructuring have been launched in the early 90’s. These measures also include the proposed sale of a number of petrochemical complexes in the southern district. As a result of the crisis and the following restructuring packages, unemployment in southern Veracruz has increased alarmingly. In the Cosoleacaque - Minatitlán - Coatzacoalcos corridor, which used to be the single most important source of employment of southern Veracruz, more than 50 thousand jobs have been lost; the city of Coatzacoalcos features the highest unemployment rate (9.8%) in the domestic trade and services sectors.

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\(^5\) (Pare, 1993; Chevallier & Buckles, 1995).
3. The model

This paper proposes an application of computer-based modelling of dynamic systems to the study area to predict land use changes at the community level over a 10-15 years time horizon. The model, which is constructed using the dynamic modeling software Stella 5.0 for Windows, consists of three broad sectors: a) Households and Land Tenure, b) Land Use, and c) Off-site economy (see Figure 2).

In sector a), the processes are modeled, of formation of new households, and of allocation of land among existing and new households given tenure rules. Based on decisions taken in sector a), sector b) describes the processes of transition of land among different uses, as well as the extraction of natural resources from the wild. The off-site economy (sector c) is the market for selected goods produced in the study area (livestock, ornamental palm), as well as for labor not employed in agricultural and harvesting activities.

![Figure 2: building blocks of the land use and resource extraction model](image)

The objective of the model is to simulate changes over time in a selected number of key land stocks and resource flows, based on farm-level resource allocation and land use decisions. The latter are modeled in detail in a companion paper to the present one (Cervigni, 1997), which proposes a multi-period, safety-first constrained, linear programming model of land use and resource extraction from the wild based on the literature on agriculture households. The model is specified in three settings: a) subsistence farming in presence of encroachable communal spaces, b) eviction from communal areas resulting from tenure reform, and c) stationary farming in areas with no access to communal land. For each of these situations, the linear programming model generates estimates of labor allocated by the farm to various activities (including extraction of forest products, on- and off-farm work), and of areas of land allocated to different uses: conservation of primary and secondary forest, clearance of either type of forest for agriculture and for pasture, use of forested areas for perennial, under-shade crops (coffee).

To improve realism, most of the variables and parameters included in the present model are arrayed in one or both of two dimensions of variability. The first dimension refers to the Zoning and Administrative Units (ZAUs) described above (section 2). The second dimension is the household type (HT): the model distinguishes among i) new households (who are assumed to have no land of their own), ii) existing households with no secure tenure, iii) existing households with secure tenure.
The model consists of a set of equations describing the relationships between stocks and flows. Stock/flow relationships are also represented visually by diagrams, like the one of Figure 3 for the household sector. Each icon in diagrams like Figure 3 represents an equation, or the initial value of a variable. In the following sections, the structure of the model will be explained by presenting and discussing a set of key equations.

3.1. The household sector

At the beginning of the simulation (which is assumed to be the beginning of 1996, i.e. right after data collection was completed in the study area), there is a stock of “settlers”, that is, households who have rightful or de facto access to land. As time goes by, a stock of “space seekers” is generated; inflows to this stock are given by i) the process of new household formation, and ii) by the process of eviction of existing settlers with no formal title to land. Households flow out of the space seekers stock through seven different channels (see Figure 3):

a) Migration
b) Land Purchase;
c) Encroachment in communal secondary forest (acahual) in the community of residence;
d) Encroachment in communal primary forest (monte) in the community of residence
e) Use of existing agricultural space via reduction on the average parcel size (minifundio);
f) Encroachment in primary forest areas outside the community of origin, and
g) Destitution

Equation 1 summarizes, at the generic time \( t \), the balance of flows to, and from, the space seekers stock:

\[
\text{Space Seekers}[\text{Zone}, \text{Hhold type}](t) = \text{Space Seekers}[\text{Zone}, \text{Hhold type}](t - dt) + \\
(\text{Hhold formation}[\text{Zone}, \text{Hhold type}] + \text{Eviction}[\text{Zone}, \text{Hhold type}] - \\
\text{Encroachers Acahual}[\text{Zone}, \text{Hhold type}] + \text{Minifundistas}[\text{Zone}, \text{Hhold type}] - \\
\text{Encroachers Monte}[\text{Zone}, \text{Hhold type}] + \text{Off site encroachers}[\text{Zone}, \text{Hhold type}] - \\
\text{Destitution}[\text{Zone}, \text{Hhold type}] + \text{Land Purchasers}[\text{Zone}, \text{Hhold type}] - \text{Migration}[\text{Zone}, \text{Hhold type}]) * dt
\]

Equation 1

Outflows b) to f) entail increases in the Settlers stock; however, only outflows c), d) and f) entail land use changes:

\[
\text{Settlers}[\text{Zone}, \text{Hhold type}](t) = \text{Settlers}[\text{Zone}, \text{Hhold type}](t - dt) + \\
(\text{Encroachers Acahual}[\text{Zone}, \text{Hhold type}] + \text{Minifundistas}[\text{Zone}, \text{Hhold type}] + \\
\text{Encroachers Monte}[\text{Zone}, \text{Hhold type}] + \text{Off site encroachers}[\text{Zone}, \text{Hhold type}] + \\
\text{Land Purchasers}[\text{Zone}, \text{Hhold type}] - \text{Eviction}[\text{Zone}, \text{Hhold type}]) * dt
\]

Equation 6

Equations are reported directly in the format given by the Stella software: variable names are the same, descriptive ones, used in the diagramming layer of the software (the source of Figure 3). Because of their array nature, several variables are in the form \( \text{Variable}[\text{Zone}, \text{Hhold type}] \); quantity appearing in square brackets are not arguments, but rather equivalents to subscripts denoting variation across dimensions. In more standard notation, the same expression would be \( \text{Variable}_{ij} \), meaning value of the variable for zone \( i \) and household type \( j \).
Outflow a) increases the stock of permanent workers in the off-site economy, whereas outflow g) increases the stock of landless households:

\[
\text{Landless\_Hholds}[\text{Zone, Hhold\_type}](t) = \text{Landless\_Hholds}[\text{Zone, Hhold\_type}](t - dt) + (\text{Destitution}[\text{Zone, Hhold\_type}]) \cdot dt
\]

Let us look in some more detail at the determination of the flows to, and from, the \textit{Space Seekers} and \textit{Settlers} flows.

**Figure 3. Household sector: basic stock and flow structure**

(Note: for visual simplicity, the diagram reproduces all stocks and flows, but not all the converters that link them)

3.1.1. Inflows to the Space Seekers stock

*Formation of new households*

Based on field evidence, it is assumed that a new household is formed every time a male individual reaches the adult age (18 years). To obtain estimates on the yearly numbers of new adults, the following procedure was used. Official data on the age structure of the male and female population was available for a subset of 17 communities of the Mecayapan and Soteapan municipalities (2 in the buffer and 15 in the influence zone).
Age classes were of one year intervals for the youngest ages (up to 15 years), and of wider (two to four years) intervals for the remaining classes. Through linear interpolation of the non-unit intervals, it was possible to construct a year-by-year cumulative age distribution function of the population. This distribution did not exhibit substantial variation over the subset of the 17 sampled communities.

An average of the percentage distribution of ages was therefore used, weighted by the size of the total (male and female) population relative to the total of the 17 units sample. The result is indicated by the function $\text{FDISTRIB}(\cdot)$ reported in Equation 2, which maps into number of new adults the flow of time, and the consequent decrease of the 1995 adult age (for example, individuals who were 16 years old in 1995 will be 18 in 1997, that is, in year 2 of the simulation)$^7$.

$$H\text{hold\_formation}[\text{Zone, Hhold\_type}] = \text{Dummy\_New\_Hholds}[\text{Hhold\_type}] \times \text{People\_per\_Hhold}[\text{Zone}] \times \{\text{delay}(\text{Average\_men\_age\_structure}, 1) - \text{Average\_men\_age\_structure}\} \times \text{INT}(\text{Proportion\_of\_men}[\text{Zone}] \times [\text{INIT}(\text{Settlers}[\text{Zone, Existing\_NoTitle}]) + \text{INIT}(\text{Settlers}[\text{Zone, Existing\_Title}])])$$

$$\text{Average\_men\_age\_structure} = \text{FDISTRIB}(\text{Decline\_of\_Adult\_age})$$

Equation 2

Figure 4 displays, in quality of example, the process of household formation in one of the seven ZAUs, the Influence zone in the Soteapan Municipality.

Figure 4: Formation of new households

**Eviction**

As discussed above, application of PROCEDE, the land titling program currently under way in Mexico, is likely to result in eviction of farmers who are not in possess of a valid *ejidatario* title and who do not own private land. Assuming that no mitigating measure will be in place, displaced farmers will be forced to join the pool of space seekers. The rate at which this will happen depends upon the implementation modalities of the land titling program. For simplicity, it will be assumed here that

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7 In several of the equations specified in the model, “dummy” variables are used. These have in general the purpose of limiting to impact of given processes of change to selected components of arrayed variables. For example, the quantity $\text{Dummy\_New\_Hholds}[\text{Hhold\_type}]$ in Equation 2, has the purpose of activating the household formation process only in the “New” component of the Household Type array.
displacement of titleless farmer will be evenly distributed over the time horizon of the simulation, starting from the second year:

\[
Eviction[\text{Zone},\text{Hhold}\_\text{type}] = \text{IF}(\text{time}<2) \text{ then } 0 \text{ else } \text{Dummy\_avencid}[\text{Hhold}\_\text{type}] \times \text{INIT}(\text{Settlers[Zone,}\text{Hhold}\_\text{type}]) / (\text{STOPTIME}-1)
\]

### 3.1.2. Outflows from the Space Seekers stock

**Migration**

As discussed earlier, some of the inhabitants of the study area tend to migrate to the municipalities of the oil district. Migration is assumed to depend on the demand for regular (i.e., non temporary) work in the oil district; this, in turn, is a function of the region’s income, and will be modeled in section 3.2, which describes the off-site economy sector.

