13.

An overview[1]: Reconciling demands on woodlands through modelling

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1. CHOICE OF MODELING APPROACHES

A modeling approach was employed to reconcile the demands of various stakeholders on the woodland resources in ways that safeguard incomes and food security to local communities as well as sustaining the woodlands. The aim was to model problems and not systems like general household behaviour or woodland management systems. The candidate models adopted were arrived at in two workshops in 1998 and 1999 based on the following criteria:

- suitability for policy analysis,
- capacity to model real agent's behaviour,
- availability of data,
- capacity to handle various stakeholders and their various and conflicting goals,
- availability of research capacity and skills within the group,
- possibility for including some ecological considerations in the model, and
- potential for development of models that share some of the data.

The models were considered with respect to policies driving change in rural development and specifically forestry at the household level. These included policies on:

- Financial sector reform (credit and interest rates)
- Prices of inputs and outputs, especially for agricultural production.
- Non-farm income, especially that arising from sale of forest products and labour.
- Infrastructure development, including market development and roads.
- Direct limitations on harvest quantity and/or age class of woodlands and pricing of primary forest produce

- Decentralization/devolution of power to local authorities.
- Population growth.

Other considerations that influenced choice of models included:

- Presence of farmers with varying degrees of resource endowments and economic behaviour.
- Presence of farmers mainly engaged in agriculture, and some with livestock. Others have off-farm activities.
- Availability of woodland resource of varying quality and products.
- Availability of small scale commercial activities in all rural communities.
- Presence of unequal accessibility to woodlands (in some cases strict restrictions on government forest reserves allowed minimal access or completely denied access).
- Awareness of role and effectiveness of government in managing woodland resources.
- Local community woodland resource management strategies and initiatives existing in some areas.
- Experiences with joint management of forest resources.
- Awareness on loss of biodiversity and need for environmental conservation.
- Movement of forest produce from rural localities to markets, mainly in urban areas.
- Lack of a system that integrates the efforts of all stakeholders or directs such efforts towards desired goals.

Given this background weighted goal programming and system dynamics were selected as the most appropriate modeling approaches for local community interactions with the woodlands. The key highlights from this work are summarized in the following sections.

2. IS COMMUNITY-BASED MANAGEMENT THE BEST FOR SOUTHERN AFRICAN WOODLANDS?

There is a lot of emphasis (and rhetoric) to devolve the management of woodlands and other forest types in Southern Africa and elsewhere in the world to local communities. This is rooted in the belief is that this is the best thing to do because local communities have lived with these resources for time immemorial and presumably have the best skills and knowledge to manage the resources. But this is mainly a qualitative assessment.

This section presents results of research undertaken in Malawi, Mozambique, Tanzania and Zimbabwe that examines this quantitatively and demonstrates how use could be made of a system dynamic model, MIOMBOSIM, in planning and evaluating woodland management. The model was used to evaluate the outcome of three sets of management options, namely, communities managing the woodlands on their own in a cooperative manner (cooperative model), communities and other stakeholders having free access to the woodlands and with no stakeholder in charge, i.e. an open access situation (uncooperative model), and the government (central, local or village government) being in control (command model). The latter (command model) had three management options depending on goals emphasised in management. On one hand we had emphasis on conservation or biodiversity protection (environment concern), while on the other extreme we had society allowed to extract what they needed, but within limits set by the managing authority (social concern). This provided for the possibility of the public to satisfy their social demands for woodland products. The third option was a combination of social considerations tempered with conservation of the woodlands (environmental concern + social concern). This involved putting weights on the parameters that represented both environmental and social concerns. Thus, in total five management scenarios were evaluated using MIOMBOSIM, the evaluation criteria including total benefits that would accrue to all stakeholders (as well as to individual stakeholder groups), potential for employment creation, area of woodland converted to agriculture, standing volume of miombo on a sustainable basis. A number of sensitivity analyses were performed to test the sensitivity of some chosen variables as well as effects of some macroeconomic and sectoral policies.

Apart from supplying firewood to the rural people the next most important thing the communities looked for in the woodlands was income. The MIOMBOSIM results indicate, for all countries, that the cooperative management option, whereby the communities manage the woodlands jointly would not be the best management approach to employ if income generation to rural households were the criterion guiding management. Involvement of government in management but with guided access to these resources by local communities (i.e. command with social concerns management) would appear to be the best approach to pursue such an objective. This appears to contradict the belief that if these resources were devolved to local communities, then they would be better managed and therefore be more beneficial to the communities – an important finding for policy makers. Apparently this is also true of Joint Forest Management (JFM) in India[2] The present situation on the ground in the study countries is that mimicked by the 'uncooperative model' (open access), while policy drive in all the four countries is to move largely towards the 'cooperative' regime; though with a limited role for government (command regime). However, from the study results the best two management regimes advocated are the command with social concerns followed by the cooperative management approach.

In addition, the results show that there is no management regime capable of satisfying all goals (i.e. increased rural incomes, food security and environmental/ biodiversity conservation); that is some trade-off between goals is necessary.

Rural unemployment is a serious problem in all the four countries, various policies are being implemented with one of the objectives being to increase employment. However, the model results indicate that the employment potential offered by all management regimes is fairly small. The implication is that the forestry sector appears to have a fairly small potential to alleviate rural unemployment.

The four countries, as well as others in the region, are signatories to important international agreements, protocols and conventions related to forestry. One such convention is on biodiversity conservation. The model results demonstrate that introducing biodiversity concerns in a resource abundant area (such as Gokwe, in Zimbabwe) could reduce deforestation at a lower cost in terms of loss in benefits from the woodlands as compared to a resource poor area (such as Chivi in Zimbabwe).

The specific model results are presented in Chapters 20 to 22 and should be interpreted carefully because the impact of any management regime and/or policy intervention on the welfare of stakeholders and on the forest resource will depend on the amount of natural resource endowment and the initial economic conditions on the ground. While the general direction of policy or institutional change can be predicted, the actual impact will depend on the initial conditions, which are site specific.

3. ARE HOUSEHOLD DEMANDS FOR FOOD SECURITY AND BETTER HOUSEHOLD INCOMES IRRECONCILABLE WITH BIODIVERSITY/ ENVIRONMENTAL CONSERVATION?

This question was addressed through modeling the linkages between these three important rural development goals in the countries of study, i.e. Malawi, Mozambique, Tanzania and Zimbabwe. A weighted goal programming model, MIOMBOGP, was employed to reconcile the goals of various stakeholders as they relate to improving household incomes, food security, and environmental protection or conservation. These were the three main goals identified and ranked by households in the study sites. They are also the key rural development goals in each of the countries. The model demonstrated how rural development planners can help households satisfy these goals using the principal resources they have, viz. their own labour, woodland resources and agricultural investments. Some of these issues were also evaluated using MIOMBOSIM.

In Zimbabwe the results indicated that households owning draft animals have higher incomes, are more food-self-sufficient, allocate more land to agricultural crops than non-draft owning households. It was also possible to demonstrate the tradeoffs in meeting the three goals. For example the results from Tanzanian sites indicate that the food security goal was satisfied in all sites. However, with respect to the income goal, it was only satisfied in Iringa, while there were negative deviations from this goal of about 13%, 10% and 7% in Babati, Handeni and Mufindi respectively. These deviations represent the tradeoff the households have to make in terms of incomes forgone or not realized by satisfying their food security concerns.

Overall extra sectoral policies intended to promote agriculture were observed to have mixed effects on forest development. For example, for draft-owning and non-draft owning households in Zimbabwe it is unlikely that moderate increases in the input and output prices of agricultural crops or moderate improvement in crop yield would encourage encroachment on the remaining few woodlands for agricultural land. A similar observation was made on Malawian, Mozambican and Tanzanian households. The reason is that with a moderate input price or crop yield increase, by say 25%, households contain this by re-aligning the area allocated to crops and not by expanding cropland area. However, this changes, for example when we have significant yield or output price increases, say by 75%, there is a significant shift of land from the low priced crops, and where this is not possible then encroachment on woodlands for additional land is likely. The households would definitely try to earn more through higher yields (from improved seed for example) or output prices.

It was also observed through the MIOMBOSIM for Zimbabwe that a significant increase in agricultural input prices could lead to a decrease in woodland area on both sites (Chivi and Gokwe) in the long run. However, the change in steady-state proportion of remaining woodland would appear to be indeterminate tending to support the hypothesis that there are two opposing impacts caused by input price increases, namely, decrease in deforestation due to decline in profitability, and increase in deforestation due to substitution of land for cash inputs. Also an increase in agricultural product prices has the potential to increase deforestation with the magnitude of woodland loss more in the forest resource abundant Gokwe area compared to a resource poor Chivi area. Similar trends were observed in Malawi, but with relatively insignificant changes to the area of woodland remaining at the end of the simulation period, i.e. the sustainable woodland area.

It was noted in Zimbabwe that a decrease in income required to meet subsistence needs could lead to mixed impacts on deforestation under both community profit maximisation and maximisation subject to environmental concern constraints. Though a reduction in the requirement for agriculture to meet basic needs might lead to less encroachment on forests, the labour released from existing agricultural land could promote non-agricultural forms of woodland use that exert pressure on the environment.

In general sectoral policies in the form of fees charged on various forest products manifest their impact on the forest resource mainly through commercial sector activities in the form of a reduction of harvesting activities, when there is no compensation in the form of an increase in sales price. In the case of the household sector, short-term compensation would be achieved through land clearing for agriculture. The reduced employment resulting from reduced private sector activities could have negative ramification to rural development, if complementary policies are not put into place to create alternative employment opportunities. However, it was noted that a policy that aims at controlling harvest of firewood through pricing would only have noticeable effects if firewood prices were increased substantially. We see for example that in Malawi, the response to firewood prices starts only when prices are increased by more that 50%. This could most probably be due to the fact that labour for harvesting and transporting the product on the head or with bicycles to distant markets could be a limiting factor for households to take advantage of the high prices. Further, fuelwood prices are fairly low, and modest increases in prices might not trigger a significant reallocation of labour from crop production to fuelwood harvesting and selling.

Further, policies leading to employment creation outside agriculture and forest activities appear to have insignificant impact on forest conservation when wages are low.

For both the MIOMBOSIM and MIOMBOGP:

- The results in most cases conformed to theory or logic. That is, it was possible to resort to theory (socio-economic or biophysical) to justify or understand the results.
- The two models were robust in that they provided a richness of information from each of the countries and they also provided considerable diversity in the way each country used the same generic model to suit its specific local conditions, as well as in terms of how individuals or groups of scientists manipulated the models according to their own skills.
- The results gave important scenarios that hold potential for improving planning the livelihoods of local communities that depend directly on the woodlands, as well as for improving management of the woodlands.
- There is need to emphasize that the models fail to capture some benefits of forests such as those related to biodiversity and those arising from non-marketed goods and services.

4. CAN WE USE THE MODELS TO ANTICIPATE THE EFFECTS OF HIV/AIDS AND OTHER DISEASES ON RURAL LIVELIHOODS AND THE FOREST CONDITION?

One interesting output of the MIOMBOGP model relates to potential influences on household food security, income and the woodland condition resulting from constraining availability of labour, either in its totality and/or by gender. Many things can constrain labour availability including emigration of a family member, say to urban areas to seek employment. However, in many rural areas the message received during data collection was one of frequent deaths, some most probably due to HIV/AIDS infections. It was possible to demonstrate using MIOMBOGP the implications of total loss of household adult(s) or partial loss of their labour due to illness or attending the sick and funerals.

For example in Malawi if male labour is completely absent in the household due to death or emigration, the results indicate the potential for more firewood to be collected and sold, to maintain level of household income that results from loss in tobacco production, an activity that is male dominated. However in Zimbabwe the results imply that loss of male labour or its very limited availability results in less clearing of the woodlands because opening up of farms is a male dominated activity and firewood trade is not as pronounced as in Malawi.

This in no way claims that the model analysed the implications of AIDS because we did not collect data on the deaths and neither did we have clinical evidence of the causes of the deaths. We only performed a sensitivity analysis based on certain assumptions on the extent of labour availability at the household level, and HIV/AIDS influences this availability.

ENDNOTES

1. This text is based on chapters 14 to 22.
2. S.J. Kumar 2002. Does “Participation” in Common Pool Resources Management Help the Poor? A Social Cost-benefit Analysis of Joint Forest Management in Jharkhand, India. World Development, 30(5): 763-782.

14.
A system dynamics model for management of miombo woodlands[1]

U.R. Sumaila, A. Angelsen and G. Kowero

ABSTRACT

The miombo woodlands of eastern, central and southern Africa are some of the most extensive dry forests in Africa. They supply a myriad of products and services for local populations, governments and the private sector, the main stakeholders. Planning the management and use of the woodlands by many and diverse stakeholders who often have conflicting interests in the woodlands continues to be a great challenge to national governments and other interested parties.

This paper presents a system dynamic model, MIOMBOSIM, which has potential for facilitating planning developments in the woodlands in ways which reconcile the aspirations of the three major stakeholders. The model holds potential for analysing various policy implications on people and the woodlands, as well as the desirability of various partnership arrangements for managing and using the woodland resources.

Key words: System dynamics model, miombo woodlands, stakeholders, management.

1. INTRODUCTION

Miombo woodland is one of the most extensive dry forest vegetation types in Africa occurring in seven countries in eastern, central and southern Africa; namely Angola, Malawi, Mozambique, Tanzania, Democratic Republic of Congo, Zambia and Zimbabwe (White, 1983). They occupy an area of about 2.7 million square kilometres, almost equal to the combined land area of Mozambique, Malawi, Zimbabwe, Tanzania and Zambia.

The miombo ecosystem forms an integral part of rural communities living in them or in their proximity by providing them with virtually all their energy requirements in terms of fuelwood. The woodlands also provide building materials like poles and grass for thatching, medicines, wild meat and other types of food and fruits, fodder for livestock and wild game, and many other timber and non timber products.

The woodlands offer a number of opportunities to various stakeholders. *National governments* are interested in them in terms of their capacity to support wildlife that is important for tourism, a major foreign currency earner. Governments also consider society wide interests which the private sector and local communities might not give high priority. These include conservation of woodlands important for water supplies and control of soil erosion.

The *private sector* (firms and individuals) is interested in the woodlands for commercial products, which may be extracted from them. The *communities* bordering these woodlands are interested in them for a number of reasons, including their clearing for agriculture, their use for livestock grazing, and as a source of a number of products for local consumption and trade.

In each country there are general policies guiding socio-economic development, which affect these three stakeholders in complex ways. Other policies attempt to target the government as an institution, are specific to the private sector, or target the rural communities. Each of these three entities responds to the policies in their own different ways.

The objective of this paper is to analyse the interaction between these three stakeholders: How do local communities and the private/commercial sectors respond to sectoral and macroeconomic policies? Given the reactions of these two agents to policy initiatives, is it possible for the country to achieve its stated goals with respect to miombo woodland use? The fulfilment of some of these goals may create undue demands on the woodland resources. It is these demands and the extent to which they manifest themselves in the woodlands that the current paper addresses. In particular, the paper focuses on how to meet these demands in a sustainable manner.

There are several approaches that can be used to reconcile the demands of these three sectors on the woodland resources. This paper presents a systems based model for miombo woodlands, MIOMBOSIM (miombo simulation), to serve as a tool for the analysis of the sustainable use of these important natural resources, given the prevailing socio-economic environment in the region. The paper is organised as follows. The next section presents some background information, and especially the context in which woodlands are managed. Section 3 presents the conceptual model and gives a description of its interpretation for purposes of empirical application. Particular attention is given to the modelling of the household sector. In Section 4 data requirements for the empirical implementation of the model are identified.

2. BACKGROUND

2.1 CIFOR research

In 1996-98, CIFOR in collaboration with institutions from Malawi, Tanzania and Zimbabwe implemented an exploratory study in these countries with the broad objective of evaluating the potential for improving the livelihoods of miombo woodland dependant communities. This exploratory project took into account the impact of some of the macro-economic policies implemented by the respective national governments in their efforts to promote economic development. The study confirmed varying dependency of these communities on the woodlands for their incomes, with the woodlands contributing up to 70% of household incomes in some study sites in Tanzania (Monela *et al.* 2000) and as little as 10% in some sites in Zimbabwe (Campbell *et al.* 2000). Further, the study through regression analysis, confirmed the expansion of agricultural cropland (Chipika and Kowero 2000; Minde *et al.* 2001), though not always conclusively into the woodlands and/or grazing fields.