**Land purchase**

Some of the households forming the space seekers pool may in fact benefit from the revitalization of the land market which should follow the titling regularization process. Farmers with necessary resources may purchase land instead of encroaching into remaining communal areas. It is plausible that land purchases will be more likely among established households, who might have had more saving opportunities in the past than newly formed households. It is assumed that a fraction of the evicted household will flow from the space seekers to the settlers stock through land purchases:

\[
\text{Land\_Purchasers[Zone,}\text{Hhold}\_\text{type}] = \text{INT}(\text{Delay}(\text{Eviction[Zone,Existing\_NoTitle]},1) \times \text{Percent\_wealthy\_avenc})
\]

**Searching land for subsistence farming**

The linear programming model mentioned earlier (Cervigni, 1997) provided indications on the size of the agricultural area which will be needed by new and evicted households pursuing survival strategies, with no access to land of their own. In that model it is illustrated that the size of the area converted depends on a number of factors, including access to credit, family size and employment prospects. The last two are explicitly included in this model: family size varies across household types, and the determination of the employment probability is included in the off-site economy sector of the model, as explained below (section 3.2).

The impact on land use (and thus ecosystem condition) depends on the way the demand for land of space seekers will be met. This, in turn, depends on a) the land use and conversion options available, b) the relative attractiveness of the various options, and c), given constraints on the overall area of the different land types, the way in which a given land use option will be adjudicated to different household types competing for it.

Based on the existing literature (Pare et al., 1993) on field observations, and on a priori judgment, this model proposes a conceptual framework addressing these three issues. This is summarized by the decision tree depicted in Figure 5.

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8 Based on survey information, this fraction is estimated at 15%.
Both types of space seekers, newly formed and evicted households, will be faced with a number of options to meet their demand for land. This model assumes that both groups will follow the same decision path, which dictates the land use options chosen at each of six decision nodes illustrated in Figure 5, as a function of the “state of nature” prevailing at that node. When land of a given type is not sufficient to meet the demand of the entire space seekers group, it is assumed that evicted farmers will have priority over new households. Given that evicted farmers have by definition more “seniority of residence” in the community, this may not be an implausible assumption.

In their study of deforestation in Mexico, (Barbier & Burgess, 1996) observe that a critical determinant of deforestation is the choice of whether to increase production in land already converted (previously cultivated and currently idle), or in “frontier” land. They argue that much of the forest loss is due to the fact that policies have been inducing farmers to prefer the second to the first option. In the present model, the choice of “frontier land” is not directly affected by policies, but is a result of the “space seekers” not having access to credit, and hence to land, markets.

Note that this is not necessarily a “space-efficient” allocation rule. A more efficient rule may be to allocate land across different user groups in a way that minimizes the total space requirement of those who have to be excluded from the allocation.
(*) Land purchase assumed as additional option for this group

Figure 5: decision tree for land conversion and use
Let us now elaborate on the various steps of the assumed sequential decision making process. The first option will be use of encroachable spaces\textsuperscript{11} to establish milpa-type subsistence agriculture.

Because of lower cost, conversion of communal second growth (acahual) vegetation will be preferred to conversion of primary forest (monte), which it is assumed will start only upon complete conversion of the first type of land. The number of households encroaching into acahual areas will be:

\begin{verbatim}
Encroachers_Acahual[Zone, Hhold_type] = IF(Encroachable_Acahual[Zone] > (Space_Seekers[Zone, New] * Milpa_size[New] + Space_Seekers[Zone, Existing_NoTitle] + Milpa_size[Existing_NoTitle])) THEN
INT(Dummy_non_settled[Hhold_type] * Space_Seekers[Zone, Hhold_type]) ELSE
Dummy_avencid[Hhold_type] * INT(Encroachable_Acahual[Zone] / Milpa_size[Existing_NoTitle])
\end{verbatim}

At any given time and in any given zoning unit, if space allows it\textsuperscript{12}, all space seekers will settle in remaining encroachable acahual. Otherwise, the above mentioned rule will apply, which benefits evicted households: only a certain number of evicted farmers will encroach in acahual areas. This number is given by the encroachable land under second growth divided by the per-household farm area, again borrowed from the companion model to the present one (Cervigni, 1997).

Space seekers who don’t manage to settle down in acahual land (Non_acahual_encr) are likely to follow the next option in the decision tree of Figure 5, that is conversion of monte areas:

\begin{verbatim}
\end{verbatim}

The number of encroachers in primary forest will be equal to the number of non-acahual encroachers, if there is sufficient communal monte area; otherwise, much as in the case of encroachment in second growth areas, priority will be given to evicted farmers.

**Sharing farm land with existing household ( minifundio )**

Field observations suggest that in communities with little remaining encroachable land, households in search of areas for farming tend to establish themselves in spaces already under agricultural production, which is rented (often against payment in kind of labor or crops) or borrowed from friends and relatives. This process, known locally as Minifundio, entails an increase in settlement density, and correspondingly a decrease in the average parcel size. The Minifundio is a short-term response to land scarcity, based on family and community-based exchange and support mechanisms; the Minifundio is unlikely to be sustainable in the medium to long term unless improvements in fertility conservation techniques prevent

\textsuperscript{11} Encroachment is likely to take place in land which has not yet been parcelled, as well as in private or parcelled land where topographical conditions make monitoring difficult. The percentages of encroachable land for the various zoning and administrative units of the region used in the present analysis are based on survey evidence of the communal land parceling process.

\textsuperscript{12} In each ZAU, total space needed for milpa use is given by the dot product of space seekers times milpa size across the different household types.
the decreases of yields per hectare eventually resulting from smaller crop areas and shorter fallow periods\textsuperscript{13}.

It is assumed that in communities where the average milpa size has dropped to critical thresholds\textsuperscript{14}, minifundio will no longer be a settlement option. Otherwise, all space seekers who did not manage to encroach in communal forest (primary or second growth), will turn into “minifundistas”.

\[
\text{Minifundistas}[\text{Zone}, H\text{hold}_{\text{type}}] = \begin{cases} 
0 & \text{if } \text{Non_monte_encr}[\text{Zone}, H\text{hold}_{\text{type}}] = 0 \\
\text{IF}(\text{Avg_Milpa_Size}[\text{Zone}] < \text{Minimum_Milpa_Size}) & \text{then } 0 \\
\text{else if } \text{Non_monte_encr}[\text{Zone}, H\text{hold}_{\text{type}}] 
\end{cases}
\]

Encroachment in communal land outside the community of origin

In cases where encroachment in communal areas is not possible and settlement density is too high, space seekers may turn to other nearby communities to meet their demand for land. Precise modeling of inter-community migration would require a great deal of information on resettlement and transport costs, patterns of relative land fertility and so forth. In the present context, it is assumed that a) space seekers coming from land units with a land deficit will be evenly distributed across land units with remaining land availability; b) outsiders will only encroach in monte areas; and c) land sharing (minifundio) outside of the community of origin will not take place (it is likely that kin-based support mechanisms will be less common outside the community of origin).

\[
\text{Off_site_encroachers}[\text{Zone}, H\text{hold}_{\text{type}}] = \begin{cases} 
0 & \text{if } \text{Non_minifund}[\text{Zone}, H\text{hold}_{\text{type}}] = 0 \\
\text{IF}(\text{Non_minifund}[\text{Zone}, \text{New}] * \text{Milpa_size}[\text{New}] + \text{Non_minifund}[\text{Zone}, \text{Existing_NoTitle}] * \text{Milpa_size}[\text{Existing_NoTitle}] + \text{Non_minifund}[\text{Zone}, \text{Existing_Title}] * \text{Milpa_size}[\text{Existing_Title}] < \text{Total_encr_monte}) & \text{then } 0 \\
\text{else if } \text{Dummy_avencid}[H\text{hold}_{\text{type}}] * \text{INT}(\text{Total_encr_monte}/\text{Milpa_size}[\text{Existing_NoTitle}]) 
\end{cases}
\]

The demand for encroachment outside the community of residence is given by all those households that have not been able to settle down as minifundistas (and, by implication, who were not able to encroach in communal forested areas). The supply of potential settlement space will be given by the sum of remaining encroachable monte areas in all the ZAU's of the study area. If that area is smaller than the dot product of non-minifundistas, times milpa sizes, across the different household types, only evicted farmers will be able to encroach in primary forest located outside the community of origin.