Macroeconomic policies such as the liberalization of trade, and the elimination of government subsidies to agriculture, were arguably responsible for these outcomes. Also market and policy failures lead to the under-valuation of natural forest resources. The basis for governments to jointly manage the natural forests with the local communities was challenged in both Zimbabwe (Mukamuri *et al.* 2001) and Malawi (Luhanga *et al.* 2001). The study also raised a number of potential research questions. In addition, the study did not constitute a strong basis for understanding the policy impacts and their pathways. Neither did it facilitate generating scenarios useful for developing plans to guide sustainable management and use of these woodland resources.

With financial support from the European Commission, CIFOR embarked on a four-year research initiative in 1998, which sought to carry this work further and specifically address the issue of multiple stakeholders in sustainable management of these woodlands. This was considered to be crucial because governments in the region continued to implement macro-economic reforms, which affect the stakeholders differently, with the consequence that their reactions with regards to their use of the woodlands are unclear. The emphasis has been on understanding the pathways of the policies. Such information is useful in generating alternative scenarios useful for managing and using the woodland resources sustainably. Some of the candidate policy oriented hypotheses proposed for evaluating and generating such scenarios include:

- Economic reform policies, especially those that improve credit availability to smallholder farmers and agricultural input and output prices, serve as incentives for increased agricultural land expansion into woodland areas.
- Higher incomes and the increased demand for food that accompanies population growth boost the demand for agricultural production as well as trade in forest products, and this has the potential to degrade the woodlands.

On the other hand, governments in the region are very weak in managing natural forest resources. With economic reforms central government resources are becoming increasingly limited, to the point where the central government is unable to effectively manage large tracts of land in their countries. However the emphasis on liberalization of the economies of these countries and promotion of democracy has led to increasing participation of local communities and other entities in decision making, even in natural forest resource ownership and management.

2.2 New perspectives in forest management

According to Matose and Wily (1996), there is a clear move away from the centralised and state-driven forest and woodland management of the colonial and post-independence periods towards decentralised, and mainly community-based regimes. This shift has prompted governments and non-government agencies to realign their own functions away from direct management functions towards supporting technical and advisory roles. The local communities, who are actually the main user groups, are increasingly becoming partners in natural forest management. In some cases they manage the forests on their own.

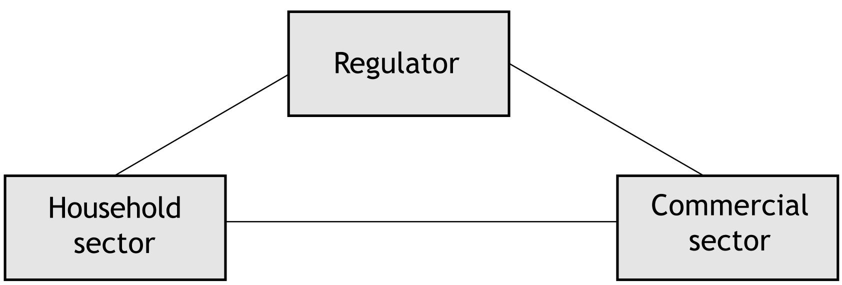
However, local management and control of natural forest resources is constrained by the weakened state of local institutions and the presence or even absence of policies and legislation that are either not enabling to local management and control or else absent altogether. Further, the rural communities are undergoing rapid social, economic and political change, due to economic development and modernisation. The question is whether local management of these resources will survive and persist, in the face of modernisation pressures and other socio-economic developments. This notwithstanding, the said changes have increased the number of stakeholders in natural forest resources, with the government (central and local), private sector, and local communities as the major stakeholders in this region.

Besides providing a methodology for analysing the effect of various economic policies, the paper also presents a framework for evaluating different partnership arrangements for managing the woodlands and especially those involving local communities, private/commercial sector and the government/state. The methodology can be employed to demonstrate impacts on long-term resource use and income for different user groups. For example, it can be used to answer questions about what, for the different groups, will be the gains of some form of joint forest management (*cooperative*) compared to a situation of unregulated resource competition (*non-cooperative*) among the groups.

3. THE CONCEPTUAL MODEL

A model is developed with two user groups (that is, commercial and household users) of miombo woodland resources who are under the control of a *regulator* (Figure 1). The regulator can be a central/local/village government, or any other authority. Three different versions of the model are presented and are based on some assumptions on the relationship between the user groups and the regulator. In what is denoted as the *command* model, the regulator can dictate the behaviour of the two sectors directly. In the *cooperative* model the users reach an agreement on how best to jointly use the miombo resources. On the other hand, in the *non-cooperative* model each of the different user groups aims to maximize its own private benefits without any regard to the implications of their actions on the other groups (see Sumaila 1999 and the reference

Figure 1. The main agents in the model



therein).[2] It should be noted that in the cooperative and non-cooperative versions of the model, the regulator could influence the use of miombo resources indirectly by changing the parameters that affect the decisions taken by the commercial and household users.

3.1 Modelling woodland resources

The miombo woodland resource is defined in terms of the land area on which the miombo is standing or the average volume of miombo on the land. Analytically and computationally, it does not really matter which of this is considered in the model. This is especially because for simulation purposes this quantity is normalised to one. At the start of the analysis, part of the woodland is cleared for agricultural production while the rest remains forested. This is the initial condition, and conforms to reality in the region (Minde *et al.* 2000; Chipika and Kowero 2000). As described in detail later, the area maintained as miombo woodland can change from year to year due to conversion to agricultural use. Hence, in each year in the time horizon of the model, the amount of land under agricultural production is the sum of the land already under cultivation plus the *new land* converted from miombo woodland to agricultural use that year. One of the important outputs from this modelling exercise is therefore the amount of woodland resources cleared for agriculture in each year.

3.2 Modelling household users

It is assumed that household users are involved in three economic sectors, that is, miombo products (firewood, charcoal and poles), agriculture, and off-miombo/off-farm. Modelling agricultural household behaviour is complicated by the fact that farmers are not fully integrated in the market and/or that markets do not function perfectly. This implies that market prices and wages cannot be used as the only guide for economic behaviour. The opportunity cost of labour will be determined within the households by variables such as the degree of poverty, assets held, labour force participation level, etc. The market assumptions form the basis for the distinction between non-separable and separable models. In a separable model the production decisions are solved first, and then the consumption decisions. In a non-separable model they must be solved simultaneously. In the separable model, all prices (including wages) are assumed to be constant, and given by the market (perfect market assumption). Households' production decisions can be studied as a profit maximising problem. Market prices and technology determine the behaviour. Variables such as population size and poverty level are assumed to have *no* direct effect on resource use.

A more realistic, but also more complex, non-separable household model takes these factors into account, as it determines the shadow price or opportunity cost of labour within the model. The standard formulation of a non-separable model is to assume that households maximize utility, which increases consumption and leisure time. The households balance the drudgery or disutility of work against the utility of consumption, and reach a "subjective equilibrium". Further, they must allocate their labour time to different activities in the most optimal way (marginal return to labour is the same for all activities). This is often referred to as the Chayanovian model (see Angelsen 1999). In this article, the focus will be on a representative household, whose objective is to maximize utility (U (.)), a function of income (I) and leisure ($T = L^{max} - L$);

$$Max \quad U(I, T) = (I - I^{min})^{\alpha} + v(L^{max} - L)^{\beta} \qquad (1)$$

This specification of the utility function, which draws on Angelsen (1999), includes both a subsistence level of consumption (I^{min}) and a limit on labour input (L^{max}). In the above equation, L is total labour used by the household in the activities they undertake, I is the gross income to households, and are parameters of the utility function.

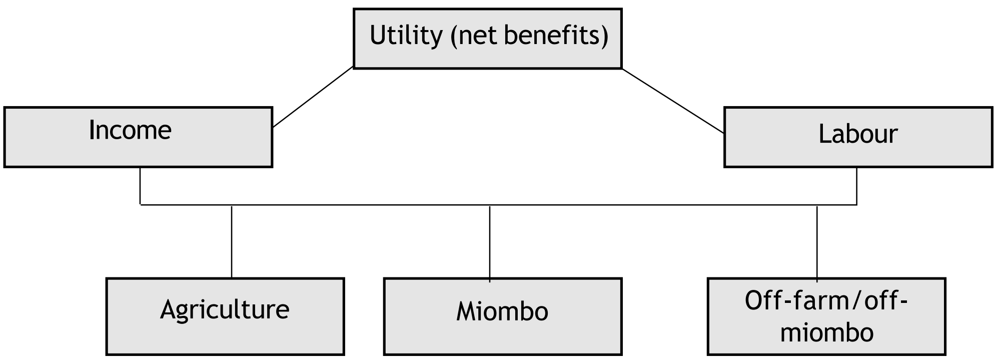
Total differentiation of the utility function in (1) yields the shadow wage rate, *z*:[3]

$$z = z(I, L) \equiv \frac{-U_T}{U_I} = \frac{v\beta\left(I - I^{min}\right)^{1-\alpha}}{\alpha\left(L^{max} - L\right)^{1-\beta}} 1 \qquad (2)$$

where *v* is a parameter. In the current model, the household is assumed to allocate labour such that the marginal productivity of labour or marginal return to labour – *MRL* - is the same across all activities and equal to the shadow wage rate. For instance, the marginal return to labour employed in agriculture (L_a) should equal that to labour employed in harvesting wood products (L_m):

$$z = MRL_a = MRL_m \qquad (3)$$

Figure 2. Main structure of the household component of the model



3.2.1 Adding-up equations

The gross household income comes from the net sale of miombo woodland products (I_m), agricultural produce (I_a), and off-miombo/off-farm activities (I_{of}), that is,

$$I_h = I_m + I_a + I_{of} \qquad (4)$$

Total labour is found by simply adding the time devoted to the three main activities the household is involved in.

$$L_h = l_m + (l_a + L_n) + l_{of} \quad (5)$$

Within the agricultural work, a distinction is made between labour for cultivation (L_a) and labour for clearing new land (L_n) (i.e., converting miombo woodland into agricultural land).

3.2.2 Agricultural activities

Farmers are assumed to apply only two inputs, that is, labour and fertilizer, in addition to land. But since use is made of yield functions (and outputs and inputs are on a hectares basis), land becomes an implicit input in the model. Labour per ha (l) is assumed to be constant, whereas fertilizer (f) is a variable input. For computational simplicity (and as a fair approximation) use is made of an additive production function. Output per ha or yield (x) is then given by;

$$x = a + bl + cf^d \quad (6)$$

a, b, c, d are parameters to be estimated from household survey data.

The farmers decide how much fertilizer to apply per ha in such a way that the income, ignoring labour costs for the time being, is maximized;

$$Max \quad p_a x - p_f f \quad (7)$$

The condition for optimal fertilizer use is then;

$$p_a cdf^{d-1} - p_f = 0 \Leftrightarrow f = \left(\frac{p_f}{p_a cd}\right)^{\frac{1}{b-1}} \quad (8)$$

This formulation makes this part of the model recursive and easier to compute. First, fertilizer use in each period is determined by the exogenous agricultural output price (p_a) and fertilizer price (p_f) ratio, plus the parameters. The next step is to put this into the production function to determine the yield.

Net agricultural income is then defined as;

$$I_a = (p_a x - p_a f)H_a \quad (9)$$

Total labour employed in the agricultural sector is similarly expressed as;

$$L_a = lH_a \quad (10)$$

H_a is the total agricultural area, given by the sum of their initial agricultural land area (H_i) and new land converted from miombo to agriculture (H_n). A key decision for the households is whether or not to expand their land area, and if they do, by how many hectares. The starting point is to compare the net benefit that accrues to them per ha of miombo used for wood products (B_m), and that which accrues to them from the conversion of the woodland resources for agricultural production (B_a).

Current benefits from one ha of agricultural land are defined as;

$$B_a = p_a x - p_f f - zl \quad (11)$$

For new agricultural land we must also subtract the clearing costs per ha, *zl*. These should be convex in land cleared (e.g., as they move further away to convert miombo to cropping land), and a possible function would be;

$$l_c = gH_n^{\tau} \qquad (12)$$

where l_c is the labour required for clearing per ha, *g* and are parameters, and H_n denotes new land cleared. The key is that the labour inputs should be convex in area, H^c, and therefore be raised to a number greater than one (> 1; set to 1.5 in Equation 13).

Total labour for clearing new land is then given by;

$$L_n = \int_0^{H_n} gx^{1.5}dx = g\frac{1}{2.5}H_n^{2.5} \qquad (13)$$

Note that the calculation of labour for clearing becomes a bit more complex as the labour requirements per ha increase.

Thus, if the benefits from miombo are greater than those from agriculture on new land;

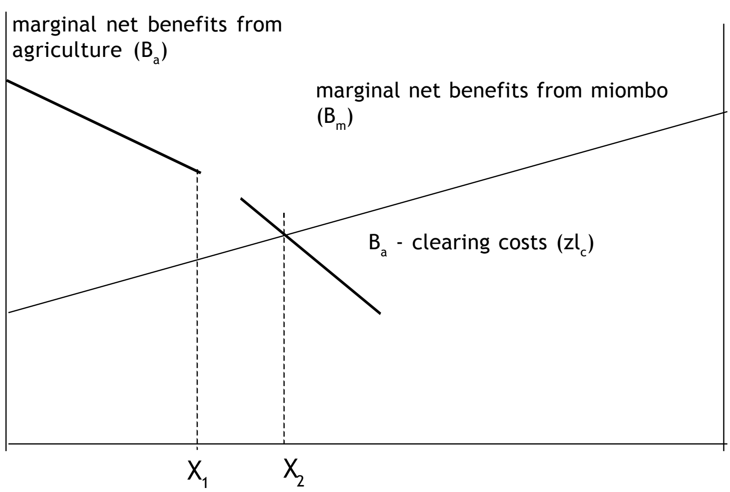
$$B_m > B_a - zl_c \qquad (14)$$

for all positive values of H_n, *then* there will be no conversion of miombo to agriculture. If this is not the case, then agriculture will be expanded up to the point where:

$$B_m = B_a - zl_c \qquad (15)$$

The situation can be illustrated graphically in a box-diagram as in Figure 3. The length of the box represents total land area. Agricultural land is measured from the left *y-axis* to the right, while miombo land is measured from the right *y-axis* and to the left.

Figure 3. Farmer choice of agricultural land expansion



The initial amount of land under agricultural cultivation is depicted at point X_1. Net marginal benefit from agriculture (B_a) is denoted by the thick line. This line is discontinuous at point X_1 as the net benefits from agricultural production on land beyond this point has to include the clearing costs (zl_c). As the figure is drawn, it will be beneficial to the farmer to clear some new land, up to point X_2 where the (B_a – zl_c) is equal to the marginal net benefits of the remaining miombo land (B_m). Thus, in this situation there will be some deforestation.

3.2.3 Miombo activities

Farm households are assumed to collect three different products from miombo woodlands: poles, fuelwood and timber. The gross income from this activity is given by;

$$I_m = p_{ave} H_m \tag{16}$$

where H_m is the quantity of miombo harvested for use as poles, fuelwood and timber, p_{ave} is the average weighted price received for the three different wood products. The portion of H_m that is used as poles, fuelwood or timber is determine by multiplying H_m by the corresponding relative prices.

Harvest (or miombo use) is a function of both the labour used in the miombo sector (L_m) and volume of standing miombo (N). Using a Cobb-Douglas function we get;

$$H_m = q_h N^{\mu} L_m^{\psi} \tag{17}$$

where μ *and* $\psi \in$ (0,1) parameters of the harvest function, and q_h is the harvest efficiency coefficient for the household sector. This is a fraction depicting the rate or portion of N that can be harvested or used in a given period if all the labour available to household were to be used for this activity.

3.2.4 Off-farm/off-miombo activities

We introduce a fixed off-farm and off-miombo employment (L^{OF}) and a given market wage rate (w), such that total off-farm/off-miombo income is;

$$I^{OF} = wL^{OF} \tag{18}$$

Since both the wage rate and off-farm labour are fixed, these variables can be used to study the effects of more economy-wide changes in the economy (e.g., high economic growth or recession), which usually affect both the wage rate and employment opportunities.

In summary, the total net benefits to household users, B_h, of miombo is given by

$$B_h = I_h - zL_h \tag{19}$$

where $B_h = B_a + B_m$

3.3 Commercial users

Commercial users are assumed to decide on how much miombo to harvest in each year in order to maximize their discounted economic benefits. This means they face only one economic sector, namely, the miombo products sector. Modelling commercial users behaviour is a lot simpler than modelling household user behaviour because they are involved in only one activity, that is, harvesting miombo woodland. In addition, the wage rate for commercial users (k) is exogenously fixed. In a similar fashion to the household users, we define the harvest function of commercial users as;

$$H_c = q_c N^{\mu} L_c^{\psi} \tag{20}$$

where L_c is the labour used by commercial users, and q_c is the harvest efficiency coefficient for the commercial sector. Note that the total labour available to both household and commercial sectors, L_t, is then $L_c + L_h$.

Net income (benefits) for the commercial users is then;

$$B_c = p_c H_c - kL_c \tag{21}$$

3.4 Miombo woodland dynamics

The ecology of miombo is represented by the following equations

$$R_t = K_t \tag{22}$$

$$N_t = sN_{t-1} + R_t - H_{c,t} - H_{h,t}; \qquad N_0 \text{ given} \tag{23}$$

$$g_t = \frac{\varepsilon}{1+\phi\gamma^{t}} \tag{23'}$$

Equation (22) captures any natural regeneration that takes place, with K_t denoting the volume in a given year. Equation (23') describes the growth over time of the miombo. The parameters and are ecological, they can be used to vary the quality of the miombo stand (see Frost 1996).

3.5 Institutional aspects of the model

In all countries with miombo woodlands it is assumed that a body (a stakeholder) regulates the use of this resource. This body may be a government authority, a community-based management entity or a sole owner of the resource. This body is assumed to be concerned with maximizing *overall* benefits from the use of the resource through time. Elements of the overall benefit function may include *direct economic* benefits; *social* benefits, e.g., the need to preserve settlement patterns in rural areas; and *environmental* benefits not traded in the market, e.g. benefits derived from biodiversity. The challenge facing the regulator is to determine the quantity of the woodlands to be used by the households and the commercial sectors in each year in order to maximize the management objectives.

The problem can be conceived in the following way. Let the net private benefits to the commercial and household users (from the use of the woodland resources) be B_c, and B_h, respectively, as defined in equations (19) and (21). Social benefits are denoted B_s, while B_e represents environmental benefits. Social benefits may depend in some way on the amount of woodland resources used by one of the groups, say household users, for social, cultural or other reasons. Environmental benefits will depend positively on the amount of standing miombo ($N - H_c - H_h$) or negatively on the total woodland harvested ($H_c + H_h$), where N is the total volume (or even biomass) of miombo woodland resources at a given time.

Formally, we have,

$$B_s(\theta_c H_c, \theta_h H_h);\ B_e(N - H_c - H_h);\ or\ B_e(H_c + H_h) \qquad (24)$$

where

$$\partial B_s / \partial H_c < \text{or} > 0;$$
$$\partial B_s / \partial H_h < \text{or} > 0;$$
$$\partial B_e / \partial (N - H_c - H_h) > 0;$$
or
$$\partial B_e / \partial (H_c + H_h) < 0;$$

It should be noted that $_c$ and $_h$ are the weights put on the harvests of the commercial and household users due to social concerns. These express the social preferences of society. These parameters can take values of 0 or 1. They take a value of 0 if society does not have any social preference for the harvest of a given participant, and a value of 1 if otherwise. Later we introduce an environmental parameter, , to reflect the extent to which society-wide environmental concerns are incorporated into the decision making process (see Lopez and Altobello 1994).

3.5.1 Decision making by household and commercial users

Before going into detailed discussions of the different game theoretic models in this paper, it is proper to give an overview description of how decisions by household and commercial users are made in the model. At the start of the game or simulation, we begin with the volume (or even land area) of miombo woodland (N_t). As illustrated in Figure 4, part of N_t is cleared for agricultural cultivation (N_a), while the remaining, N_m, is retained under miombo. The models that are developed are therefore concerned with the further use and allocation of N_m among household and commercial users.

Commercial users decide how much of N_m to harvest (H_c) in order to maximize their discounted benefits (profits). This is done in a single step. In the case of the households, however, their decision-making is made in three stages. First, they decide how much of N_m to retain under miombo for their use (H_h) so as to maximize their utility over time. In the second stage, household users decide how much of H_h to clear and put the land into agricultural production (H_a), and how much to retain as woodland (H_m) for supply of their forest products (see Figure 4). Again, this decision is made with a view to maximizing their utility. Finally, household users decide how much of H_m to use as fuelwood (H_{fw}), poles (H_{po}) and timber (H_{tim}). The allocation of resources to all of these activities depends on the relative prices or utilities received from each of them by the households. To elaborate more on this important aspect of the MIOMBOSIM model, let the price for agricultural produce be given by p_a and that for fuelwood, poles and timber be p_{fw}, p_{po}, and p_{tim}, respectively. If the optimal amount/quantity of miombo resources for household use from Equation (25) is H_h^*, then the portion of this quantity forgone in preference to agricultural cultivation is given by

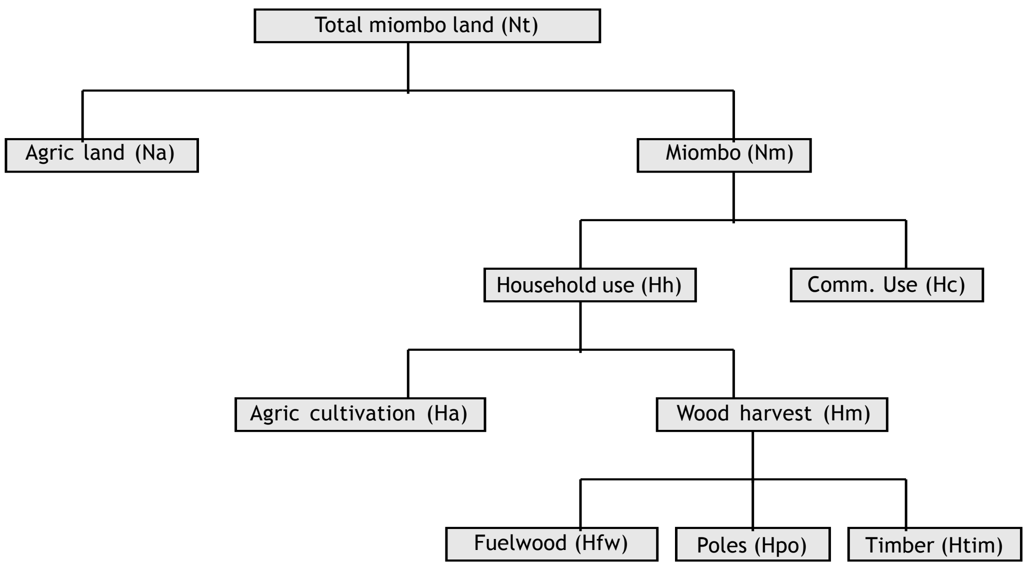
$$H_a = \frac{p_a H_h^*}{p_a + (p_{fw} + p_{po} + p_{tim})} \tag{25}$$

The quantity of miombo exploited for wood products, H_{wd}, is then given by the difference between H_h^* and H_a. Finally, the portions of H_a that go to fuelwood (and similarly for poles and timber), is given by

$$H_{fw} = \frac{p_{fw} H_a}{p_{fw} + p_{po} + p_{tim})} \tag{26}$$

In any given year, each of the above H quantities can be computed, and the total amount of land under agricultural cultivation determined by adding N_a to H_a. The total area under agricultural production is determined using relevant conversion factors.

Figure 4. Steps in decision making by the household and commercial sectors



3.5.2 The command model

The *command model* mimics the approach employed by many government forestry departments in the eastern and southern African region in the planning, management and use of their natural forest resources. Usually governments consider forest benefits to households (B_h), the private/commercial sector (B_c), the society as a whole (B_s), as well as national and international public goods like environmental benefits (B_e). The model developed in this paper shows potential for use as a planning tool in government forestry departments. It is hence assumed in the model that the "commander" seeks to maximize total net benefits B_t through the choice of the amount of labour to be used by the commercial sector and the households in each year in the time horizon of the model, t=1.T, where T is the last (terminal) period:

$$\max_{L_h, L_c} \sum_{t=1}^{T} [B_t] \rho_{t-1} \qquad (27)$$

subject to the ecological and household labour constraints described earlier.

In the above equation,

$$B_t = B_{c,t} + B_{h,t} + \theta B_{e,t} + B_{s,t}$$

$$\rho_{t-1} = \frac{1}{(1+r)^{t-1}}, \ \rho_0 = 1, \ t = 1,\ldots,T.$$

is the discount factor and r is the discount rate. It is important to note that the amount of miombo resources to be used for both agricultural cultivation and supply of wood products is determined from Equation (27). The division of these into the various activities carried out by the household users is already described in section 3.5.1.

3.5.3 The cooperative model

As mentioned earlier there are moves towards participatory management of the natural forestry resources. The command model can be modified so as to incorporate the involvement of the stakeholders in the management of the resource in a cooperative setting. For instance, if we consider a situation in which there is joint management of natural forest resources between the households (local communities) and the private sector, a cooperative management objective can be presented as follows:

$$\max_{l_h, l_c} \sum_{t=1}^{T} \left[\alpha \rho_{h,t-1} B_{h,t} + (1-\alpha) \rho_{c,t-1} B_{c,t} \right] \qquad (28)$$

subject to the constraint in Equation (27).

In the cooperative setting the households and the private sector put weights and (1-) respectively on their individual benefits (which is a measure of their preferences) so as to maximize their combined benefits from exploiting the woodland resource (see Munro 1979). The private benefits are likely to differ from the social planner's benefits as represented in the command model. For instance, private stakeholders may not care much about social, cultural or environmental benefits from the woodlands, and even if they do, it is likely to be in a manner different from that of a social planner.

3.5.4 The non-cooperative model

There are situations in which local communities (households) or the private sector own and manage natural forest resources on their own and without taking the interest of other stakeholders into account. Under such situations, we have a *non-cooperative* *model*. The management problem facing household users can be defined as follows:

$$\max_{L_h} \sum_{t=1}^{T} \left[\rho_{h,t-1} B_{h,t}\right] \tag{29}$$

subject to the stock constraint in Equation (27).

Similarly, the non-cooperative management problem facing the private sector can be stated as follows.

$$\max_{Lc} \sum_{t=1}^{T} \left[\rho_{c,t-1} B_{c,t}\right] \tag{30}$$

subject to the stock constraint in Equation (27).

3.6 Solving the models

To solve the above general models, appropriate Lagrangian functions have to developed. The command model is used to illustrate how this is done. In this case the Lagrangian is given by:

$$Lag = \sum_{t=1}^{T} \rho_{t-1} \begin{bmatrix} B_c(H_{c,t}) + B_h(H_{h,t}) + B_s(\theta_c H_{c,t}, \theta_h H_{h,t}) \\ -\theta B_e(H_{c,t} + H_{h,t}) \end{bmatrix}$$

$$+ \sum_{t=1}^{T} \lambda_t \left[N_{t-1} + K_t - N_t - H_{c,t} - H_{h,t}\right] \tag{31}$$

$$+ \sum_{t=1}^{T} \xi_t \left[L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t}\right]$$

The first order conditions for optimisation are:

$$\frac{\partial Lag}{\partial L_{c,t}} = \rho_{t-1}\left[\partial B_c / \partial e_{c,t} + \partial B_s / \partial e_{c,t} - \theta \partial B_e / \partial e_{c,t}\right] - \lambda_t = 0 \tag{32}$$

$$\frac{\partial Lag}{\partial L_{h.t}} = \rho_{t-1}\left[\partial B_h / \partial e_{h,t} + \partial B_s / \partial e_{h,t} - \theta \partial B_e / \partial e_{h,t}\right] - \lambda_t = 0 \tag{33}$$

$$\frac{\partial Lag}{\partial \lambda_t} = N_{t-1} + K_t - N_t - H_{c,t} - H_{h,t} = 0 \tag{34}$$

$$\frac{\partial Lag}{\partial \xi_t} = L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t} = 0 \tag{35}$$

In the above system of equations, and are defined as the Lagrangian multipliers or the shadow price of miombo and household labour, respectively. Equation (32) states that in any given period the net present value of the marginal harvest by commercial users plus the discounted net marginal social benefit from the exploitation of the resource by this group minus the net marginal stock effect of their exploitation activities on the environment, must equal the shadow price of the miombo resource. A similar interpretation stems from equation (33), with respect to the harvesting activities of the household users. When combined the two equations demonstrate that the optimal allocation of harvest to the two groups of users must be such that the marginal net benefit to the commercial users must equal that to the household users. Solving these equations for the unknown variables yields the optimal harvest to each user and the optimal stock levels in each period. Once these are determined the remaining task of the regulator is to ensure, by some means, that the user's harvest precisely the optimal quantities determined by the model.

3.7 Simulating the model

The numerical approach presented in Flåm (1993) and applied in Sumaila (1995), the system dynamics simulation package Powersim, and data collected during fieldwork can be combined to help us provide quantitative answers to a number of questions, including but not limited to the following:

- How much (i) harvest, (ii) benefits and (iii) employment will different woodland management options translate into for the commercial and household sectors?
- How much woodland is lost under different management regimes, government and macroeconomic policies?
- How does the harvesting technology used by the stakeholders affect the benefits they derive from using the woodlands?
- How sustainable are the harvest levels that will emerge from various government regulatory policies?
- How do prices of inputs and outputs (in agriculture and forestry) impact on production volume and methods, employment potential, and structure of the industry?
- How does off-miombo and/or off-farm income change the various outcomes of the model?
- How does change in subsistence income to household users impact on the outcomes of the model?

ENDNOTES

1. Also available as: Sumaila, U.R., A. Angelsen and G. Kowero. 2001. A system dynamics model for management of miombo woodlands. In: Modelling methods for policy analysis in miombo woodlands.

Occasional Paper No. 35, CIFOR, Bogor. pp.17-30.

2. By developing both the cooperative and non-cooperative models, it is possible to demonstrate whether decentralization of forest management could lead to the emergence of a cooperative management regime.

3. This is alternatively called the marginal rate of substitution between labour and consumption (income), the virtual price of labour, the opportunity costs of labour, or the subjective wage rate.