Landless households

Where no settlement options is available, households will flow out of the space seekers pool and will add to the stock of landless farmers\textsuperscript{15}. These destitute households will only be able to support themselves through temporary employment, and through extraction of natural products from forested areas in the buffer and nucleus zone.

\[
\text{Marginalization}[\text{Zone}, H\text{hold}_{\text{type}}] = \text{Non_minifund}[\text{Zone}, H\text{hold}_{\text{type}}] - \text{Off_site_encroachers}[\text{Zone}, H\text{hold}_{\text{type}}]
\]

\textsuperscript{13} See (Buckles & Erenstein, 1996) for a discussion of causes of, and remedies to, the declining productivity of maize-based systems in the region.

\textsuperscript{14} For heuristic purposes, the numerical value of this minimum average milpa size threshold has been set at 2 has.

\textsuperscript{15} Initial values for this stock are taken from table 4-10, column “totally landless”.

17
3.2. The off-site economy sector

This sector is the market for goods and services not exchanged within the household sector, but rather supplied for external purchase or hiring. In this model there are three main types of transaction between the rural household sector and the rest of the region’s economy: a) the sale of forest products (Chamedor Palm) b) the sale of livestock products (milk and beef), and c) and the supply of labour.

However, in order to concentrate the subsequent policy analysis on a limited number of key parameters, the attention will be focused on the last two variables (livestock and labor supply), leaving aside explicit modeling of the Chamedor Palm market\(^\text{16}\).

The off-site economy sector is the “gate” through which the national and global economies affect productive activities and natural resource use in the Sierra. As it will be discussed in this section, aggregate production and income in the southern Gulf of Mexico oil district are assumed to determine the demand for products and services exported by the Sierra. Output in the oil district is clearly responsive to the overall volume of activity of Mexico’s economy, which in turn, in a context of growing integration in the global markets, is affected by the world economy. Based on the objective of this research, the linkages between regional, national and global economy, albeit important, will not be addressed here.

3.2.1. Labour markets

Labor market modeling will be by necessity simple, given the fact that the main emphasis of this research is on the rural sector, and that during field work it was possible to collect only a limited amount of information on the urban sector’s labour market.

Households of the study area may supply labor to the off-site economy in two ways: permanent migration and temporary employment. Equilibrium in both markets is achieved through adjustments in the quantities supplied; wages are assumed constant and equal to the marginal products of labor. Let us look at the way demands for temporary and regular labor are determined.

\(^{16}\) Constant farmgate prices for Palm will be assumed, on the grounds that a) most of the sales are for exports outside the region, and in part outside the country, so that regional policy makers are unlikely to be able to exercise control on Palm’s price; b) the Sierra is a small producer, and hence unable to affect Palm prices.
Figure 6 The off-site economy sector
The starting point is the assumption of a simple production function for the aggregate output of the trade, manufacture, mining and services industries, whereby production is a function of regular labour, non-regular or unskilled labour, and capital:

\[ Y = f(L^R, L^{NR}, K) \]

**Equation 3**

Data on 1994 employment of regular and non-regular labour and on value of aggregate production was obtained from the Economic Census for that year (INEGI, 1994; INEGI, 1997). The data is available at the municipio level of aggregation; so that information was collected on the four municipalities which provide most of employment opportunities in the region: Acayucan, Coatzacoalcos, Cosoleacaque, and Minatitlan.

For each labour type (regular, non regular), the ratio, \( y_L \), between the value of production \( Y \), and labour input, \( L \), gives the average value of product of that labour type: \( y_L = Y/L \). At any point in time the demand for each labour type is simply the product of the value of output times the reciprocal of the average value product of labour. For example, assuming a simple exponential growth of income, demand for labour at time \( t \) is (\( r \) is income’s growth rate)

\[ L_t = \frac{Y_0 e^{rt}}{y^L_t} \]

**Equation 4**

The actual value of the demand for labor depends on the assumed behavior of the average (value) product of labour, which in turn depends on assumptions on technical progress. Assumption on technical progress are important in the context of the present study area: the various reorganization plans being formulated for the oil district suggest that labor intensity of production in a number of firms of the manufacture and service sectors may decrease, with important consequences for overall employment patterns in the region.

With no technical progress, the average product of labor stays the same, which amounts to dropping the time subscript in Equation 4: labor demand always grows (and at a constant rate) when production grows. With technical progress that substitutes the selected labor type with other inputs, the correspondence between increase in production and increase in labor hiring no longer always holds.

One simple way of describing the impact of technical progress on the demand for labor is to express the average (value) product as an exponential function of production increase:

\[ y^L_t = y^L_0 e^{\rho (Y - Y_0)} \]

**Equation 5**

where \( y^L_0 \) is the initial value of the average value product of labor, \( Y_0 \) is the initial level of income, and \( \rho \) is a rate of growth parameter. If \( \rho = 0 \), there is no technical progress, and the average product of labor is constant along the production’s expansion path. If \( \rho > 0 \), the average product of labor for given level of output increases with production. Whether the actual demand for labor will in fact increase depends on whether the “income” effect associated to the increase in production prevails over the “substitution”
effect (less labor necessary per any level of output). The two possibilities are addressed in the model’s simulation through appropriate choice of the technical change parameters in a scenario analysis (see section 4).

Initial values of the demand for labor and average labor product are obtained from INEGI data, as explained in detail in Annex 1. The equations for the demand for labor are thus:

\[
\text{Perm\_labor\_demand} = \frac{\text{Income}}{\text{Avg\_labor\_product}[\text{Perm}]}
\]
\[
\text{Temp\_Labor\_demand} = \frac{\text{Income}}{\text{Avg\_labor\_product}[\text{Temp}]}
\]

The equation(s) for the average value product of labor (which reiterates Equation 5) is:

\[
\text{Avg\_labor\_product}[\text{Labor\_type}] = \text{Initial\_Avg\_labor\_product}[\text{Labor\_type}] \times \exp(\text{Change\_of\_labor\_demand}[\text{Labor\_type}] \times (\text{Income\_billion\_N$} - \text{INIT(Income\_billion\_N$))})
\]

So much for the demand for labor; let us now turn to the determination of the equilibrium quantities in the two segments of the labor market.

Temporary employment. As discussed in the LP model mentioned earlier, a given portion of the total household’s time will be supplied in the labor market of the urban sector for temporary employment. The actual amount of household’s labor supplied will respond to the perceived probability of finding employment.

This probability, in turn, will also affect household’s decisions concerning agricultural land and natural product extraction: the subsistence constraint will be met by a combination, on the one hand, of use of natural resources obtained from the wild and from agriculture, and, on the other hand, of cash income earned through temporary employment. Higher employment chances will decrease farm land size and natural products extraction.

It is assumed that the probability of finding temporary employment is simply the ratio between the demand and the supply for temporary labour:

\[
\text{Employment\_chance} = \frac{\text{Labor\_demand}}{\text{Max(\text{Temp\_labor\_supply}, \text{Labor\_demand})}}
\]

The initial stock of temporary workers is increased by the process of temporary job search:

\[
\text{Temp\_labor\_supply}(t) = \text{Temp\_labor\_supply}(t - \text{dt}) + (\text{Temp\_job\_search}) \times \text{dt}
\]

The total temporary job seekers’ flow depends on size of the space seekers pool, as well as on the labor supplied by each household. At any time, labour supply decisions are taken on the basis of the previous period’s value of the employment chance (which is expected to prevail in the current working season):

\[
\text{Labor\_supply\_per\_Hhold[Hhold\_type]} = \text{Delay}[\text{Employment\_chance}, 1]
\]

Total supply of temporary labour is given by the dot product of per household labour supply times the total number of households of various types in the different ZAUs:

\[
17 \text{ In order for this ratio not to exceed one, the actual expression used in the model is: probability of empl = l_d / Max (l_d, l_s), where the subscripts refer to labor demand and supply, respectively.}
\]
Migration and regular employment.
In this model, migration simply responds to excess demand for regular labor. Given a “labor gap” between the demand for permanent labor and the stock of regularly employed workers:

\[ Perm\_labor\_gap = Perm\_labor\_demand - Regularly\_employed \]

total migration will cover the employment gap; the distribution of migration across the different ZAUs will be proportional to each ZAU’s share in the total space seekers pool:

\[ Migration[Zone,Hhold\_type] = INT(Perm\_labor\_gap * Space\_Seekers[Zone,Hhold\_type] / Max(1, Total\_space\_seekers)) \]

3.2.2. Demand for livestock products

As discussed in the literature (Toledo, 1992; Barbier & Burgess, 1996), the expansion of cattle ranching activities depend on a variety of factors, including local, national and international demand for meat and dairy products, relative prices, public policies, availability of suitable pasture land.

In the study area livestock development, widely encouraged by proactive public policies, has been one of the main driving forces of social change and natural habitat modification in the region. Most of the public programs supporting cattle ranching have been discontinued in recent years; the future of ranching in the region is therefore likely to depend mainly on relative output and input prices, and patterns of demand.

On the unit margin front, prospects may improve because of the devaluation-induced increased competitiveness of the region’s low-inputs ranching system. More uncertainty is associated to the evolution of demand in presence of stagnating or falling production (and hence income) in Mexico’s economy, and in particular in Veracruz oil district. The present analysis therefore focuses on the impact of income (via demand for livestock products) on cattle ranching activities.