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APPENDIX 1. LIST OF VARIABLES AND PARAMETERS FOR MIOMBOSIM

	Model parameter
A	parameter in production function
A	superscripts agricultural sector
B	parameter in production function
B	Benefits
C	parameter in production function, subscript commercial sector
D	parameter in production function (yield effect of fertilizer)
E	effort in commercial sector
F	fertilizer (per ha)
G	parameter in labour for clearing function
H	subscript household sector
H	hectare of land
I	Income
K	costs of effort in commercial sector
L	labour per ha in agriculture
	Model variables
L	Labour
M	subscript miombo sector
N	subscript new (cleared) land)
N	stock of miombo resources
Of	subscript off-farm sector (OF)
	Model functions
P	Price
Q	efficiency parameter in harvest function
S	survival rate in miombo growth function
T	leisure for household (L^{max} – L)
U	utility for household
V	parameter in utility function
W	market wage rate for household
X	agricultural yield
	Subscripts and superscripts
Y	miombo harvest
Z	shadow wage rate for household
	parameter in utility function
	parameter in utility function
	parameter in harvest function
	parameter in harvest function
	weights in social benefit function
	discount factor
	parameter in labour for clearing function
	parameter in miombo growth function
	parameter in miombo growth function
	parameter in miombo growth function

APPENDIX 2. THE SOLUTION PROCEDURE (See Sumaila 1997)

$$\frac{\partial \ell}{\partial L_{c,t}} = \rho_{t-1}(\psi p_c q_c N_t^{\mu} L_{c,t}^{\psi-1}\nu - 0.5 k_c L_{c,t}^{-0.5}) - 0.5(\theta - \theta_c) q_c N_t^{\mu} L_{c,t}^{\psi-1} - 0.5\lambda_t \mathit{switch}\,1 q_c N_t^{\mu} L_{c,t}^{\psi-1} \quad (1)$$

$$\frac{\partial \ell}{\partial L_{h,t}} = \rho_{t-1}(\psi p_h q_h N_t^{\mu} L_{h,t}^{\psi-1}\nu - \xi z L_{h,t}^{\mu-1}) - \psi(\theta - \theta_h) q_h N_t^{\mu} L_{h,t}^{\psi-1} - \psi\lambda_t \mathit{switch}\,1 q_h N_t^{\mu} L_{h,t}^{\psi-1} \quad (2)$$

$$\frac{\partial \ell}{\partial N_t} = \rho_{t-1}(\mu p_c q_c N_t^{\mu-1} L_{c,t}^{\psi}\nu + \mu p_h q_h N_t^{\mu-1} L_{h,t}^{\psi}\nu) + \theta(\mu q_c N_t^{\mu-1} L_{c,t}^{\psi} + \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) \quad (3)$$
$$-(\theta_c \mu q_c N_t^{\mu-1} L_{c,t}^{\psi} + \theta_h \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) + \lambda_t \mathit{switch}\,1(s - \mu q_c N_t^{\mu-1} L_{c,t}^{\psi} - \mu q_h N_t^{\mu-1} L_{h,t}^{\psi}) - \lambda_{t+1} s_{\text{switch2}}$$

$$\frac{\partial L}{\partial \lambda_t} = -\mathit{switch}\,1(\mathit{switch}\,1\ \arg) \quad (4)$$

$$\frac{\partial L}{\partial \xi_t} = -\mathit{switch}\,3(\mathit{switch}\,3\ \arg) \quad (5)$$

where,

$$\mathit{switch1} = \begin{cases} 1\ \mathit{if}\ (N_{t-1} + R_t - N_t - H_{c,t} - H_{h,t}) < 0 \\ 0\ \mathit{otherwise} \end{cases}$$

$$\mathit{switch2} = \begin{cases} 1\ \mathit{if}\ (N_t + R_{t+1} - N_{t+1} - H_{c,t+1} - H_{h,t+1}) < 0 \\ 0\ \mathit{otherwise} \end{cases}$$

$$\mathit{switch3} = \begin{cases} 1\ \mathit{if}\ (L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t}) < 0 \\ 0\ \mathit{otherwise} \end{cases}$$

$$\mathit{switch}\,1\ \mathit{arg} = N_{t-1} + R_t - N_t - H_{c,t} - H_{h,t}$$

$$\mathit{switch}\,2\ \mathit{arg} = N_t + R_{t+1} - N_{t+1} - H_{c,t+1} - H_{h,t+1}$$

$$\mathit{switch}\,3\ \mathit{arg} = L_t - L_{m,t} - L_{a,t} - L_{n,t} - L_{of,t}$$

The above adjustment equations can be manipulated to capture:

The command model: when , and either $_c$ or $_h$ are not zero. It should be noted that there is room for flexibility in the command model in the sense that one can give varying emphasis to social and environment values by selecting different values for the s.

The command model reduces to a **cooperative model** if all the s are set equal to zero.

The command model collapses to a **non-cooperative model** if in addition to all the s being zero, the marginal stock effect on benefits of each stakeholder is not internalised by the users. That is, when the first term in the stock adjustment Equation (27) is set equal to zero.

APPENDIX 3. SCIENTISTS WHO PARTICIPATED IN DEVELOPING THE MODELS

Country and institution	Area of specialization
A. Malawi	
University of Malawi	
Dr. Charles Mataya	Agricultural economics
Mr. Charles Jumbe	Economics
Mr. Richard Kachule	Agricultural economics
Mr. Hardwick Tchale	Agricultural economics
B. Mozambique	
1. Eduardo Mondlane University	
Dr. Isilda Nhantumbo (now with IUCN)	Natural resource management
Dr. Gilead Mlay	Agricultural economics
Mr. Mario Falcao	Forest economics
2. Forestry Research Centre	
Mr. Jose Soares	Forestry
C. Tanzania	
Sokoine University of Agriculture	
Dr. Gerald Monela	Forest economics and management
Dr. Abdallah Kaoneka (late)	Forest economics and management
Dr. Yonika Ngaga	Forest economics
Dr. George Kajembe	Anthropology and social forestry
Dr. Zebedayo Mvena	Rural sociology
Dr. Florens Turuka	Agricultural economics
D. Zimbabwe	
University of Zimbabwe	
Dr. Ramos Mabugu	Economics
Dr. Chris Sukume	Agricultural economics
Southern Alliance For Indigenous Resources (SAFIRE)	
Mr. Peter Gondo	Forestry
E. Canada	
University of British Columbia	
Dr. Ussif Rashid Sumaila (also with CMI, Bergen, Norway)	Environmental and Natural Resource Economics and Management
F: Norway	
Agricultural University of Norway	
Dr. Arild Angelsen (also with CIFOR)	Economics
G. CIFOR	
Dr. Godwin Kowero	Forest economics and management
Prof. Bruce Campbell	Ecologist

15.
Manual for users of MIOMBOSIM: A simulation model for the management of miombo woodlands

G. Kowero and U.R. Sumaila

1. INTRODUCTION

What is Miombosim?
Miombo woodland is one of the most extensive dry forest vegetation types in Africa occurring in seven countries in eastern, central and southern Africa; namely Angola, Malawi, Mozambique, Tanzania, Democratic Republic of Congo, Zambia and Zimbabwe. The woodlands occupy an area of about 2.7 million square kilometres, almost equal to the combined land area of Mozambique, Malawi, Zimbabwe, Tanzania and Zambia.

The miombo ecosystem forms an integral part of rural communities living in them or in their proximity by providing them with virtually all their energy requirements in terms of fuelwood. The woodlands also provide building materials like poles and grass for thatching, medicines, wild meat and other types of food and fruits, fodder for livestock and wild game, and many timber and non-timber products. The woodlands offer a number of opportunities to various stakeholders. In each country there are policies guiding socio-economic development that affect the stakeholders and their environment in complex ways.

Miombosim is a system dynamics model that can be used to reconcile the demands of these stakeholders on the woodland resources in a sustainable manner. It uses a simulation software package, commonly known as Powersim, to simulate a game theoretic computational model for the management of miombo woodland resources. We first described in the model the different elements that characterize the interactions of the stakeholders (or players in game theory language) with the woodlands as a dynamic system. Mimbosim is therefore a platform on which we can evaluate the implications of different policies. This allows decision makers to understand the policy implication for further refinement (if necessary) before recommending their implementation.

What are the goals of Miombosim?

A main goal of Miombosim is to provide researchers, resource managers, government departments and non-governmental organizations a tool for policy exploration regarding the use and management of miombo woodland resources. Miombosim therefore helps all these stakeholders to understand the complex relationships that characterize the management and use of miombo woodlands, and this can be enhanced by experimenting with different policy options or through sensitivity analysis on values of chosen parameters.

What is expected from runs of Miombosim?

Each Miombosim run will represent different policy initiatives under different scenarios for the management and use of the miombo woodland resources. The user specifies the policy options to experiment with and the Miombosim runs facilitate the selection of the most favourable policy option.

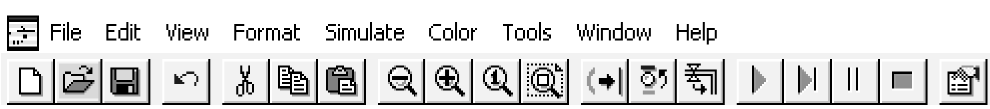
2. USER ENVIRONMENT

Powersim application window displays menus and provides the workspace for any simulation run of Miombosim. The Powersim application window is based on the same principles as any typical Windows application such as Excel, hence, knowledge of how to use other Windows based applications will be of great benefit to Miombosim users.

This manual is not intended to give the basics of Powersim; rather, it is intended to guide users on how to make use of a model (Miombosim) developed using Powersim. The assumption is that policy makers and other users will already have the problem formulated for this simulator and their interest is to use this as a basis for creating scenarios on different policy options and even testing the sensitivity of the values of various parameters. This therefore expands their scope for planning and decision-making as well as grounding such decisions in science.

For further details on this simulator and on the casual loop diagramming in Powersim see http://www.powersimsolutions.com/default.asp

Powersim menubar



The menu bar is located below the title bar at the top of the application window and contains all the Powersim commands. To view all the commands in a menu, do one of the following:

- Click the menu name
- Press Alt + N, where N is the underlined letter in the menu name. For example, press Alt + F to open the File menu.

Powersim commandbar

The commandbar is located below the menubar, and contains a set of buttons for performing the most frequently used commands in Powersim, for example, Open; Save, and Copy files; Run and Stop.

Powersim workspace

The workspace is where you view casual loop and flow diagram models and adjust model parameters using input presentations. This is the area that will be of interest to policy makers and other interested parties. It is in the workspace that scenario generation for different policies as well as sensitivity analyses are made. This can be done by modifying the casual loops and the model parameters in the equations using information supplied by stakeholders like policy makers.

Powersim statusbar

The statusbar is usually displayed at the bottom of the Powersim application window. It contains different kinds of status information, for example, context-sentitive menu help and the current simulation time.

3. MENU COMMANDS

This section provides you with a detailed description of all commands and options found in Powersim menus. Note that some of these are also available as buttons in the commandbar.

File menu

You use this menu to open, save and print documents or quit Powersim workspace. To use a document, you must first open and display it on your screen. You can then perform simulation runs.

Overview of File menu commands

- Open – Opens an existing document
- Close – Closes all windows of the active document
- Save – Saves changes made to the active document
- Save As – Saves and names the active file
- Page setup – defines page setup for the current document
- Print – prints the active window according to the parameters you specify
- Print Setup – identifies the printer you want to use and sets options for it
- Properties – Displays properties of the active documents
- Exit – Quits Powersim, prompts to save any unsaved documents

Edit menu

You use this menu to copy areas from your document, view the scaling of parameters, and searching for variables and parameters in a diagram.

Overview of Edit menu commands

- Copy – Copies the selected area and places it on a clipboard
- Scale – Displays the minimum and maximum scaling settings for variables
- Find – Searches for a variable or parameter in the active diagram

View menu

Use this menu to show or hide the commandbar and statusbar and to shrink or enlarge the diagram.

Overview of View menu commands

- Commandbar – Toggles the commandbar on/off
- Statusbar – Toggles the statusbar on/off
- Zoom – Enlarges or reduces the contents of the active diagram window

Simulate menu

Use this menu to start, stop or pause a simulation, and to inspect/specify run and simulation parameters, including time step and integration methods.

Overview of Simulate menu commands

- Run – Start a simulation
- Pause – Toggles pause on/off
- Stop – Stops a simulation
- Clear Results – Clears stored simulation results
- Run Setup – Defines run parameters
- Simulation Setup – Defines simulation parameters (start, stop, time step, etc.)

Tool menu

You use this menu to build your model in Powersim language

Overview of tool menu commands

- Level – symbol used to represent a stock
- Auxiliary – symbol representing an auxiliary function
- Constant - symbol used to represent a parameter
- Flow-with-rate – used to represent a flow into or out of a stock
- Link – used to link variables and parameters in the model
- Erase – used to erase/delete a symbol
- Camera – used to make a photocopy of a symbol
- Number – used to report a number (a parameter) in the model
- Time table – used to report results from a simulation in table form
- Time graph - employed to report results in graphical form
- Scatter gragh – illustrates results form simulations using scatter diagrams
- Array graph – used to report results of array variables (see Figure 2).

Window menu
You use this menu to rearrange windows or activate specified windows

Overview of Window menu commands
- Cascade – Arranges windows in an overlapping pattern
- Tiles – Arranges windows side by side so that all windows are visible
- Arrange Icons – Arranges icons in rows
- Close All – Closes all Powersim windows
- <list of windows> - Lists open windows

Help menu
Use this menu to get help on using Powersim

Overview of Help menu commands
- Contents – Displays the contents screen of Help
- Getting Started – Displays the Getting Started screen of Help
- Current Document - Opens the Help file associated with the current document
- About Powersim – Displays version number, copyright notice, and license information.

4. RUNNING MIOMBOSIM

This section contains step-by-step instructions on how to perform an experimental simulation session using Powersim. By following the instructions below, you will learn how to open and simulate a ready-made Miombosim model. However, for this we have to first familiarize ourselves with key symbols used in Powersim.

Symbols and building blocks for Miombosim
The aim of this section is to familiarize the user with key Powersim symbols and building blocks, which are used to develop Miombosim. Figure 1 shows a simple example that demonstrates how the symbols are put together in a model.

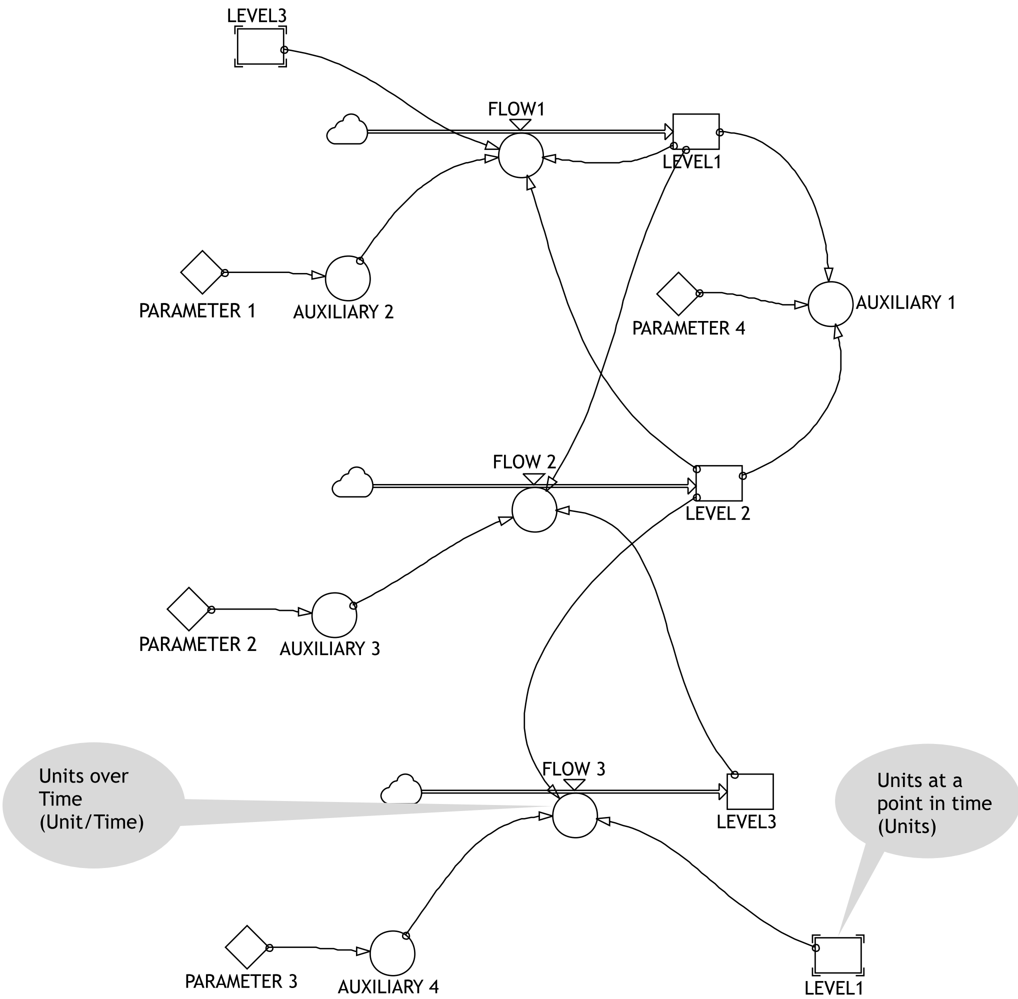
Level: Represented as a square, it is a variable type, which accumulates changes, for example, the volume of miombo in a stand or the number of people who cut miombo trees at any given time. It can be increased or decreased by what we call 'flows', as defined below (see next definition). See Appendix 1 for an example.

Flow-with-rate: Represented as a circle with an arrow sitting on top of the circle, it influences levels by adding the net flow of new stock, for example, new miombo growth, into levels. The flow is controlled by the connected rate variables, normally an auxiliary variable which defines how the stock of miombo changes (see below). Examples of these are given in Appendix 1.

Auxiliary: Represented as a circle, it is a variable type or function, which contains calculations based on other variables and parameters. It is usually a 'help' function that is used to define parts of a larger equation in the model. A function that describes miombo growth can be expressed using an auxiliary function, which can then be fed into the calculation of a flow function.