It is assumed that cattle herds adjust to variation in demand for livestock products. In the absence of detailed information on the demand for individual products (milk, meat from various beef types, etc.), we have to use the number of heads of cattle as the actual dependent variable in the demand function. This may not be an implausible first order approximation: if the demand for meat or milk increases, there will need to be more animals to be milked or slaughtered.

Given the nature of the data collected during the field work of this research, it was not possible to estimate the demand for cattle numbers directly. Rather, it was assumed that, based on an underlying demand function \( C=f(P, Y) \), cattle number adjust to changes in income via an elasticity coefficient. An initial value for this coefficient was borrowed from the Mexico study of Barbier and Burgess (Barbier & Burgess, 1996). Based on cross-country regressions estimated on state-level data, these authors find

\[ \text{It is assumed that the adjustment in cattle numbers and thus pasture (the latter is addressed in section 3.3.2) follows a short-term increase in price of livestock products caused, for given herd sizes, by higher demand.} \]
that a 1% percent increase in income generates a 0.09% increase in cattle numbers\textsuperscript{19}. At the beginning of the simulation, there is a stock of cattle in the study area, which reflects previous patterns of demand for livestock products. Increase in demand for cattle in excess of the existing stock are given by the livestock demand’s income elasticity, times the increase in income:

\[
\text{Increase\_Cattle\_Demand} = \text{INT}(\text{Elasticity\_cattle\_demand} \times \text{DERIVN}(\text{Income\_billion\_N\$}, 1) \times \frac{\text{Demand\_for\_Cattle}}{\text{Income\_billion\_N\$}})
\]

When the demand for cattle numbers increases, herds sizes in the different ZAUs are adjusted in proportion to their relative share in the regions’ total herd size.

\[
\text{Cattle\_Expansion[Zone]} = \begin{cases} 
\text{INT}(\text{Demand\_for\_Cattle} - \text{Total\_Cattle}) \times \frac{\text{Cattle[Zone]}}{\text{Total\_Cattle}} & \text{if Increase\_Cattle\_Demand > 0} \\
0 & \text{otherwise}
\end{cases}
\]

\textbf{3.3. The land use sector}

This sector of the model studies the variation over time of a selected number of stocks of land uses: primary forest or monte, secondary forest or acahual, farm land or milpa, and pasture. In addition, it also examines the impact of human activities on the stock of a resource extracted from forested areas, Chamedor Palm. As visualized in Figure 7, conversion and/or regeneration flows link the various stocks. For example, forest conversion determines the decrease of the monte or acahual stocks, as well as the corresponding increase of the milpa or pasture stocks; conversely, regeneration flows determine increases in the stock of acahual at the expenses of pasture land.

\textsuperscript{19} However, it is plausible that, as income grows, the weight of meat consumption in the average diet increases. If this is the case, the income elasticity of cattle numbers will not be constant, but rather positively correlated with income. As explained in \textit{Annex 2}, the model assumes a logistic growth of the elasticity of cattle numbers, from an initial to a ceiling level.
Figure 7 The land use sector
(Note: for visual simplicity, the diagram reproduces only stocks and flows, and not the converters that link them)
3.3.1. Land conversion to agriculture

Based on the number of encroachers determined in the land tenure sector of the model, in any given zone conversion of acahual to milpa is given by:

\[
Conversion_{\text{Acahual to Milpa}}[\text{Zone}] = \begin{cases} 
\text{IF}(Encroachable_{\text{Acahual}}[\text{Zone}] > 0) & \text{THEN} \\
\text{(Encroachers}_{\text{Acahual}}[\text{Zone,New}] \times \text{Milpa}_{\text{size}}[\text{New}] + \text{Encroachers}_{\text{Acahual}}[\text{Zone,Existing,NoTitle}] \times \text{Milpa}_{\text{size}}[\text{Existing,NoTitle}] + \text{Encroachers}_{\text{Acahual}}[\text{Zone,Existing,Title}] \times \text{Milpa}_{\text{size}}[\text{Existing,Title}]) & \text{ELSE} 0 
\end{cases}
\]

That is, subject to space availability, conversion is equal to the dot product of the number of encroachers times the size of milpa area (as determined in the LP model referred to earlier) across the different household types. The same dot product applies to the conversion of primary forest to farm areas, which, as indicated in the tenure sector of the model, does not start before all encroachable areas under secondary vegetation have been cleared:

\[
Conversion_{\text{Monte to Milpa}}[\text{Zone}] = \text{Encroachers}_{\text{Monte}}[\text{Zone,New}] \times \text{Milpa}_{\text{size}}[\text{New}] + \text{Encroachers}_{\text{Monte}}[\text{Zone,Existing,NoTitle}] \times \text{Milpa}_{\text{size}}[\text{Existing,NoTitle}] + \text{Encroachers}_{\text{Monte}}[\text{Zone,Existing,Title}] \times \text{Milpa}_{\text{size}}[\text{Existing,Title}]
\]

In addition to conversion carried out by community residents, primary forest areas may also be cleared by space seekers coming from other communities:

\[
\text{Off-site monte conversion}[\text{Zone}] = \begin{cases} 
\text{IF}(Encroachable_{\text{Monte}}[\text{Zone}] - Conversion_{\text{Monte to Milpa}}[\text{Zone}] > \text{ARRAYSUM(Milpa}_{\text{needed off-site}}[\ast]) \times \text{Perc tot encr monte}[\text{Zone}]) & \text{THEN} \\
\text{ARRAYSUM(Milpa}_{\text{needed off-site}}[\ast]) \times \text{Perc tot encr monte}[\text{Zone}] & \text{ELSE} 0 
\end{cases}
\]

Equation 6

Equation 6 indicates that in any community, provided that even after local encroachment, there are still areas of primary forest available for outsiders, total demand for off-site milpa will translate into conversion in proportion to the community’s share of total remaining forest. Demand for off-site milpa, in turn, will again be given by the dot product of off site encroachers times the size of milpa area across the different household types:

\[
\text{Milpa}_{\text{needed off-site}}[\text{Zone}] = \text{Off-site encroachers}_{\text{Zone,New}] \times \text{Milpa}_{\text{size}}[\text{New}] + \text{Off-site encroachers}_{\text{Zone,Existing,NoTitle}] \times \text{Milpa}_{\text{size}}[\text{Existing,NoTitle}] + \text{Off-site encroachers}_{\text{Zone,Existing,Title}] \times \text{Milpa}_{\text{size}}[\text{Existing,Title}]
\]

3.3.2. Pasture

Pasture is the largest use of land in the study area. Historical and current processes of land conversion to pasture are the result of a complex interplay of policy, tenure, social and technology factors, some of which have been studied in detail elsewhere in the literature on the region (Buckles, 1987; Chevallier & Buckles, 1995) (Lazos, 1995). The analysis of the process provided by the rest of this subsection (and complemented by Annex 3) is a simplified one.

On the basis of the LP companion model (Cervigni, 1997), households without tenure are unlikely to convert communal forested land for pasture; therefore, the present model focuses on ranches already established in private land. Inflows to the Pasture stock come from (young and mature) acahual lands,
and both on-site and off-site conversion of Monte; outflows are related to the process of pasture abandonment.

\[
\text{Pasture}[\text{Zone}, \text{Land Type}](t) = \text{Pasture}[\text{Zone}, \text{Land Type}](t - \Delta t) + \\
(\text{Conversion_{acahual to pasture}}[\text{Zone}, \text{Land Type}] + \text{Conversion_{Monte to Pasture}}[\text{Zone}, \text{Land Type}] + \\
\text{Conversion_{off site monte pasture}}[\text{Zone}, \text{Land Type}] + \\
\text{Conversion_{Young_Acahual pasture}}[\text{Zone}, \text{Land Type}] - \text{Pasture_abandoning}[\text{Zone}, \text{Land Type}])\times \Delta t
\]

Conversion of land from other uses to pasture may take place either to support a fixed herd when overgrazing leads to declining productivity in existing grazing lands, or to enable herd expansion. This model addresses both sources of demand for additional pasture land. At any point in time, conversion to pasture is given by the sum of pasture to be replenished following abandonment of overgrazed land, and of new pasture required to meet increase in the demand for cattle numbers (determined, as explained in section 3.2, in the off-site economy sector):

\[
\text{Demand for pasture}[\text{Zone}, \text{Land Type}] = \text{Dummy_Private_space}[\text{Land Type}] \times \left( (1 - \text{Percent_Undergrazed}[\text{Zone}, \text{Land Type}]) \times \text{Cattle Expansion}[\text{Zone}] / \text{SR_Max}[\text{Zone}, \text{Land Type}] + \text{Pasture_abandoning}[\text{Zone}, \text{Land Type}] \right)
\]

**Equation 7**

Equation 7 says that not all of the increased demand for cattle is met by pasture increase. In undergrazed lands, herds increase by simply increasing the stocking rate (heads of cattle per hectare)\(^\text{20}\). Conversely, in overgrazed areas, conversion to pasture will be given by the ZAU’s share in herd expansion divided by the going stocking rate\(^\text{21}\). The first option for meeting the demand for pasture is conversion of young *Acahual*. In particular, there will be a fraction of young *Acahual* that is converted to pasture:

\[
\text{Conversion_{Young_Acahual pasture}}[\text{Zone}, \text{Land Type}] = \text{LEAKAGE OUTFLOW; LEAKAGE FRACTION} = \text{Min}(1, (\text{Demand for pasture}[\text{Zone}, \text{Land Type}] / \text{Max}(1, \text{Young_Acahual}[\text{Zone}, \text{Land Type}])))
\]

The fraction is given by the ratio between the demand for pasture and the stock of Young *Acahual*, if this is less than one; if the fraction is larger than one, then all the existing stock will be converted to pasture, and the difference will be made up for by the existing mature acahual:

\[
\text{Conversion_{acahual to pasture}}[\text{Zone}, \text{Land Type}] = \text{IF}(\text{Acahual}[\text{Zone,Private}] > 0) \text{ then} \\
(\text{Demand for pasture}[\text{Zone}, \text{Land Type}] - \text{Conversion_{Young_Acahual pasture}}[\text{Zone}, \text{Land Type}]) \text{ else} \\
0
\]

If the demand for replenishment or new pasture can not be met by conversion of *acahual* areas, conversion of primary forest takes place:

\[
\text{Conversion_{Monte to Pasture}}[\text{Zone}, \text{Land Type}] = \text{Demand for pasture}[\text{Zone}, \text{Land Type}] - \\
(\text{Conversion_{acahual to pasture}}[\text{Zone}, \text{Land Type}] + \\
\text{Conversion_{Young_Acahual pasture}}[\text{Zone}, \text{Land Type}])
\]

\(^{20}\) The division of pasture in over- and undergrazed land, and the process of regeneration of young and mature *Acahual* are both explained in *Annex 3*. 
If there is still an excess demand because all accessible land has been cleared in communities with herds in excess of going stocking rates, the deficit may be met by converting forested land in neighboring communities, and renting the resulting pasture to the ranchers of the deforested communities. Conversion in communities with remaining forest will take place by distributing the pasture deficit in proportion to the community’s share in total monte:

\[
Conversion_{off\_site\_monte\_pasture}[Zone,\text{Land\_Type}] = \text{Dummy}_{Private\_space}[\text{Land\_Type}] \times \text{ARRAYSUM}(\text{Pasture\_deficit}[*],Private) \times \text{Monte}[\text{Zone},Private]/(\text{Max}(1,\text{Total\_private\_Monte}))
\]

### 3.3.3. Forest extraction

Settlers in the various zoning units extract a variety of products from forested areas; however, only *Chamedor* Palm’s extraction will be modeled here.

On the basis of the recorded altitudinal distribution of extracted species, Palm populations are likely to be found in parts of the total area under primary forest in the core and buffer zones (approximately 50% of it). Accretions to the stock of Palm are given by the process of generation. For simplicity, a simple logistic growth process is assumed here, whereby the stock grows at a given rate per annum, up to the attainment of the habitat carrying’s capacity.

![Graph 1 (Untitled)](image_url)

**Figure 8: logistic growth of Palm stock when the habitat shrinks**

Once this level is reached, and in the absence of other perturbations, the population stabilizes. Carrying capacity is pragmatically determined by multiplying the observed density of plants per hectare, times the area of the habitat suitable for the species. As the latter decreases over time because of land conversion, the shape of the logistic growth functions shifts downwards over time as well, as illustrated.

---

21 The stocking rate used for determining conversion is the maximum, over a range of possible values prevailing in each ZAU: newly converted land are likely to be initially rich in nutrient, and thus able to support relatively large number of animals. Additional details on the estimation of stocking rate ranges are provided in Annex 3.
in Figure 8. The diagram assumes a density of 350 gruesas per ha, and a habitat of 100 has in the case of the upper curve, and of 80 has, in the case of the lower curve.

The equation for the process of Palm generation is thus:

\[
\text{Palm\_generation}[\text{Zone}] = \text{Palm\_presence\_per\_zone}[\text{Zone}] \times \text{Palm\_stock}[\text{Zone}] \times \\
\text{Rate\_of\_Palm\_generation}[\text{Zone}] \times (1 - (\text{Palm\_stock}[\text{Zone}] / (1 - \text{Palm\_presence\_per\_zone}[\text{Zone}] + \text{Habitat\_carrying\_cap}[\text{Zone}])))^{22}
\]

In each zone, a given percentage\(^{23}\) of the various household types will be carrying out extraction activities. Extraction intensity figures (i.e. gruesas per household per annum) are based on the estimates of LP companion model. These, in turn, are sensitive to employment opportunities off site: the better the chance of temporary employment in the oil district, the lower the extraction of Palm from the wild.

Extraction takes place mostly under condition of open access; to capture this feature, it is assumed that extraction activities will be distributed across the different ZAUs in proportion to the relative availability of Palm (proxied by the ZAU’s relative share of total Palm’s habitat):

\[
\text{Palm\_extraction}[\text{Zone}] = \text{ARRAYSUM}[\text{Extraction\_per\_zone}[*]] \times \text{Relative\_Palm\_Habitat}[\text{Zone}]
\]

Extraction per zone, in turn, is given by the usual dot product of extraction across household types:

\[
\text{Extraction\_per\_zone}[\text{Zone}] = \text{Extractors}[\text{Zone},\text{New}] \times \text{Palm\_per\_Hhold}[\text{New}] + \\
\text{Extractors}[\text{Zone},\text{Existing\_NoTitle}] \times \text{Palm\_per\_Hhold}[\text{Existing\_NoTitle}] + \text{Extractors}[\text{Zone},\text{Existing\_Title}] \times \\
\text{Palm\_per\_Hhold}[\text{Existing\_Title}]
\]

Extractors come from the settlers and landless farmers stocks:

\[
\text{Extractors}[\text{Zone},\text{Hhold\_type}] = \text{INT}((\text{Landless\_Hholds}[\text{Zone},\text{Hhold\_type}] + \text{Settlers}[\text{Zone},\text{Hhold\_type}]) \times \\
\text{Percent\_gatherers}[\text{Hhold\_type}])
\]

\(^{22}\) In a standard logistic growth function, the term in the last denominator would normally be: \text{Habitat\_carrying\_cap}[\text{Zone}]; the term actually used (1 - \text{Palm\_presence\_per\_zone}[\text{Zone}] + \text{Habitat\_carrying\_cap}[\text{Zone}]) has the purpose of avoiding division by zero in the ZAUs with no recorded presence of Palm populations.

\(^{23}\) Base on field evidence, it is estimated that this percentage is of 6.5% and 2% for the buffer and influence zone, respectively.
4. Results

Based on the equations illustrated in the previous sections, the model is capable of simulating the behavior over time of several stocks and flows in the household, land use and off-site economy sector. Clearly, the results will depend on assumptions on several parameters, related to the overall state of the regional economy, the demand for the study area’s agriculture and forest products, farming technology, tenure adjustments, and to the ecosystem’s ability to recover from perturbations. In this section, I will first present, for illustrative purposes, results related to a reference, or baseline case; then, I will analyze how results are affected by changes in key exogenous, and policy-controlled parameters.

4.1. Reference case

A reference case is presented in this section, with the purpose of both illustrating the kind of diagramatic results generated by the model, and of providing a benchmark for the subsequent sensitivity analysis. The reference case is based on the assumption of zero income growth in the off-site economy sector (a pessimistic extrapolation of the situation prevailing at data collection time). A first set of results refers to changes in the various stocks of population inside and outside the study area. Figure 9 displays the behavior of the stock of permanent migrants to, and temporary workers in, the urban area; the stock of settlers in the study area, and the stock of landless farmers.

![Figure 9. Reference case: migration, settlers and landlessness](Graph 4 (Untitled))

(Units: temporary employment in days of work per annum; other variables in number of people)

If income is constant, there will be no opportunities for new permanent employment, there will be stagnating or declining chances of temporary employment, and increasing number of destitute households. Therefore, in Figure 9 the number of settlers grows, but so does (and at an increasing rate) the stock of landless household. Given declining employment opportunities on the temporary job market, the supply of temporary labor stagnates.
The lack of income growth has clear implications on land use patterns. Figure 10 illustrates some of the most significant trends.

**Figure 10 Reference case: land use (Has)**

While pasture land is stationary (no additional demand for livestock products), farm land increases significantly at the expenses of both secondary and primary forest, in order to accommodate the subsistence needs of a growing number of aspiring settlers with no alternative income sources. The reason why *milpa* stabilizes before year 10 of the simulation is not that the demand for land decreases, but rather that communal spaces are being exhausted, as illustrated by Figure 11. Both primary and second growth forest in communal land shrink towards rapid exhaustion to meet space seekers’ demand for land.
Changes in private forest are driven by the need of maintaining pasture for a stationary cattle herd. As described in section 3.3.2 and in Annex 3, the rate of nutrient accumulation and of transition to mature acahual, as well as the speed of the overgrazing process, determine the feature of the process. If secondary succession is rapid enough, and overgrazing slow enough, the impact on primary forests may be limited. In Figure 12, which assumes nutrient storing time (T_n) and regeneration time (T_r) of 2 and 3 years respectively, after an initial drop due to the replacement of overgrazed land, Acahual picks up again around the initial level; primary forest tends to stabilize at about 70% of the initial level.