Constant: Represented as a diamond, it is a variable, which contains fixed values that are used in calculations of other variables or flows. Examples of constants are

Figure 1. The main Powersim symbols as used in a simple Miombosim model



prices in a constant price model or natural mortality rate of miombo woodland (see Appendix 1 for an example). Constants hold the parameters of the model

Cloud: Represented as a cloud, it is an undefined source or outlet for a flow to, or from a level. It denotes that we are at a model's outer limits. A cloud delimits the model; it represents the end of a model, as it were. For example, to define a flow of 'new' miombo biomass (due to growth) into the existing biomass, we show a flow by an arrow leaving a cloud and pointing into the Level. Cloud symbol expresses the fact that the growth comes from 'something' exogenous to the model.

Figure 1 and Appendix 1 display the structure of an example of Miombosim in diagram and equation formats, respectively. The diagram demonstrates how the above symbols are put together to build Miombosim, while the equations define the variables and parameters of the model mathematically. A brief description of various elements of the model are given in the Appendix 1.

Opening Miombosim

- From the File menu of Powersim choose Open or click Open in the Commandbar.
- From the Open dialog box select the model you want to open from the File Name listbox and select OK.

Data input and model runs

Choosing Start- and-Stop Time:

- An important aspect of the modeling of a problem is the choice of a time horizon for your model. The default start- and-stop times for Miombosim are 0 and 100, respectively. The time horizon may be simply units of computational time as in Miombosim, or some period of time (weeks, months, years, etc). In Miombosim, the actual computational time horizon assumed depends on how quickly the model converges to the equilibrium solution.
- Click Run in the commandbar to start a simulation run based on the original parameter values of the model.
- You may pause and resume a simulation whenever you like by clicking the Pause button.
- Let the simulation run until it has reached its stop time, or stop it manually by clicking the stop button. Note that you cannot resume a simulation after you have stopped it. You will then have to start a new simulation run.
- As the simulation runs, you will see that the current simulation time is indicated in the statusbar.

Policy analysis using Miombosim

Simulating Miombosim means to have Powersim compute the results over time based on the assumptions used to construct the model.

To simulate the impacts that different causes of actions might have on the results of Miombosim, we can make parameter adjustments before a simulation run. For example, we are interested in understanding the implication (s) of a move taken by a government of a country through a policy that leads to a 10% increase in the price of poles from miombo woodlands. This change needs to be incorporated into Miombsim, and the model re-run to determine the effect of this change on the predicted outcomes of the model. To do this physically, open the base case diagram of the model, find the price of poles parameter (see Appendix 1) and by double clicking it you will get to the interface where you can make changes to the price. Make the change and close the interface. Then run model.

After opening the relevant Miombosim model and performing a base run, follow the following steps to generate another policy scenario or to perform a sensitivity analysis:

From the Window menu, choose the parameter to be tested, for example price of poles because of policy changes or the growth rate of standing volume of miombo to check how sensitive the predicted results of the model are to any of these parameters, and hence, the consequences of policy changes that lead to such changes to the parameters

- Note base case value of the parameter(s) to be tested.
- Change the value of this parameter as the situation dictates, for example, if it is price of poles or fuelwood, it can be increased or decreased by say 10%

depending on the anticipated market condition, price controls or government policies.
- Start a new simulation.

Compare results from new simulation with those of base case simulation to identify the effect of the parameter adjustment. For example, the base results of a simulation run of a Miombosim model for one forest reserve, showed, among other things, that a 30% decrease in post harvest losses of agricultural produce could lead to a decrease in the benefits to the household sector from the use of miombo wood resources by between 3 and 6%, while the overall benefits to them would increase by about 30%. This is because the households would derive most of their benefits from agricultural produce, so the impact of the decrease in post harvest loss would be felt fully.

5. PRESENTING SIMULATION OUTPUT

Outputs and information from a simulation may be presented by any of the methods listed in Table 1.

Table 1. Outputs and information from a simulation

Name	Method
Auto Reports	Number, animation or graph
Array Graph	Presents an array of numbers in a 2-dimensional graph
Number	Presents values as numbers
Scatter Graph	Presents two variables in a 2-dimensional graph
Time Graph	Presents values as 2-dimensional line graphs and/or areas
Time Table	Presents values as tables of numbers

Auto reports

Auto reports are presentations of simulation results automatically displayed within or next to variable symbols in a diagram. Powersim offers 3 possible auto reports. It should be noted that the user does not have to do anything to initiate the auto reports:

Animation auto report:
Levels are animated as vertical hollow bars that capture changes in the simulated value of the variable represented by the level.

Auxiliaries and constants are animated as gauges, i.e., as needles with their center at the bottom of the variable symbol.

Number auto report:
The variables value is presented as a number, outside the variable symbol, at the side opposite of the variable name

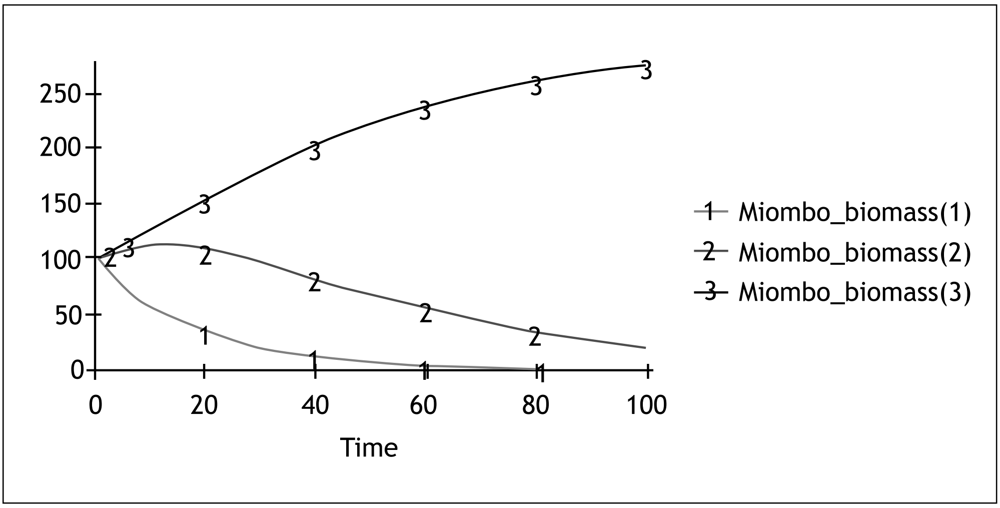
Graph auto report:
The graph is drawn as a simple line graph inside the level rectangle. The line color follows the symbol color.

To see examples of each of the above simply start a simulation and watch the symbols representing the various variables in the model.

Array graph
The array graph is an input/output presentation that displays an array variable or a series of scalar variables as a line graph or bar, optionally filled with a color. Figure 2 gives an example of an array graph. The graph shows the time paths of different year classes of miombo biomass. To construct array graphs do the following:

- Click the tool menu
- Select 'Array gragh'
- Click any where in the diagram view, and an empty graph will appear
- Double click inside this graph and an interface will appear.
- Choose the array variable(s) to be graphed
- Close platform and run model

Figure 2. Array graph of the variable miombo-biomass



Number
A number presentation displays the current value of a certain variable as a real number. An example is provided in Figure 3. To construct this, do the following:

- Click the tool menu
- Select 'Number'
- Click any where in the diagram view, and an empty 'Number' box will appear
- Double click inside this box and an interface will appear.
- Choose the variable to be reported
- Close platform and run model

Figure 3. Number boxes showing the price and revenue from a simulation

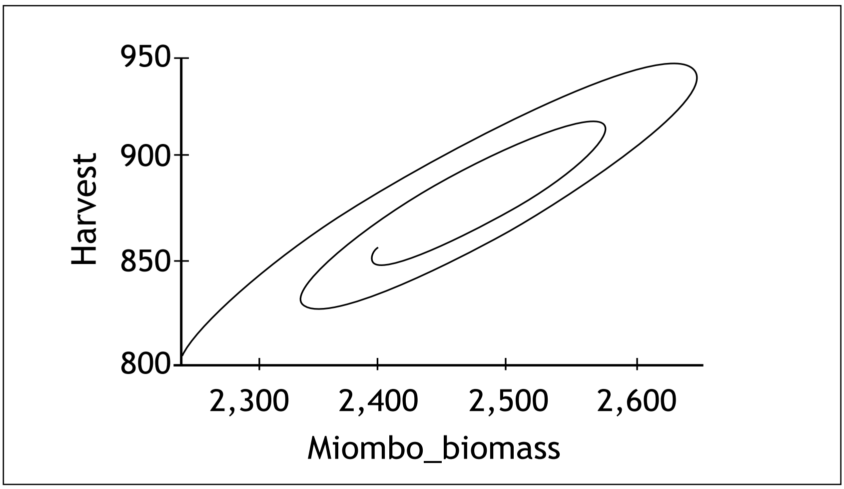
Revenue	478.36
Price	10.00

Scatter graph

A scatter graph displays the relationship between two variables in a 2-dimensional graph by using one variable as the X-coordinate and the other as Y-coordinate. Figure 4 is an example of a scatter graph. To construct this, do the following:

- Click the tool menu
- Select 'Scatter graph'
- Click any where in the diagram view, and an empty graph will appear
- Double click inside this graph and an interface will appear.
- Choose the variable(s) to be reported
- Close platform and run model

Figure 4. Scatter graph illustrates the possible path of biomass and harvest levels



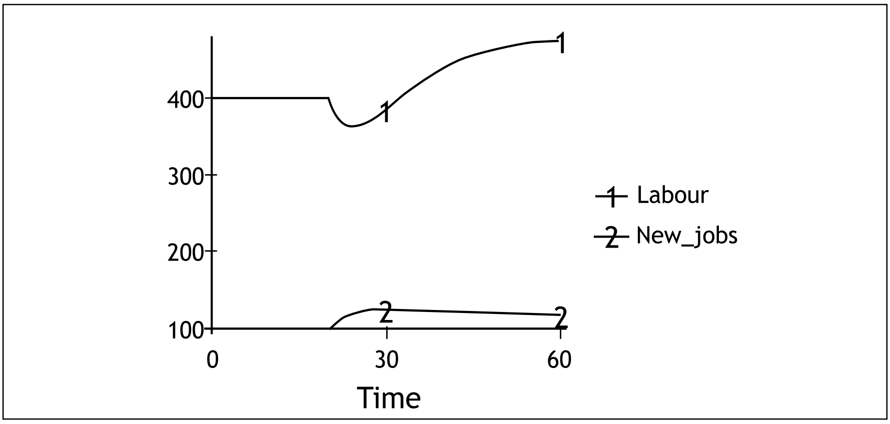
Time graph

A time graph displays a graphical overview of one or more variables' development over time. It has Time as the variable along the x-axis, and one or more dependent variables along the y-axis. Figure 5 is an example of a scatter graph. To construct this, do the following:

- Click the tool menu
- Select 'Time graph'
- Click any where in the diagram view, and an empty graph will appear
- Double click inside this graph and an interface will appear.

- Choose the variable(s) to be reported
- Close platform and run model

Figure 5. Time graph illustrates the possible time path of the current level of labour and new jobs over time



Time table

A time table presents the time paths of certain variables in columns and rows. An example of a time table is given in Figure 6. To construct this, do the following:

- Click the tool menu
- Select 'Time table'
- Click any where in the diagram view, and an empty table will appear
- Double click inside this table and an interface will appear.
- Choose the variable(s) to be reported
- Close platform and run model

Figure 6. Time table reports the miombo biomass and the growth in biomass over time

Time	Miombo_biomass	Growth_in_biomass
24	11,212.85	1,233.41
36	12,446.26	1,369.09
48	13,815.35	1,519.69
60	15,335.04	1,686.85
72	17,021.90	1,872.41
84	18,894.30	2,078.37
96	20,972.68	2,306.99
108	23,279.67	2,560.76
120	25,840.44	2,842.45

FURTHER READING

Byrknes, A. and Cover, J. 1996 Quick Tours in Powersim 2.5. Powersim Press, 99p.
Byrknes, A. 1996 Run-Time User's Guide and Reference Manual. Powersim Press, 57p.
Byrknes, A. and Cover, J. 1996 Quick Tours in Powersim 2.5. Powersim Press, 99p.
Anon. 1996 Powersim 2.5 User Manual, 225p.
Sumaila, U.R., Angelsen, A. and Kowero, G. 2001 A system dynamics model for management of miombo woodlands. In: Modelling methods for policy analysis in miombo woodlands. Occasional Paper No. 35, CIFOR, Bogor. pp.17-30.

APPENDIX 1: SAMPLE MIOMBOSIM MODEL IN POWERSIM EQUATION INTERFACE

The following are equations in a typical Miombosim model. The first column presents model variables (levels, flows, auxiliaries, and constants) by their dimensions (whether a scalar, vector or matrix); the initial value (init) if variable is a level; and documentation (Doc) explaining the variables. For instance, in the case of the variable 'labour' the dimension or 'dim' is a vector consisting of 'player' and 'period'. Like all levels, labour has to be given an initial or 'init' value to start of the simulation, this is defined as '0.1' in the example below – in theory this could be any number but in practice it should be a reasonable guesstimate of the model solution to speed up the simulation. Flow into the variable, labour, is defined next. The second column defines the variables, for instance, the 'flow into labour' is defined by the time step (dt) multiplied by the rate at which labour changes in a time step (Rate_labour).

dim	labour = (p=player, t=period)
init	labour = 0.1
flow	labour = +dt*Rate_labour
doc	labour = Effort level: initialized
dim	Mu = (t=period)
init	Mu = 1
flow	Mu = +dt*RMu
doc	Mu = Multiplier constraint for labour: initialized
dim	Multiplier = (t=period)
init	Multiplier = 1
flow	Multiplier = +dt*RMultiplier
doc	Multiplier = Multiplier constraint for WLRs: initialized
dim	WLR = (t=period)
init	WLR = 1/(1+0.02)^INDEX (t)
flow	WLR = +dt*Rate_WLR
doc	WLR = Miombo woodland resources
dim	Rate_labour = (p=player, t=period)
aux	Rate_labour = IF ((labour (p, t) + R_labour (p,t)/ (2*TIME+1))<0,0,R_labour (p,t)/(2*TIME+1))
doc	Rate_labour = Rate of labour equation
dim	Rate_WLR = (t=period)
aux	Rate_WLR = IF ((WLR (t) + R_WLR(t)/(2*TIME+1))<0,0,R_WLR(t)/ (2*TIME+1))
doc	Rate_WLR = Rate of stock equation
dim	RMu = (t=period)

```
aux     RMu = -Switch3(t)*S3fn(t)
doc     RMu = Rate of effort multiplier
dim     RMultiplier = (t=period)
aux     RMultiplier = -Switch1 (t)*S1fn(t)
doc     RMultiplier = Rate of stock multiplier
aux     Ave_agric = SUM (t=1..LAST (period);H_agric(t))/LAST(period)
doc     Ave_agric = Proportion of miombo lost by converting land to
        agricultural (agric.) production
aux     Ave_area_of_standing_miombo = Ave_WLR*Forest_Area
aux     Ave_commercial = SUM (t=1..LAST (period); WLR_use (1,t))/
        LAST(period)
doc     Ave_commercial = Proportion of miombo harvested by the commercial
        sector
aux     Ave_converted_agric_land = Ave_agric*Forest_Area
aux     Ave_fwd = SUM(t=1..LAST(period);H_fwd(t))/LAST(period)
doc     Ave_fwd = Proportion of miombo used for fuelwood
aux     Ave_hsehld = SUM (t=1..LAST(period); WLR_use(2,t))/LAST(period)
doc     Ave_hsehld = Proportion of miombo used by households (fuel, poles
        and fraction lost by converting land to agric production)
dim     Ave_labour = (p=player)
aux     Ave_labour = SUM (t=1..LAST(period); labour(p,t))/LAST(period)
doc     Ave_labour = Average labour employed by the households and the
        commercial sector.
aux     Ave_pole = SUM (t=1..LAST(period); H_poles(t))/LAST(period)
doc     Ave_pole = Average fraction of miombo used for poles by households
aux     Ave_vol_miombo_used_by_commer =
        Ave_commercial*Forest_Area*Volume
aux     Ave_vol_miombo_used_by_hh = Ave_hsehld*Forest_Area*Volume
aux     Ave_vol_miombo_used_for_fwd = Ave_fwd*Forest_Area*Volume
aux     Ave_vol_miombo_used_for_poles = Ave_pole*Forest_Area*Volume
aux     Ave_WLR = SUM (t=1..LAST(period); WLR(t))/LAST(period)
doc     Ave_WLR = Proportion of standing miombo after some is converted to
        agric and other uses (residual miombo)
dim     Benefit = (p=player, t=period)
aux     Benefit =
        Discount_factor(1)^INDEX(t)*(price_com*WLR_use(1,t)*Forest_Area*Volume
        - cost_H*labour(1,t))|p=1;
        Discount_factor(2)^INDEX(t)*(price_hld*WLR_use(2,t)*Forest_Area*Volume
        - cost_fn(t)*labour(2,t))
doc     Benefit = Benefit function for users; 1=commercial; 2=household
dim     Converted_land = (t=period)
aux     Converted_land = H_agric(t)*Forest_Area
dim     Converted_land_t1 = (t=period)
aux     Converted_land_t1 =
        Converted_land(t+1)|t<LAST(t);Converted_land(LAST(t))
dim     cost_fn = (t=period)
aux     cost_fn = v*Disposable_income^0.5/Leisure^0.5
doc     cost_fn = shadow price of labor for households
```

dim	Cum_land_under_agric_cultivation = (t=period)
aux	Cum_land_under_agric_cultivation = Converted_land+Tot_existing_land_under_agric
dim	Disposable_income = (t=period)
aux	Disposable_income = Income_from_agric_on_converted_miombo_land + Income_from_sale_of_wood_from_converted_land + Income_from_wood_products + Net_income_from_existing_agric_land + Off_income - subs_income
doc	Disposable_income = Auxiliary to household cost function
dim	Exisitng_agric_lab = (t=period)
aux	Exisitng_agric_lab = 0.1*Tot_existing_land_under_agric/ Init_existing_agric_land
doc	Exisitng_agric_lab = Fraction of total labour in the household used for current agricultural production (that is, this labour is not available for expanding agriculture into miombo)
aux	G_benefit = Tot_Benefit(1)+Tot_Benefit(2)
doc	G_benefit = Sum of benefits
dim	H_agric = (t=period)
aux	H_agric = Price_agric*WLR_use(2,t)/(Price_agric+price_Wprod)
doc	H_agric = Fraction of miombo used for agricultural purposes in the household.
dim	H_fwd = (t=period)
aux	H_fwd = price_fwd*H_Wprod/(price_fwd+price_pole)
doc	H_fwd = Fraction of miombo resources used as fuelwood
dim	H_poles = (t=period)
aux	H_poles = price_pole*H_Wprod/(price_fwd+price_pole)
doc	H_poles = Fraction of miombo used as poles
dim	H_Wprod = (t=period)
aux	H_Wprod = price_Wprod*WLR_use(2,t)/(Price_agric+price_Wprod)
doc	H_Wprod = Total fraction of miombo used for wood products (poles, fuelwood).
dim	Income_from_agric_on_converted_miombo_land = (t=period)
aux	Income_from_agric_on_converted_miombo_land = H_agric*Forest_Area*Rev_per_ha_of_Agric_land
dim	Income_from_sale_of_wood_from_converted_land = (t=period)
aux	Income_from_sale_of_wood_from_converted_land = 0.17*H_agric*Forest_Area*Volume*price_fwd + 0.83*H_agric*Forest_Area*Volume*price_pole
dim	Income_from_wood_products = (t=period)
aux	Income_from_wood_products = price_fwd*H_fwd*Forest_Area*Volume + price_pole*H_poles*Forest_Area*Volume
dim	labour_in_man_days = (p=player, t=period)
aux	labour_in_man_days = labour(2,t)*Total_man_day_in_community
dim	Leisure = (t=period)
aux	Leisure = max_labour(t) - labour(2,t) - off_miombo_labour - Exisitng_agric_lab
doc	Leisure = Auxiliary function to the household cost function (maximum labour in household less the labour used in converting miombo into

```
        agriculture less labour employed by household to produce poles and
        fuelwood less off miombo labour less labour employed in  current
        agricultural production)
dim     M_cost = (p=player, t=period)
aux     M_cost = (0.5*0.8*v*price_hld*eff_para(2)*Disposable_income(t)^-
        0.5*Leisure(t)^-0.5*WLR(t)^0.6*Volume*labour(2,t)^-0.2 +
        v*0.5*Disposable_income(t)^0.5*Leisure(t)^-0.5)/Leisure(t)
doc     M_cost = Marginal cost of household labour
dim     MultT1 = (t=period)
aux     MultT1 = Multiplier(t+1)|t<LAST(t); Multiplier(LAST(t))
doc     MultT1 = End period mulitplier adjustment
dim     Net_income_from_existing_agric_land = (t=period)
aux     Net_income_from_existing_agric_land =
        Tot_existing_land_under_agric*(Rev_per_ha_of_Agric_land -
        purchased_inputs*Volume)
aux     Off_income = off_wage*off_miombo_labour
doc     Off_income = Off-miombo income to household users
aux     Price_agric = price_per_cum_equiv_from_agric - Conv_cost -
        purchased_inputs
doc     Price_agric = Net income from agric from use of a unit of woodland
        resources adjusted for cost of purchased inputs and conversion
aux     price_hld = (Price_agric + price_Wprod)/2
doc     price_hld = Average income to household users from both agricultural
        produce and wood products
aux     price_Wprod = (price_fwd+price_pole)/2
doc     price_Wprod = Average price to household users from timber, poles
        and fuelwood
aux     purchased_inputs = fertilizer_cost+seed_cost
doc     purchased_inputs = Cost per unit of inputs in terms of cu.m. miombo
        equivalent
dim     R_labour = (p=player, t=period)
        auxR_labour = preference*Discount_factor(1)^INDEX(t)*(0.8*eff_para
        (1)*price_com*Forest_Area*WLR(t)^0.6*Volume*labour(1,t)^-0.2 -
        cost_H) + 0.8*theta(1)*eff_para(1)*WLR(t)^0.6*labour(1,t)^-0.2 -
        beta*eff_para(1)*WLR(t)^0.6*labour(1,t)^-0.2 -
        0.8*Multiplier(t)*Switch1(t)*eff_para(1)*price_com*WLR(t)^0.6*labour(1,t)^-
        0.2  |p=1; (1 -
        preference)*Discount_factor(2)^INDEX(t)*(0.8*eff_para(2)*price_
        hld*Forest_Area*WLR(t)^0.6*Volume*labour(2,t)^-0.2 - cost_fn(t) -
        labour(2,t)*M_cost(2,t)) +
        0.8*theta(2)*eff_para(2)*WLR(t)^0.6*labour(2,t)^-0.2 -
        beta*eff_para(2)*WLR(t)^0.6*labour(2,t)^-0.2 -
        0.8*Multiplier(t)*Switch1(t)*eff_para(2)*price_hld*WLR(t)^0.6*labour(2,t)^-
        0.2 - Mu(t)*Switch3(t)
doc     R_labour = Auxiliary to rate of labour equation
dim     R_WLR = (t=period)
```

```
aux     R_WLR =
        Discount_factor(1)*Volume*(0.6*price_com*eff_para(1)*labour(1,t)^0.8*WLR(t)^-
        0.4) +
        Discount_factor(2)*(0.6*price_hld*eff_para(2)*labour(2,t)^0.8*WLR(t)^-
        0.4) +  ((theta(1) - beta)*eff_para(1)*labour(1,t)^0.8 + (theta(2) -
        beta)*eff_para(2)*labour(2,t)^0.8)*0.6*WLR(t)^-0.4 +
        survival*MultT1(t)* Switch2(t) - Multiplier(t)*Switch1(t)*(1+
        0.6*WLR(t)^-0.4*(eff_para(1)*labour(1,t)^0.8 +
        eff_para(2)*labour(2,t)^0.8))
doc     R_WLR = Auxiliary to rate of biomass equation
dim     Regeneration = (t=period)
aux     Regeneration = 0.03*WLR
doc     Regeneration = 3% constant annual regeneration assumed
dim     S_WLRuse = (t=period)
aux     S_WLRuse = WLR_use(1,t)+WLR_use(2,t)
doc     S_WLRuse = Proportion of miombo used by both the household and the
        commercial sectors annually
dim     S1fn = (t=period)
aux     S1fn = survival*WLR(t-1) + Regeneration(t) - WLR(t) - S_WLRuse(t) |
        t>1; survival*WLR0 + Regeneration(t) - WLR(1) - S_WLRuse(1)
doc     S1fn = Auxiliary to switch function1
dim     S2fn = (t=period)
aux     S2fn = survival*WLR(t) + Regeneration(t) - WLR(t+1) -S_WLRuse(t+1)
        | t < LAST(t); WLR0 + Regeneration(t)
doc     S2fn = Auxiliary to switch function2
dim     S3fn = (t=period)
aux     S3fn = max_labour-labour(2,t)-off_miombo_labour
doc     S3fn = Auxiliary to switch function3
dim     Switch1 = (t=period)
aux     Switch1 = IF(S1fn(t) <0,1,0)
doc     Switch1 = Switch function1 to enforce constraint
dim     Switch2 = (t=period)
aux     Switch2 = IF(S2fn(t) <0,1,0)
doc     Switch2 = Switch function2 to enforce constraint
dim     Switch3 = (t=period)
aux     Switch3 = IF(S3fn(t) <0,1,0)
doc     Switch3 = Switch function3 to enforce constraint
dim     Tot_Benefit = (p=player)
aux     Tot_Benefit = SUM(t=1..LAST(period); Benefit(p,t))/1000
doc     Tot_Benefit = Total benefit to each user over time horizon of model
dim     Tot_existing_land_under_agric = (t=period)
aux     Tot_existing_land_under_agric =
        Init_existing_agric_land|t=1;Converted_land_t1+Init_existing_agric_land
dim     WLR_use = (p=player, t=period)
aux     WLR_use = eff_para(p)*WLR(t)^0.6*labour(p,t)^0.8
doc     WLR_use = Proportion of miombo used by either the household or the
        commercial sectors annually
const   beta = 1
```

doc	beta = Environmental concern parameter, takes values of 0 or 1. Zero if you care about the environment and 1 if you do not.
const	Conv_cost = 0
doc	Conv_cost = Conversion cost per cu.m. of miombo, which can easily be converted to per ha (it is the opportunity cost of labour because labour is the sole input, otherwise it includes cost of other inputs).
const	cost_H = 4.18
doc	cost_H = Cost of inputs including labour used by commercial sector
dim	Discount_factor = (p=player)
const	Discount_factor = [0,0.893]
doc	Discount_factor = Discount factor
dim	eff_para = (p=player)
const	eff_para = [0,0.103]
doc	eff_para = Labour efficency parameter: This implies commercial sector will need 11.06 years, at full capacity utilization, to harvest all miombo woodlands in the area. The household will need the same time because they employ people from the same pool.
const	fertilizer_cost = 0.52
doc	fertilizer_cost = Cost of fertilizer
const	Forest_Area = 44508
doc	Forest_Area = Forested area at the beginning of the analysis
const	Init_existing_agric_land = 15844
doc	Init_existing_agric_land = Existing agric land at start of analysis
dim	max_labour = (t=period)
const	max_labour = 1
doc	max_labour = Maximum annual labour available to household users: normalized
const	off_miombo_labour = 0.1
doc	off_miombo_labour = Labour employed by household users on off-miombo activities
const	off_wage = 2001120
doc	off_wage = Off miombo wage
const	preference = 0
const	price_com = 6.04
doc	price_com = price per cu. m. of miombo used for charcoal by the commercial sector
const	price_fwd = 2.4
doc	price_fwd = Price per cu.m. of miombo used as firewood by the household. Impose royalty fee of 25% of price of firewood.
const	price_per_cum_equiv_from_agric = 5.05
doc	price_per_cum_equiv_from_agric = Value of agricultural products obtained when land which that supports a cubic metre of miombo (firewood or poles or timber or a combination of these) is put under crops (Opportunity cost of agricultural production in terms of wood lost)
const	price_pole = 2.40
doc	price_pole = Price per cu.m. of miombo used as poles
const	Rev_per_ha_of_Agric_land = 252.61

doc	Rev_per_ha_of_Agric_land = Revenue from a hectare of land used for agricultural production.
const	seed_cost = 0.28
doc	seed_cost = Cost of seeding
const	subs_income = 1909800
doc	subs_income = Subsistence income for the community
const	survival = 0.95
doc	survival = Survival rate for miombo woodland
dim	theta = (p=player)
const	theta = [0,0]
doc	theta = Social concern parameters: Takes values of 0 or 1. They are zeros when no social concerns are taken into account and are I otherwise.
const	Total_labour in person days_in_community = 4562558
doc	Total_labour in person days_in_community = Total person days in community per year available for miombo woodland activities.
const	v = 0.5
doc	v = parameter to labour cost function of households
const	Volume = 50
doc	Volume = Standing volume of wood per hectare
const	WLR0 = 1
doc	WLR0 = Initial volume of miombo for the site

16.

A goal programming model for planning management of miombo woodlands[1]

I. Nhantumbo and G. Kowero

ABSTRACT

This paper presents a methodology employed in reconciling demands of households, private sector, and government on miombo woodlands of Southern Africa.

A Weighted Goal Programming approach is presented for planning management and use of the woodlands as well as a framework for policy analysis. The approach is based on essentially two models, viz., household and private sector models, which are linked into a miombo woodlands model (MIOMBOGP). The MIOMBOGP provides a framework for evaluating the impact, on these two sectors and the woodlands, of some government macro-economic policies as well as some forestry and agricultural sector policies.

Key words: Weighted goal programming, miombo woodlands, household sector, private sector, and Southern Africa.

1. INTRODUCTION

Miombo woodland is an African woodland dominated by species of *Brachystegia*, either in pure stands or in association with those of *Julbernadia* and/or *Isoberlinia* (Lind and Morrison 1974; White 1983). It occurs in seven eastern, central and southern African countries namely Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe (White 1983). These woodlands are the major forest formations in this region. They occupy an area of about 2.7million km^2 and support over 40 million people. The people live in the vicinity of the woodlands, while some reside in woodlands that are in public domain. They rarely live in the woodlands set aside as government forest reserves, but do encroach on them for several demands.

Where the woodlands occur outside forest reserves, their clearing for agriculture has taken place over the years.

Dewees (1994) report that what is known about these woodlands is very much limited to their ecological and silvicultural characteristics. Further, most of the woodlands have been very heavily disturbed given the high local value they have to the inhabitants of this region. The woodlands offer a number of opportunities to various stakeholders, being people and/or institutions.

The national governments are interested in them in terms of revenues realized from licences and concessions issued to organizations and individuals harvesting forest produce, as well as their potential for tourism. In some cases the governments are interested in conservation of woodlands important for water supplies.

The private sector (institutions and individuals) is interested in extracting commercial products from the woodlands.

The communities bordering these woodlands are interested in them for a number of reasons. The woodlands are cleared to give way to agriculture. They are used as domestic animal grazing areas. They offer a number of timber and non-timber products for local consumption and trade.

In each country there are many policies guiding socio-economic development. Some of the policies target the government as an institution, or are specific to the private sector or target the rural communities. Each of these three entities has ways through which it can respond to the policies.

The objective of this paper is to present a methodology for planning woodland management and use, as well as for evaluating how the three principal woodland stakeholders respond to some macroeconomic and sectoral policies in ways that satisfy the achievement of their goals. The satisfaction of some of these goals makes demands on the woodland resources. It is these demands and the extent to which they manifest in the woodlands that the paper seeks to address, and especially their sustainable satisfaction.

There are several approaches for evaluating the impact/effect of the trade-off between the demands of these three sectors on the woodland resources. A weighted goal programming model is proposed as one of the approaches which can be employed to reconcile the objectives of the State, the household, and private sectors as they relate to the miombo woodland resources in this region.

This paper shall not present the basics of goal programming. Such information and examples of relevant applications can be found in, but not limited to, Romero (1991), Romero and Rehman (1989), Rehman and Romero (1993), Norton and Schiefer (1980), Nhantumbo (1997), Mendoza and Sprouse (1989) Hazell and Norton (1986), Day (1963) McCarl (1992), and Yoon and Hwang(1995).

The goal programming (GP) approach, of the acronym MIOMBOGP, is used side by side with a system dynamic approach (MIOMBOSIM) to model these sectors in chosen sites in Malawi, Mozambique, Tanzania and Zimbabwe as part of a CIFOR research project funded by the European Commission and implemented in these four Southern African Development Community (SADC) countries. These two approaches are intended to operationalise one of the objectives of this research project, which is to evaluate how some selected macroeconomic and sectoral policies are impacting on local communities and the industry dependent on these woodlands. Also evaluated is how the policy responses by these two sectors are impacting on the woodland resource management, use and conservation.