However, if regeneration is slow and/or overgrazing fast, monte can quickly be depleted: with T_r=3, T_w=4 and an average duration of the overgrazing process of seven years, the entire stock of private monte is cleared after 15 years (not shown in Figure 12).
The high dependency of the region’s households (especially those without secure land tenure) on natural resources, in the absence of other income sources, has clear impacts on Chamedor Palm populations. Figure 13 plots the behavior of the habitat’s carrying capacity, and of the total stock of Palm (both are measured in *gruesas* - a *gruesa* is a bunch of 12 leaves). As primary forest shrinks, carrying capacity drops to the level that can be supported by the nucleus zone (due to poor access, the nucleus zone is assumed unaffected by deforestation); the Palm stock, however, is exhausted much earlier because of excessive extraction. Sensitivity analysis indicates that depletion occurs for all rates of Palm growth below 1.7.

**4.2. Variations in exogenous parameters**

Most of the above results are likely to be affected by changes in the various parameters of the model. Given the purposes of this paper, I will concentrate on changes in:

a) two exogenous parameters: a1) the rate of growth of the regional income, \( r \), and a2) the regeneration time of second growth forest, \( T_r \), intended as a measure of the ecosystem’s ability to recover from human-induced perturbations (see Annex 1 for details on the process of secondary forest regeneration and the role of \( T_r \));

b) one “semi-exogenous” parameter, i.e. a parameter which may be partially affected by local policy makers (see ensuing discussion, section 4.3): the rate of change of the marginal (value) product of labor \( r_r \), defined in Equation 5.

c) two parameters capturing effects of local policy making choices: b1) the percentage of “wealthy avencidados” i.e., the percentage of households without secure title that have enough means to access land markets, therefore avoiding eviction; and b2) the availability of technology for intensifying farming practices (see section 4.3 for details).

Variations in a) and b) will be studied in this section; section 4.3 will extend the analysis to variations in c). Different sets of results can be obtained, depending on the value taken on by the various parameters. To keep the analysis simple, only a relatively small numbers of scenarios are considered, based on the assumption that each parameter can only take “low” and “high” values.
heuristically determined. The total number of scenarios is $H=2^q$, where $q$ is the number of parameter that are allowed to vary.

In order to compare results of this section with results obtained under different policy interventions (section 4.3), it is necessary to select key features of the land use change process, and aggregate them into a single index, representing the “desirability” -in terms of likely impacts on human welfare- of changes prevailing in the various scenarios. A given policy may then be deemed “successful” in terms of addressing land use change concerns if it can increase the index under the various scenarios considered. Let us see how such an index may be constructed.

As indicated at the beginning, much of the debate on “deforestation” is motivated by its possible impacts on the ability of the ecosystem to deliver services affecting human welfare. The underlying argument is that land under some uses (typically forested land) is better suited to deliver eco-services than land under other uses; so a reduction in the area of forested land will decrease the provision of ecological services. However, size of perturbations may not be the only thing that matters. The ability of any given type of land to deliver eco-services may also be affected by the frequency of shocks. For example, an area under secondary forest may be periodically cleared for agriculture; even though vegetation may be able to regenerate in between clearances, some species residing in the area my suffer if the time between one shock and the other is too short.

Ideally, then, the impacts of human welfare of a change in the pattern of land use, would need to be assessed on the basis of the size and frequency of disturbances, and on some measure of how much, say, a large disturbance in one form of land use may be compensated by stability in another form of land use. It seems reasonable to have such an index depend positively on conservation of the various forms of vegetation cover, and negatively on the frequency and magnitude of changes in land uses.

Furthermore, changes in different stocks of land uses will affect the index differently, as there will be some types of vegetation cover (e.g., primary forest) that will contribute more than others to the maintenance of the overall ecosystem stability and to the provision of ecological services

It has be noted that different environmental management objectives will be represented by different selections of land uses (and associated size and frequency of change), and different coefficient of substitution of one land type for another. For example, if the management objective is the sustainability of agricultural production, changes in the various types of farm and pasture land are likely to be included in the index; substitution of some form of forested land with some forms of farm land may be associated, through appropriate choice of the function’s parameters, with constant or increasing levels of the utility index.
It is assumed here that the primary concern of an “environmental planner” is conservation of
the various forms of forest cover. A simple index of utility of such an environmental planner is
defined here, which increases in the end-of-simulation areas under primary \( m_T \) and secondary
\( a_T \) forest cover (relative to the their respective initial values), and decreases in the variability
over time of those areas (proxied by the relative variance -the coefficient of variation squared).
A simple Cobb-Douglas form is used:

\[
U = \left( \frac{m_T}{\sigma_M / \bar{M}} \right)^\alpha \left( \frac{a_T}{\sigma_A / \bar{A}} \right)^{1-\alpha}
\]

Equation 8

where \( \sigma_M \), \( \sigma_A \), \( \bar{M} \) and \( \bar{A} \) are standard deviation and average, respectively, for the stocks of
monte (primary forest) and acahual (secondary forest). The premium attached to large size and
low variability in primary forest is captured in the simulation by a value of \( \alpha \) of 0.8.

Table 1 summarizes the impacts on land and resource use in the eight scenarios given by a binary
variation in the three parameters \( r \) (the rate of regional income growth) \( r \), (the rate of growth
of the marginal product of labour) and \( T_r \) (acahual regeneration time). Case A is associated with the
highest value of the utility index (highest end-of simulation stocks of primary forest and Chamedor
Palm), case H with the lowest one (total depletion of primary forest). These two cases indicate that
land use impacts tend to be stronger when income growth is slow (less opportunities for off-farm
employment), and when the agro-ecosystem recovers more slowly (at any point in time, less fallow
land will be ready for conversion to farming, which increases encroachment in primary forest).

The scenarios comprised between A and H give us an idea of the interplay of the exogenous
parameters in determining impacts on land use patterns. A fast rate of ecosystem regeneration may
partially compensate for slow growth in income (cases B and C); at the same time, higher income
growth may also lead to significant land use impacts (case G) when labor-replacing technical
progress (\( r = 5\% \)) decreases employment opportunities for unskilled labour.

An important observation concerns the process of land idling. Table 1 suggest that at mid-
simulation time idle land amounts to a considerable 20-30% of farm land, and 15% of pasture land.
This points to the potential for investments in soil conservation and improvement; these can prevent
excess land abandonment, thereby providing a significant alternative to forest conversion to farmers
seeking land for subsistence cultivation.
<table>
<thead>
<tr>
<th>Units</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td>1.5%</td>
<td>1.5%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>1.5%</td>
<td>5.0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>( Tr )</td>
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<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
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<tr>
<td>( r )</td>
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<td>5.0%</td>
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<td>5.0%</td>
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### Stocks

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<tr>
<th>Stock</th>
<th>Acahual (t=0) Has</th>
<th>Acahual (t=10) Has</th>
<th>Acahual Final Has</th>
<th>Monte (t=0) Has</th>
<th>Monte (t=10) Has</th>
<th>Monte Final Has</th>
<th>Idle (t=0) Has</th>
<th>Idle (t=10) Has</th>
<th>Idle Final Has</th>
<th>Palm stock (t=0) Gruesas</th>
<th>Palm stock (t=10) Gruesas</th>
<th>Palm stock Final Gruesas</th>
<th>Relative Variance Monte</th>
<th>Relative Variance Acahual</th>
<th>&quot;Utility&quot;</th>
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<td>1,093</td>
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<td>11,953</td>
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<td>10,846</td>
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<td>14,280</td>
<td>15,580</td>
<td>9,193</td>
<td>6,228</td>
<td>6,233</td>
<td>3,799</td>
<td>5,399</td>
<td>5</td>
<td>5</td>
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<td>18,876</td>
<td>18,876</td>
<td>18,876</td>
<td>18,876</td>
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<td>6,560</td>
<td>7,281</td>
<td>1,093</td>
<td>857</td>
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<td>8,022</td>
<td>7,914</td>
<td>6,560</td>
<td>7,281</td>
<td>1,093</td>
<td>857</td>
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<tr>
<td>Monte Final Has</td>
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<td>6,228</td>
<td>6,233</td>
<td>3,799</td>
<td>5,399</td>
<td>5</td>
<td>5</td>
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<td></td>
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<td>9,904</td>
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<tr>
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<td>6,228</td>
<td>6,233</td>
<td>3,799</td>
<td>5,399</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Palm stock (t=0) Gruesas</td>
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<td>3,283,000</td>
<td>3,283,000</td>
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<td>3,799</td>
<td>5,399</td>
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<td>0</td>
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</tr>
<tr>
<td>&quot;Utility&quot;</td>
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</tbody>
</table>
4.3. Policy implications

This section will explore two sets of options that local policy makers may pursue to reduce pressure on primary and secondary growth vegetation cover in the study area.

Intensifying agricultural activities

A first set of options refers to improvement in farming practices that would reduce the amount of land for given output. It is widely recognized that one of the key factors of loss of forested areas induced by swidden agriculture is the low productivity per hectare of key staple crops sowed by subsistence farmers in rain fed land (Southgate, 1991; Southgate, 1995; Barbier & Burgess, 1996). If credit, information or capacity constraints prevent access to productivity raising technology, total yields can only be increased by increasing cultivated areas.