The paper is organized as follows. Section 2 gives a brief overview of the problem environment. Section 3 presents the methodology for modelling the household sector, while Section 4 presents the same for the private sector. For each sector the most important activities are described, followed by a general mathematical formulation of the MIOMBOGP model. In Section 5 the two sectoral models are linked together to reflect the role these sectors play as producers and intermediaries in marketing forest products extracted from these woodlands. Section 6 demonstrates how sectoral government policies are incorporated into the MIOMBOGP model. Section 7 presents limitations of this modelling approach.

2. PROBLEM ENVIRONMENT

In the miombo woodland region planners and policy makers are faced with the challenge of maintaining land under woodland cover (Dewees 1994). This is because of the pressure for agricultural land arising from growing populations in these countries. Further, there is also pressure for increasing livestock population, not only in terms of space but also demands for fodder. The future of these woodlands would depend very much on how the demands of various sectors are reconciled in any specific location.

Planning for the welfare of the local communities depending on the woodlands would demand consideration of decisions and responses to policies at various levels as illustrated by Figure 1.

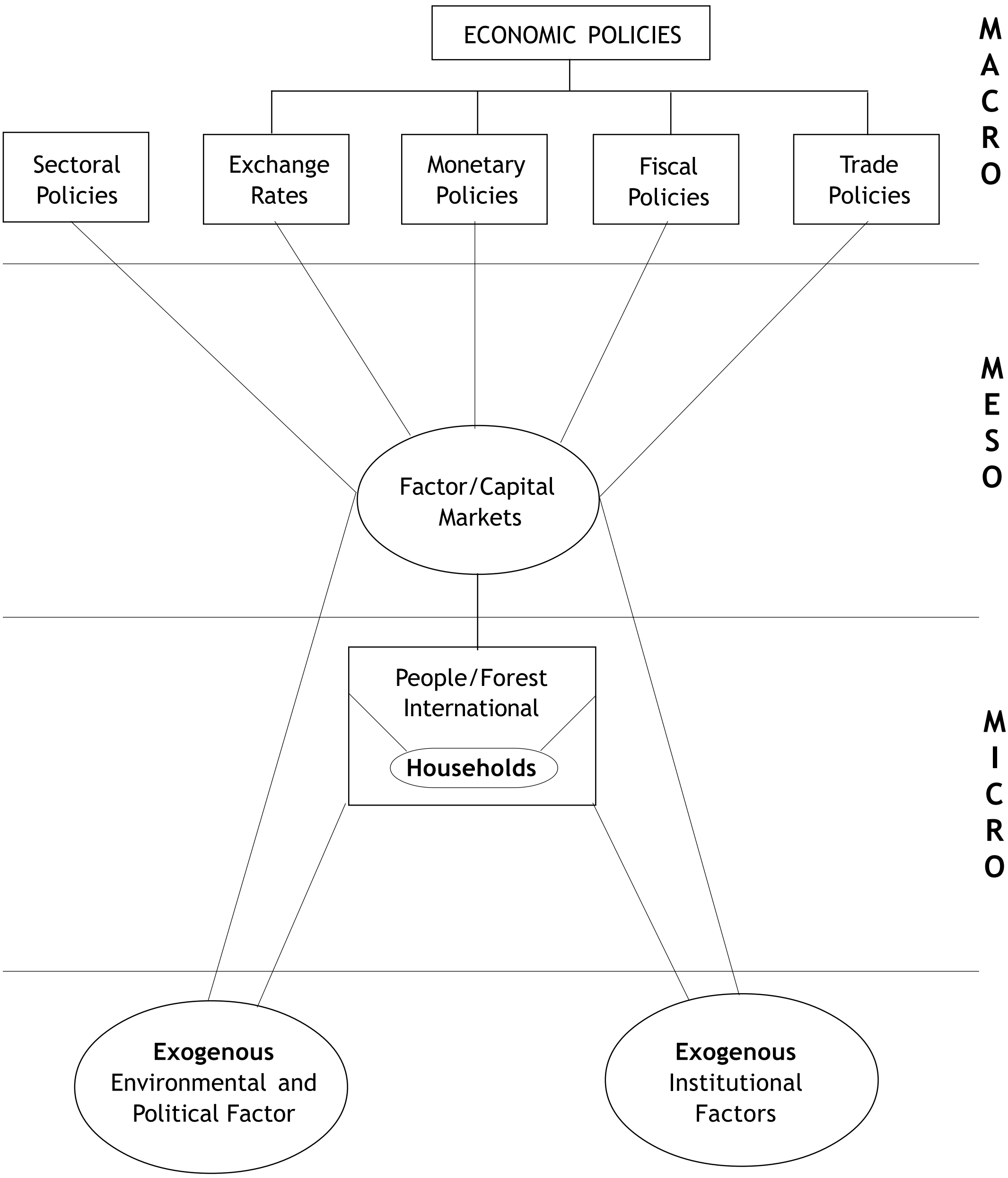
The inter-relationships between macro-economic policies, food, agriculture, natural resources (woodlands) and people in these developing countries are extremely complex. Yet, understanding of the inter-relationships is paramount in influencing the process, pace, magnitude and direction of development necessary for enhancing people's welfare. There are strong linkages between macro-economic policies (such as monetary, fiscal, exchange rate, trade and employment) and sectoral policies (such as land, agriculture, forestry, population and the environment). The macro policies influence the various sectors of the economy, including households through the following tools and instruments: market reforms, tariffs, subsidies, and taxes and transfers (Minde *et al.* 1997).

The markets (meso-level) from which these sectors and household obtain their inputs and sell their surpluses are in turn influenced by the macro-economic factors mainly through product and factor markets (capital, labour and land). Households (micro-level) absorb the overall effects of the macro and meso-level interactions and this in turn influences their decisions on employment, output, income sources and food consumption. Apart from their welfare being influenced directly by the outcome of these interactions, positive or negative effects result in the natural resource base and the environment of which they are a part. Positive effects may include increased employment in the short or long term, increased income from better product prices or factor prices. Negative effects may include increased deforestation, soil erosion leading to reduction in income and environmental degradation in the long term (*ibid.*).

Exogenous factors, mainly of institutional and political nature, also impact on the households causing further (secondary) impacts on the environment. The Mozambican war and the resulting refugee influx into Malawi is one example of exogenous factors that led to considerable depletion of forest land in Malawi (*ibid.*).

Unfortunately macro-economic policies and strategies as well as sectoral policies and strategies for forestry, livestock, agriculture development are often drawn

Figure 1. Macro-meso-micro linkages in the miombo woodlands



independent of one another and by different government departments and ministries, giving a piecemeal approach to planning.

A number of policies related to both financial and goods markets, as well as other factors have potential to influence human-woodland resource interactions. The approach presented in this paper is expected to highlight the effects of macroeconomic policies affecting prices of agricultural inputs and outputs, off-farm incomes, subsidies and credit. These are some of the key macroeconomic policies driving changes in rural areas in the region. Kaimowitz and Angelsen (1998) provide an excellent review on the impact of different policies on forest condition, and more specifically on deforestation. The impact of some agricultural and forestry sectoral policies is also expected to be demonstrated by this approach. The incorporation of different stakeholder partnerships and their impact on managing and using the woodland resources shall also be demonstrated.

The next two sections demonstrate how the weighted goal programming model (MIOMBOGP) is developed for some sites in the miombo woodland region. The research sites are located in Malawi, Mozambique, Tanzania, and Zimbabwe. Some of the assumptions made are therefore specific to those sites. Participatory Rural Appraisals (PRAs) provided the basic information on woodland condition, household economy, and demands by various sectors on the woodlands.

3. MODELLING TYPICAL HOUSEHOLD POLICY RESPONSES

The household sector is modelled in terms of major activities undertaken in order to meet daily needs and demands such activities put on family labour, land and woodland resources. The sector is comprised of mainly subsistence farmers whose primary goals are self-sufficiency in food (food security) and financial income for basics such as food, health, and education. Though local communities are aware of environmental values, these are largely secondary because the pressing needs are food security and income for meeting basic requirements.

3.1 Activities carried out by the typical household

There are three basic activities undertaken by most households in the miombo region. These are *agricultural crop production*, *livestock rearing* and *collection of firewood* for domestic use and sale. Each of these activities is further examined in greater detail. There are many other smaller activities, which can also be incorporated into the model, but these three will serve to illustrate how household activities can be modelled. The less important ones can be added onto the model as need arises.

3.1.1 Agricultural crop production activities

Many rural communities are involved in a number of agricultural activities for cash and subsistence. However, for simplicity only three crops are used in this paper to illustrate how crop production can be taken up in a model of this nature. The crops are *maize, beans* and *peanuts*. The activities associated with these three crops can be categorised as *Production, Selling, Buying, Consumption,* and *Storage*. These activities are spread over two climatic seasons prevailing in most of the countries namely, *dry* and *wet* seasons.

For crop production, information for developing the model will be needed on the following:

- Cost of inputs such as seeds and fertilizers, so that the cost of production can be determined.
- Prices for sold and bought agricultural produce. It may be reasonable to assume that the bulk of crop harvesting takes place at the beginning of the dry season making selling prices in this season lower than in the wet season. Further, buying at the market place in either season may be assumed to be at a higher price (because of the profit margin of middlemen) than the price farmers receive. Buying is an activity that allows the households to purchase food to supplement production.
- Consumption activities should incorporate demand for calories per individual member of the family and nutrient composition per crop.
- Storage allows transference of food from one season to the other. An estimate of individual crop storage losses has to be known.
- Land area demanded per crop.
- Labour demanded per crop and as supplied by each family member, as well as hired labour.
- Quantity of production per crop.

Decisions have to be made on the following and supplemented by assumptions and observations from household studies in the region:

- Size of the household and its composition.
- Supply of family labour for agricultural activities.
- Supply of labour for other activities.

3.1.2 Livestock activities

There are a number of livestock types kept by the local communities, but the main ones considered are cattle, goats and sheep. Chicken and pigs are also found in some communities. Livestock is modelled using cattle as an example.

The main activities associated with cattle are *rearing/grazing, reproduction,* and *selling*. For these activities the following information will be needed:

(a) Cattle rearing:

- Demand for pasture in tons of dry matter (DM) per animal unit. The assumption is that households already have the animals.
- Pasture supply (according to the type of vegetation in the locality of the household). This is to be estimated in terms of tons of DM that are available for grazing.
- Labour available for grazing.

(b) Selling of cattle:

- Selling price per animal.

(c) Reproduction:

- Number of animals per household
- Rates of reproduction

This helps to gauge the growth of the animal stock.

3.1.3 Wood related activities

The main woodland related activities of households in the region are collection of firewood and poles, as well as their selling. Processing of round wood into charcoal and selling charcoal are activities that can also be incorporated into the models developed for Tanzania, Malawi, and Mozambique. A basic assumption is that harvesting of the natural forest for firewood is free of charge. However, a scenario whereby the farmers might in future be required to pay a fee to the government for harvesting government forest reserves can be examined, as well as the impact of various levels of such fees. Another assumption is that the natural forest supplies wood for household consumption and sale.

For analysis of activities related to firewood and poles information shall be needed on:

- The quantity of the standing stock (volume of miombo per hectare) on which the household depends for these supplies.
- The annual increment/growth of the stock. One could introduce a constraint on amount of wood harvested not to exceed annual stock growth. This might already be a requirement of the forest sector policy.
- The quantity and price of firewood and poles sold per household. This is the gross income per household from this activity. One can assume a uniform price throughout the year or differentiate it into seasons since access to the forests during the wet season is difficult therefore constraining supplies and raising the price. The latter has been noted in Mozambique, i.e. higher prices of charcoal in the wet season.
- In the case of charcoal production, the data required should include the relevant conversion factors (from round wood to charcoal) for the alternative technologies of making charcoal. These are essentially efficiency parameters that will allow evaluation of the suitability of these technologies and their long-term impact on the woodlands.

3.1.4 Other activities

There are various domestic activities in any household. The labour distribution for such activities per member of the household (women, children and men) has to be established. Other relevant activities include the collection of non-timber products from the woodlands. In addition to data on their labour requirements, information will also be needed on the quantities harvested, prices (if sold), and use categories (e.g. by household, sold to markets or middlemen, etc).

Many of the activities in this category are what we may call off-farm activities. Apart from domestic and non-timber collection activities, relevant activities could include brewing beer, pottery, and small businesses. All these activities have to be identified, their labour demands estimated, their outputs known and quantified, and associated expense and income data collected.

Dietary demands

These communities are assumed to consume food that satisfies a minimum set of dietary requirements. The proportions of different foods (maize, beans, peanuts, etc.) that largely reflect the eating habits in these communities have to be established. This is important for establishing whether or not the typical household is self-sufficient in food. This parameter is very relevant since giving more rights to communities for management of the natural resources aims at reduction of poverty, and food security is one of the parameters or indicators that can gauge its achievement.

3.2 The general household sector model

The modelling approach that is proposed in this paper is to be constructed for representative households in different sites in Malawi, Mozambique, Tanzania, and Zimbabwe. There are two ways of going about this: identifying an average or a typical household in each of the sites and building the model around it. An average farm may not be found in the field. However, it is possible to identify a typical household from field data. This is advantageous in that frequency analysis using median and mode can allow us to gauge the principal combination of activities in the region. Further use can be made of a typical household in cross-checking the data input as well as gauging the outcome of the model.

The mathematical expression of the MIOMBOGP model is presented as follows:

(a) Objective function

The objective in the weighted goal programming context is to minimise the sum of deviations, both positive and negative, from the target levels set by the decision-maker. In this case the decision-maker is the household, the private investor, and the government. The principle of WGP is simultaneous minimisation of the sum of weighted deviations, and is given as:

$$\text{Min} \ {}_{i=1}^{k} (\ {}_i n_i + \ {}_i p_i) \qquad (1)$$

The weights ($_i$ and $_i$) are associated to goals and with deviations (n_i, p_i). This means that the decision maker (household, private investor or government) has to set a target associated with the objective and express whether he/she would allow a negative or positive deviation from the goal (objective + target).

On the other hand the expression for a linear programming (LP) objective function is maximisation of the total gross margin and is given as:

$$\text{Max} \ {}_{j=1}^{n} g_j x_j \qquad (1')$$

where g_j = gross margin per unit of the activity, for example from cropping and livestock activities, and harvesting wood products; and

x_j is the level of activity X_j,

(b) Constraints

(i) Land availability

Land allocation to various crops should not exceed the total land available to all households in a specific location.

$$ {}_{i=1}^{n} X_i <= ß \qquad (2)$$

X_i is the amount of land area allocated to crop i (i = 1,2,3 – representing, initially, the three crops, respectively maize, beans, and peanuts. The area allocated to the crops should not exceed the size of the land, *ß*, for the average or typical household. However, other constraints on land can be introduced to ensure fair representation of land allocation to different crops grown in household.

(ii) Demand for various crops
The demand for each crop (positive sign in the equation) for selling, storage, and consumption, should be less or equal to the quantity of that crop produced per ha in addition to supplements made through purchased food when deficits occur (negative sign in the equation 3).

Let:
S_i represents the quantity of crop i sold,
A_i represents the quantity of crop i stored,
B_i represents the quantity of crop i bought,
C_i represents the quantity of crop i consumed

Total crop production in a specific area is given by $y_i X_i$, where y_i is the yield per unit area of crop i. (X = 1 ha.) Total demand for each crop is then given as:

$$- \sum_{i=1}^{n} y_i X_{ij} + \sum_{i=1}^{n} S_{ij} + \sum_{i=1}^{n} A_{ij} - \sum_{i=1}^{n} B_{ij} + \sum_{i=1}^{n} C_{ij} <= 0, \tag{3}$$

Production Selling Storage Buying Consumption

where j represents the two seasons, viz. j = 1, 2, for respectively dry and wet seasons.