In the Sierra de Santa Marta, a detailed analysis of constraints to, and opportunities for, intensifying baize-based systems has recently been provided by (Buckles & Erenstein, 1996). According to these authors, current patterns of maize cultivation are characterized by relative large size of total crop area per household, and relatively long fallow times. Sustainable intensification of the current system would be achieved through a combination of technologies that increase fertility (green manures and fertilizers) and that ensure better conservation of existing fertility (green manures, shelter belts and live barriers in contour lines).

Based on this combination, it would be possible to reduce (in an equilibrium that would follow a transition period of one to three years) fallow time to just one year, and decrease total crop area to 33% or 50% of the original parcel size, depending on whether the intensification technology is applied to the buffer or the influence zone. Financial analysis suggest that the intensification package is attractive from the farmer’s point of view. Buckles and Erenstein obtain such a result in the analysis of a farm undertaking maize cultivation only; Cervigni develops (Cervigni & Ramirez, 1996; Cervigni, 1998) multi-crop farm budget models, and finds that, provided appropriate access to credit and training, adoption of the proposed alternative technologies and cropping patterns would yield NPVs between US$ 70-300 per household per hectare, with benefit cost ratios well in excess of 2.

The joint effect of the intensification package described by Buckles and Erenstein (small farmed area per household, shorter fallow time) is captured in this model by setting $T_n = 2$, reducing of 50% the minimum milpa size, and by reducing by 50% the per-type-of household coefficients of forest conversion to agricultural area referred to in section 3.3.1.

---

24 Three separate agroforestry model are analysed, which can be applied to the different agro-ecological conditions of the buffer and influence zones of the study area. The models compare a “without”, and “with” project situation, where the “without” is an average cropping pattern of a prototypical farm, and the “with” situation entails changes in the production technology and in the cropping pattern that entail lower conversion of forested land and lower extraction of forest products.

25 This was defined in section 3.1.2 as the threshold value for the continuation of the minifundio process; once the average farm size falls below the threshold level, households on existing farm land can no longer share it with landless farmers.
**Mitigating land tenure pressures**

Another important area for policy is likely to be land tenure. Newly formed households and farmers who may be evicted as a result of the PROCEDE program are unlikely to have access to own resources or to credit to purchase farm land.

A first role for public policy would be facilitating settlements of disputes on land that, as a result of eviction would be returned to the community or to owners may not have exercised their rights in many years. Under criteria of transparency and equity, farmers who have been using land for a long enough period of time without formal rights may be granted legal tenure title.

A further possibility would be to explore a program of credit (perhaps based on a revolving fund structure), which would support farmers without tenure in renting or purchasing land with some vegetation cover from larger farmers, in exchange for their commitment to dedicate part of the land to agroforestry or other uses with beneficial effects on biological resources. The program may be co-funded by the State government and/or by the Municipal water commission, in recognition of the soil conservation and watershed benefits of agroforestry uses.

This group of policies is captured in the model by an increase (from 15% to 50%) in the percentage of title-less farmers that leave the space-seekers pool as they find settlement options other than encroaching in forested land.

Introducing two additional parameters in the simulation brings the total number of possible scenarios to $2^5$, i.e. to 32. Instead of expanding Table 1 to add the new scenarios, Table 2 summarizes the impacts of the individual or joint adoption of farming and tenure policies in terms of comparison with results that would prevail in each of the eight scenarios identified by Table 1. In particular, Table 2 reports the improvement in the utility of the “environmental planner”, as defined in Equation 8; and the prevention, in percentage terms, of losses in areas under *monte* that would have prevailed in the eight scenarios of the section 4.2 (P stands for the percentage of wealthy avencidados, and I =1 means that the agriculture intensification package is being applied).

**Table 2 Impact of agriculture technology and tenure policies on land use**

<table>
<thead>
<tr>
<th>Scenarios in the absence of policies</th>
<th>Ratio of &quot;Utilities&quot;</th>
<th>Avoided &quot;Monte&quot; loss</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>$P = 50%$, $I = 1$</td>
<td>$P = 50%$, $I = 0$</td>
</tr>
<tr>
<td>A</td>
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<td>9.87</td>
</tr>
<tr>
<td>B</td>
<td>7.30</td>
<td>7.63</td>
</tr>
<tr>
<td>C</td>
<td>6.63</td>
<td>6.24</td>
</tr>
<tr>
<td>D</td>
<td>71.31</td>
<td>17.79</td>
</tr>
<tr>
<td>E</td>
<td>8.18</td>
<td>7.99</td>
</tr>
<tr>
<td>F</td>
<td>1,941.78</td>
<td>1,850.52</td>
</tr>
<tr>
<td>G</td>
<td>1,631.65</td>
<td>1,574.54</td>
</tr>
<tr>
<td>H</td>
<td>18,439.4</td>
<td>17,584.3</td>
</tr>
</tbody>
</table>

It can be seen that the joint adoption of farming intensification and tenure policies have a marked impact in both increasing the utility of the environmental planner (the ratio of alternative to baseline utility exceeds 2 in 17 out of 24 cases\(^{26}\)), and in contributing to significant savings of areas under

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\(^{26}\) The very large values obtained in the last three scenarios are due to the fact that utility in the no-policy case (the denominator of the ratio) is close to zero for those scenarios.
primary forest. The combined use of the two policies tends to be more effective than the adoption of either agriculture technology or tenure policy in isolation; however, tenure policy alone may lead to modest improvements in the conservation of the vegetation cover. Policies also are the most effective when they are undertaken in conditions of high income growth and slow labor-replacing technical progress; for example, when $r=5\%$, $rr=1.5\%$, and $I=1$, the end-of-simulation value of primary forest ranges between 10,000 and 15,000 has, which, compared to the relevant reference value (Scenarios A and D), amounts to prevention of forest loss ranging between 27% and 41%.

The sensitivity of the results on assumptions about technical progress points to a further area of intervention for local policy makers concerned with conservation of natural resources in the study area. As it is likely that the oil district will be affected by processes of industrial reorganization and modernization that may lead to lay-offs (especially in a context of stagnating or declining oil prices), it will be important to create opportunities, especially through capacity building and training programs, for non-farm employment outside of the oil sector; for example, in the handicraft, food processing or tourism sectors. That way, landless farmers may be able to take advantage of income opportunities generated by the growth of the regional economy, rather than being left at a comparative disadvantage with more skilled labor force in the urban areas.

5. Conclusions

Designing policies for conservation and sustainable use of natural resources requires an understanding of the processes of resource use that are likely to prevail in the absence of those policies. This paper has proposed an application of computer based modelling of dynamic systems to original household survey data from a biosphere reserve in the Mexican tropics to predict land use changes over a 15-20 years time horizon.

In general, the model suggest that processes of conversion of forested land to productive uses (agriculture, pasture) are likely to continue over the medium to long term. However, the magnitude of the process is likely to be significantly affected by a number of parameters, some of exogenous nature, some under the potential control of local policy makers.

In terms of the former, land use changes are likely to be of larger size and frequency when non-farm employment opportunities are scarcer (either because regional income grows slowly, or because technical progress reduces the demand for unskilled labor), and when ecosystems recovers slowly from perturbations. A fast rate of ecosystem regeneration may partially compensate for slow growth in income, and may be able to attenuate land use impacts; on the other hand, labor-replacing technical progress and slow ecosystem recovery can cancel out the potentially positive effects of income growth.

Policy makers may have opportunities for mitigating the land use impacts of growing demand for farm and pasture land by promoting land-saving agriculture techniques, by offering alternative to encroachment to title less farmers evicted as a result of tenure regularization programs, and by investing in training and capacity building programs to facilitate the entry of unskilled labor in employment markets outside the agriculture sector.

This model permits estimation of land use impacts of different courses of policy action. This is an important element of decision making, but by no means the only one. To fully assess the social value of each policy options further research would be needed, in two main areas. The first refers to the full costing of the design and implementation of the various policy options under scrutiny.
The second area concerns the detailed specification of a utility function of the land use patterns estimated to prevail as a result of the various policy, under scenarios defined by different combination of exogenous parameters. Such a utility function would take into account the full range of substitution possibilities among land uses (and possibly ecological thresholds) in the provision of ecological services, as well as trade-offs between size and stability in and between various land types.

Another question to be incorporated in a revised utility function concerns the private trade-offs between alternative land uses. Preliminary indications coming from the farm budget models (Cervigni & Ramirez, 1996; Cervigni, 1998) referred to earlier (section 4.3) suggest that in a number of situations farmers might be better off with alternative, low-intensity land uses, than with the baseline cropping patterns. The augmented utility function would need to incorporate in a systematic way private opportunity costs of switching from one type of land use to another.
Annex 1: Estimating the demand for temporary work

The approach summarized by Equation 4 and Equation 5 can be applied in a straightforward way to labour regularly employed, by simply using census data on the number of regular workers as the denominator of $y^L$. The problem with non regular labour is that the number of workers is not a good indicator of actual input to production, as the actual time of work of a temporary employee varies widely across individuals, time of the year, and production sector.

A better indicator is the number of days of temporary work employed in production\(^{27}\). No data of this nature was available in the 1994 Economic Census; therefore, a broad order of magnitude for total days of non regular work employed in production was estimated on the basis of information from the 1990 General Census of Population and Housing (INEGI, 1991; INEGI, 1997).

The 1990 Census provides a breakdown, in classes of hours worked per week, of total employment in the municipalities under investigation. Assuming that services provided under temporary work arrangements do not exceed one third of a standard working week of 48 hours, only the classes 0 to 8, and 9 to 16 hours per week were considered. The mid point of these classes times total working weeks per year (43) divided by working hours per day (8) gives, for each class, average days worked per year.

The weighted average of days worked per year, with weights given by the share of workers in the total of the two classes of temporary employment, gives a figure of 43 days of work per year per temporary or non regular worker. Multiplying this number by the 1994 Economic Census figure on total non regular workers, we obtain an estimate of total number of days of temporary work in the trade, manufacture, mining and services industries sectors of the four municipalities considered as sources of temporary non-farm employment.

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\(^{27}\) Days of work is also the unit of measurement of labour allocation decisions in the companion LP model.
**Annex 2 The income elasticity of cattle number demand**

It is assumed that livestock product and hence cattle numbers are superior goods, and hence their elasticity grows with income. However, it is not plausible that consumption of livestock product increases without limits as income grows. One way to avoid this result is to assume that the share of livestock products in the food budget (or in the overall budget) grows initially, but then levels off to a plateau level, representing a “wealthy - status” level of meat and diary products consumption.

Using a simple logistic growth function, the income elasticity \( \eta \) of cattle numbers must obey the following differential equation:

\[
\frac{d\eta}{dY} = r\eta(Y) \left(1 - \frac{\eta(Y)}{K}\right); \quad \eta(Y_0) = \eta_0
\]

**Equation 9**

where the \( r \) is the elasticity growth rate, \( K \) is the ceiling, or maximum level of elasticity, and \( Y \) is income, measured, as in section 3.2.1, by the value of total output of the trade, manufacture, mining and services industries in the four major municipalities of the region. The initial condition imposes that the at the beginning-of-simulation level of income, elasticity is equal to its postulated initial value, \( \eta_0 \), borrowed from (Barbier & Burgess, 1996). The solution to Equation 9, which is the expression for the elasticity used in the model, is:

\[
\eta_t = \frac{e^{rt}K\eta_0}{e^{rt}K + e^{rt}\eta_0 - e^{rt}\eta_b}
\]

The model uses a value of the maximum elasticity equal to three times the initial value; the rate of growth varies parametrically for use in scenario analysis, as discussed in section 4.
Annex 3 Pasture rotation

A number of studies of pasture-driven frontier expansion explain deforestation in terms of nutrient mining: as nutrients decrease due to overgrazing, it is cheaper to convert new land to pasture than to invest in maintaining the productivity of existing pasture (for the case of Brazil, see (Schneider, 1995)). However, as better quality land becomes scarcer, and/or property rights on land become better defined, ranchers may also consider pasture rotation schemes as a management option complementary to land clearance.

Figure 14 depicts the basic approach used in this model to address this possibility. If there is insufficient investment in management, a certain proportion of pasture is overgrazed and then abandoned. As time goes by, second growth vegetation will start to form on idle pasture, and nutrients will start to be stored.

Figure 14 Pasture cycle

After some time, (2 to 4 years) idle pasture will turn into young Acahual; as the process of vegetation succession continues, woody species will tend to predominate over grassy ones, and young Acahual will turn into mature Acahual (after a period of say 5 to 10 years from the original pasture abandonment).

Both young and mature Acahual may be reconverted to pasture. Conversion is motivated both by the need for replacing abandoned pasture, so that existing herds can be supported, and by the need for increasing herd size, when demand for livestock products increases.

If the demand for livestock products is constant or grows slowly, if overgrazing time is long, and if nutrient storing and vegetation regeneration time is short, the system could be in dynamic equilibrium: pasture and acahual land fluctuate around steady state values. However, in presence of growing demand for livestock, short overgrazing time, and long regeneration time, acahual tends to be depleted, and the pasture deficit will be met by conversion of primary forest.

In this model, the dynamics of pasture conversion and abandonment decisions revolves around variation in stocking rates (heads of cattle per hectare). For given cattle rearing and pasture

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28 It is plausible that land with better conditions of accessibility will be reconverted first, so that mature Acahual will be in worse location areas.
management technology, there will be an optimal level of the stocking rate, $s^*$, which will vary across lands of different quality, slope, precipitation, and so forth. Ranches with rates below $s^*$ are undergrazed, while ranches with rates in excess of $s^*$ are overgrazed.

The former have the potential of increasing herds without decreasing productivity, whereas in the latter nutrient exhaustion is bound to occur. The larger the stock of overgrazed pasture relative to the undergrazed one, the larger the need for converting land under vegetation cover, both for meeting increases in the demand for cattle numbers, and for replacing pasture eventually abandoned when nutrients are exhausted.

It then becomes important to estimate the percentage of overgrazed stock, and to determine its variation over time. For reasons of computation simplicity, it is assumed that stocking rates are distributed uniformly between a minimum and a maximum value. The minimum value is constant, and equal to the minimum value obtained in the survey sample (0.15). The maximum varies over time, and is calculated using the expression of the average stocking rate $\bar{s}$, under the assumption of uniform distribution: $s_{\text{max}} = 2 \bar{s} - s_{\text{min}}$.

Figure 15 Distribution of stocking rates

As shown in Figure 15, the percentage of undergrazed pasture is the area, under the distribution of stocking rate, to the left of the carrying capacity $s^*$, and is given by:

$$p_{\text{under}} = \frac{s^* - s_{\text{min}}}{s_{\text{max}} - s_{\text{min}}}$$

so that the percentage of overgrazed pasture is $1 - p_{\text{under}}$. If more cattle are purchased than pasture can support, nutrient exhaustion does not occur immediately, but after a given period of time, $T_e$ (Nutr_exhaust_time in the model’s terminology). Assuming that overgrazed pasture lands are distributed uniformly also across the range of times preceding exhaustion ($0 - T_e$), for every level of overgrazing maturity, overgrazed land will be:

$$\text{Overgrazing}[\text{Zone, Land Type}] = (1 - \text{Percent Undergrazed}[\text{Zone, Private}]) \times (\text{Pasture}[\text{Zone, Private}] - \text{Idle_Pasture}[\text{Zone, Private}]) / \text{Nutr_exhaust_time}$$

---

29 Based on field evidence and existing literature (including the FAO report on livestock carried out in the context of the development of the GEF-PSSM study [Cervigni & Ramirez, 1997], an educated guess for “carrying capacity” stocking rate is of 0.75 and 1 heads/ha for the buffer and influence zone, respectively.

30 Survey data, however, could have allowed use of more complex distribution, such as the normal.
The overgrazing flow adds to the stock of overgrazed land:

\[
\text{Overgrazed Pasture}[\text{Zone,Private}] (t) = \text{Overgrazed Pasture}[\text{Zone,Private}] (t - \text{dt}) + \left(\text{Overgrazing}[\text{Zone,Private}] - \text{Pasture depletion}[\text{Zone,Private}]\right) \cdot \text{dt}
\]

After \( T_e \) years, overgrazed land is depleted of nutrients and abandoned. Abandoned land flows in the Idle Pasture reservoir:

\[
\text{Idle Pasture}[\text{Zone,Land Type}] (t) = \text{Idle Pasture}[\text{Zone,Land Type}] (t - \text{dt}) + \left(\text{Abandoning}[\text{Zone,Land Type}] - \text{Initial succession}[\text{Zone,Land Type}]\right) \cdot \text{dt}
\]

The earlier stage of the succession process (Initial succession) last a certain number of years (Nutrient storing time), after which idle land turns into young acahual:

\[
\text{Young Acahual}[\text{Zone,Land Type}] (t) = \text{Young Acahual}[\text{Zone,Land Type}] (t - \text{dt}) + \left(\text{Initial succession}[\text{Zone,Land Type}] - \text{Acahual regeneration}[\text{Zone,Land Type}] - \text{Conversion Young Acahual pasture}[\text{Zone,Land Type}]\right) \cdot \text{dt}
\]

Land flows out of this stock either through formation of mature acahual (after a regeneration time \( T_r \), Acahual regeneration time in the model’s terminology), or via conversion to pasture. In particular, there will be a fraction of Young Acahual that is converted to pasture:

\[
\text{Conversion Young Acahual pasture}[\text{Zone,Land Type}] = \text{LEAKAGE OUTFLOW; LEAKAGE FRACTION = Min}(1, \frac{\text{Demand for pasture}[\text{Zone,Land Type}]}{\text{Max}(1, \text{Young Acahual}[\text{Zone,Land Type}])})
\]

The fraction is given by the ratio between the demand for pasture and the stock of Young Acahual, if this is less than one; if it is larger than one, all the existing stock will be converted to pasture, and the difference will be made up for by the existing mature acahual:

\[
\text{Conversion acahual to pasture}[\text{Zone,Land Type}] = \text{IF}(\text{Acahual}[\text{Zone,Private}] > 0) \text{ then} \left(\text{Demand for pasture}[\text{Zone,Land Type}] - \text{Conversion Young Acahual pasture}[\text{Zone,Land Type}]\right) \text{ else } 0
\]


PSSM. (1995). Sistema de Información Geográfica de la Sierra de Santa Marta (Geographical Information System of the Sierra de Santa Marta) [IDRISI/ ARC-INFO]. Xalapa, Veracruz, Mexico: Proyecto Sierra de Santa Marta.