The prime use of production in the study areas is for consumption. Therefore it is assumed that selling activities take place after the satisfaction of family consumption and that the household stores food from one season to the other. Given that losses (a) occur in crop storage (A) the following equation is relevant for the wet season:

$$\sum_{i=1}^{n} aAij - \sum_{j=1}^{n} Bij + \sum_{j=1}^{n} Cij + \sum_{j=1}^{n} Sij <= 0 \tag{4}$$

(iii) Labour demand
The total labour demand for each of the crops, SL_{ik}, is the labour demanded by crop i and supplied by source k, where:
k = 1 represents male labour
k = 2 represents female labour,
k = 3 represents child labour.

Let LA represent labour demand for livestock activities; LN, labour demand for non-farm/off-farm activities; and LD labour demand for domestic activities. The total labour demand for crops, livestock, off-farm and domestic activities should not exceed that available in the household (SL_k); and is given as follows:

$$\sum_{k=1}^{n} L_{ik} + \sum^{n} LA_k + \sum^{n} LN_k + \sum^{n} LD_k - \sum^{n} L_k <= 0 \tag{5}$$

(iv) Tie constraints
The family labour is tied to the size, gender, and age of the household members. For

example, in the equation below it is assumed that the size of the family is 5, comprising of one adult male, one adult female and three children. All or some of the children can be assumed to be old enough to perform activities such as cattle rearing and domestic chores.

$$L_k = 5 \qquad (6)$$

(v) Dietary constraints
The demand for food for household consumption in equation (3) is in kilograms. This is linked to the energy constraints through supply of Kilocalories (Kcal.) and grams of protein by each crop to family members. The supply should at least satisfy demand per season, which in turn depends on household size and composition as determined by Equation 5.

Energy supply (E) per crop to the household

$$-\sum_{k=1}^{n} E_i + \sum E_{kj} <= 0 \qquad (7)$$

The supply of energy from all crops ($\sum E_i$) should satisfy the energy requirements by household members ($\sum E_k$), where k = 1, 2, 3.

Protein supply (P) per crop to the household

$$-\sum_{j=1}^{n} P_j + \sum P_{kj} <= 0 \qquad (8)$$

(vi) Livestock constraints

Livestock grazing
The demand for feed for cattle (g tons of dry matter per head) should at least be satisfied by the amount of available pasture (p tons dry matter per ha) in a specified grazing area.

$$gC - pF <= 0 \qquad (9)$$

where:
C = cattle stock numbers.
F = land area for natural production of feed for cattle.

To take into consideration the carrying capacity of the grazing land we can set the limit on land area available or let the model calculate the grazing area necessary to satisfy the herd size of the typical household. Therefore, F can have lower and upper bounds to limit the land available or accessible for grazing by the household. In both cases the model output will indicate whether there is overgrazing or not, and this depends on the number of families keeping or owning cattle and other livestock.

Cattle herd size
The size of the cattle herd should at least equal to f.

$$C >= f \qquad (10)$$

where:
f = average herd size for a typical household

Cattle reproduction or growth of animal stock
The calving per year should supply the herd. The total herd size is therefore the sum of new borns (cvC_f) and existing stock (C); and the relationship between the two depends on the calving rate, denoted as cv net of mortality.

$$-cvC_f + C >= 0 \qquad (11)$$

where Cf is the number of female animals of reproduction age

Sale of animals
The number of animals sold, SC, should not exceed the number of the animals calved. This is assuming that the household would like to maintain a minimum stock size.

$$-cvC_f + SC <= 0 \qquad (12)$$

where SC =sale of animals

(vii) Forest products constraints

Harvesting wood for energy
The standing forest stock should at least satisfy the demand for household fuelwood consumption and for sale.

$$-SS + FwC + WdCh + SFw <= 0 \qquad (13)$$

where
SS = Standing stock (volume of miombo per hectare)
FwC = firewood consumption
SFw = sale of firewood
Wd = quantity of wood required to produce charcoal (Ch)

and:

$$-WdCh + SCh <=0 \qquad (14)$$

where
SCh = selling of charcoal

This indicates the transference of the production to the market, in that charcoal sold cannot exceed that produced. We can also include upper and lower limits for Ch since there is limited capacity in terms of labour undertaking this activity in the household in each season. The limits will eliminate unrealistic allocation of labour to produce charcoal only in the season with higher selling price (e.g. wet season in Mozambique).

FwC is determined by the size of the household and estimates of consumption in the Southern Africa indicate that in average a person consumes 1 to 2 m^3/year.

Sustainable firewood harvesting
The amount of firewood sold, if the harvesting is to be sustainable, should not exceed the annual growth in the stock. If the annual growth is denoted as s, then this relationship can be given as:

$$SFw + SCh <= sSS \quad (15)$$

This can be introduced as a goal of the regulator, which in these countries is the government. The assumption here is that harvesting for household consumption does not endanger sustainable firewood supplies.

Firewood sales
Alternatively the amount of harvested wood for sale will be limited by the capacity of the household in terms of labour. Therefore the amount sold will be tied to a maximum number of firewood sales, Qmax, in order to ensure that sufficient quantities are sold given the labour available for this.

$$SFw + SCh <= Qmax. \quad (16)$$

Other constraints, accounting or 'tie' constraints, can be introduced in order to guarantee that the solution is logical and better reflects the household situation.

The complexity of the model can be increased depending on the number of activities households undertake and structure of the households. Any restrictions from the government will be incorporated later after linking the farm and private sector models.

(c) Goals
For realism various goals guiding household behaviour and activities have to be incorporated. This is because planning household activities based on the assumption that they are driven by profit maximisation distorts reality in households' decision-making environment in the miombo region. Most households produce food and even encroach on the forest for income generation in order to meet their basic need, i.e., food security. In a broader sense food security is achieved through production or access to the market, i.e., having a purchasing capacity/power. This seems to suggest that the rural household plan (or combination of activities) in the miombo woodland has at least two goals. In the model, the goals are represented as equalities. Earning of cash income is one of the household goals in these countries. This then makes the sum of the gross margins of all activities (cropping, livestock, forest harvesting, etc) contribute to the target level set by the decision-maker, in this case the head of the household. This can alternatively be derived by running the household model as a simple linear programming (LP) model. Generally the decision-makers' aim would be to minimise the negative deviation from the set target. Therefore the income goal, I, with gross margins per activity and for all activities (X_j), could be expressed as:

$$\sum_{i=1}^{n} giX_j + n_i - p_i = I \quad (17)$$

The other common household goal is to ensure food security or meet minimum nutritional requirements. Such requirements will be defined in terms of total N Kcal of energy required by each family. Therefore the food nutritional goal, (N), can be expressed as:

$$E_k + n_i - p_i = N \qquad (18)$$

The achievement of these goals in the WGP model is subject to:

$$f_i\ (x)\ + ni - p_i = b_i$$

where,
f_I (x) is the general function of the goal as already demonstrated by Equations (17) and (18).

$$x \quad G,$$

G is the feasible set

$$x \quad 0, n \quad 0, p \quad 0$$

The expected output from the model with these two goals is the opportunity cost of satisfying one goal instead of the other, i.e., giving greater weight (or higher priority) to one goal rather than the other. This means that when the income goal is given greater weight, the household can sell most of the produce in order to maximise income realised, even if in some cases this might result into minimising consumption from their own production. Alternatively, the household could harvest large areas of forest for firewood and poles for sale, while ensuring that there is food produced and any food deficits are met through purchases using such income. All this should ensure that the minimum energy requirements are met.

Two problems might arise while solving this problem. One is associated with the fact that the coefficients might be distributed over a very wide range. This can be contained by dividing them into the constraint coefficients. The other problem is related to the fact that the simultaneous minimisation of the deviation in the WGP may result into the model mixing goals that are expressed in different units. This means that the solution might be difficult to interpret. To overcome this it is necessary to adopt a normalisation procedure, like the use of percentages. This means that all goal constraints have to be expressed in form of percentages.

4. MODELING TYPICAL PRIVATE SECTOR RESPONSES

4.1 An overview of the sector

The private sector in most of the rural areas functions like an intermediary between producers and markets for agricultural and forestry products. The producers, the household sector in this analysis, generally lack means and capacity for taking the products to the final consumer. The simple functions of the private sector are then collection of produce from farmers, transporting, storage, and selling them to retailers and rarely to final consumers. The volume of business is a function of many things, including the number of trips that the private sector entity makes between the farmers/ households and the market place.

In this modelling exercise we start with a scenario in which the profit margin per unit of product, like a bag of charcoal, made by the private sector is lower than the profit margin of the household (producer). This is based on the fact that the latter does not incur high costs apart from employment of family labour. For example households do not pay harvesting fees and transaction costs. However, the private sector has a higher total profit due to the number of sales units and trips they are able to make within a specific period, e.g. a month, as compared with the household sector. Furthermore, the transport capacity in each trip surpasses the production capacity of a household.

There are two types of private sector entities for miombo woodland products. The first category comprises of people and firms exploiting wood products such as fuelwood, poles, and construction timber. This category has strong links with the household sector. The latter actually carries out all operations that make such products available. The second group is comprised of either transporters of logs to supply the industry or the industries themselves with licenses for harvesting, transporting, and processing logs. This group generally has a diffuse association with the household sector since it can hire labour from urban and other rural areas to perform all the activities required to get the products into the industry and to the final consumer. For the sake of simplicity the modeling is done with the first type of private sector entity in mind.

One general characteristic of these private sector entities is that their main capital is old transport equipment like lorries, tractors and trailers. Bicycles are commonly used in Malawi, around Lilongwe, and in Manica province in Mozambique. This has in most cases facilitated payment for amortization. The transport costs are high due to the frequent breakdowns and there is therefore need to compensate for the high maintenance costs.

Another common characteristic is that the private sector is in most cases wholesalers, supplying retailers in the urban or other markets. They are essentially intermediaries in the energy and construction material commercialization channel.

4.2 The MIOMBOGP model

4.2.1 Context and major assumptions

Some of the assumptions, requirements and the context in which the private sector operates include:

- The private sector *buys* and *sells* firewood, charcoal and poles. This varies from one country to another. However, buying and selling are the two main activities included in the model.
- The private sector has licenses that limit the amount each of them can buy from rural markets to supply urban markets.
- The license fees are volumetric (i.e. defined per m^3) and are different for firewood and poles.
- The transportation cost should be known.
- Apart from the license fees and the transportation costs, the private entities may incur other costs. For example, they might have to pay a commercialization fee, which goes to the local council (municipality) at the urban market. Again this varies from country to country.

- The other major cost is labour. For a typical lorry or tractor operation labour could comprise of three people, a driver and two assistants. These load and unload the trucks and tractor-trailers. Nevertheless, there might be cases where some other people are hired for unloading at the market place.
- The number of trips made and capacity of trucks or other transport facility used must be known.
- The salaries or wages of the driver and assistants must be known.
- There are many buyers or retailers in the urban markets and few suppliers (represented by lorry drivers) hence the market structure can be described as oligopoly. On the other hand, at the production site, there are many producers (households) and few buyers (represented by lorry drivers) or oligopsony.

4.2.2 Mathematical presentation of the model

(a) The objective function

The LP objective function for the private sector is:

$$\text{Max} \sum_{i=1}^{n} g_i x_i \qquad (1)$$

where g_i is the gross margin of each of the products (firewood, charcoal and poles: I=1,2,3), (i.e., revenue obtained from the sales after deducting the costs) and x_i is the level of each activity, in this case selling of each of the products. In other words this can be stated as:

$$- \sum_{i=1}^{n} Pp_i Pr_i - \sum_{i=1}^{n} Tr_i Pr_i + \sum_{i=1}^{n} Ws_i Pr_i - Mc = 0 \qquad (2)$$

$$\sum_{i=1}^{n} Pr_i \, (-Pp_i - Tr_i + Ws_i) - Mc = 0 \qquad (2')$$

where:

Pr_i = quantity of product i (i = 1, 2, 3)

Pp_i = producer price of the i_{th} product in rural markets

Tr_i = transportation cost of the i_{th} product to the market

Ws_i = wholesale of the i_{th} product in urban markets

Mc = Maintenance cost per trip

Additional costs and fees specific to individual countries, like commercialization fees in Mozambique, can be incorporated in the wholesale price, hence reducing the sales price.

In the case of goal programming, the objective function is expressed as:

$$\text{Min} \sum_{i=1}^{n} ({}_i n_i + {}_i p_i) \qquad (1')$$

This represents the minimisation of deviations from target levels, assuming that the private sector also has other goals, apart from profit maximisation. We can run the model as a classic LP assuming one main objective that drives the activity of the private sector. Alternatively we can assume that apart from maximising profit, it is important for the private entity to minimise risk of the business, especially that arising from frequent truck breakdowns, and therefore a desire to minimize truck maintenance costs.

(b) Constraints

The major constraints of the private sector model include:

(i) Licensed amount

The quantity transported of each of the i^{th} product with a truck of capacity $a_{i,}$ should not exceed the quantity AQ stated in the licence.

$$\sum_{i=1}^{n} N_{ti} Tc_{i\ i} <= AQ \qquad (3)$$

where

N_{ti} is the number of trips middlemen make in transporting forest product i

Tc_l is the lorry/truck capacity for transporting product i

(ii) The supply of i_{th} wood product should be less or equal to the amount delivered to or demanded by retailers at the market.

$$-\sum_{i=1}^{n} Pr_i + \sum_{l=1}^{n} Ws_i <= 0 \qquad (4)$$

c) Transportation capacity

The quantity of the i^{th} product transported, Pr, will be equal to the truck transport capacity, Tc, for each of the products. Measurements of capacity could be in bags or m^3.

$$Pr_i = Tc_i \qquad (5)$$

d) Labour demand

The availability of drivers' labour and that of his assistants is expressed as L_{ij}, where j=1 denotes drivers' labour and j=2 denotes drivers' assistants labour.

Truck driver assistants labour

$$\sum_{i=1}^{n} L_{i2} <= LT_a \qquad (6)$$

where,

l_i is the truck driver assistants' labour allocation for loading and unloading the trucks with product i and expressed in man-hours/trip

LT_a is the total labour available in a month or year.

Driver's labour

$$\sum_{i=1}^{n} L_{i1} <= LT_d \qquad (7)$$

l_i is the driver's labour allocation to ferrying $product_i$
LT_d is the total labour available in a month or year.

Details on each of the activities in the above constraints will vary during the dry and wet seasons because the costs Pp_i, Tr_i, and Mc are different for each of the seasons.

(c) Goal

The objective function of the LP model complemented with the deviations from the set target can be expressed as:

$$\sum_{i=1}^{n} g_i x_i + n_i - p_i = \$ \qquad (8)$$

Since we assume that the private sector's prime objective will be maximisation of profit, then the target $ can be derived from the LP. In this case n_i, or the negative deviation from the goal would have to be minimised.

$$Mc + n_i - p_i = b \qquad (9)$$

The implication is that the maintenance cost has to be kept as low as possible, and that is set at the target level b. The decision maker's interest is to minimise the positive deviations from the target level. This means that in order to maximize profit, the targeted maintenance costs should be kept as low as possible.

5. LINKING HOUSEHOLD AND PRIVATE SECTOR MODELS

As mentioned earlier, there are two players in the exploitation and commercialization of the wood products from the miombo woodlands, the households and the private sector (middlemen).

Selling activities (for wood products) were defined for the household model. However, these were not differentiated into the three products included in the private sector model. But it is known or assumed that all the supply to the intermediaries (the private sector) comes from these rural households. It is at the buying points where we would then know what the households are selling. Therefore, a simple accounting or tie constraint should be able to link the two sectors.

Such a constraint states that the supply by the rural household should at least be equal to the quantity demanded by intermediaries or private sector in the commercialization channel. When the first part of the equation is higher than the second one, the producer takes longer to exhaust his/her stocks.

$$-\sum_{i=1}^{n} Ws_i + \sum_{i=1}^{n} Pr_i <= 0 \qquad (10)$$

As far as the goals are concerned there can be several of them and the MIOMBOGP model offers the possibility of evaluating how each of the goals of the actors is affected by changes in their prioritization.

6. INCORPORATION OF GOVERNMENT SECTORAL POLICIES

This section deals with potential for using MIOMBOGP model to evaluate the impact of sectoral policies. Four example policy scenarios will highlight this.

In the household model we introduced a constraint stating that for sustainable use and management of the resource, the amount harvested for sale should not exceed the allowable cut. This restriction has potential to significantly influence the producers' output (household) as well as the supply to the intermediaries (household-private sector trade) and ultimately to the retailers and urban consumers. However, it is in the government's interest to ensure that the present and the future generations benefit from these natural resources.

The constraint for this intention can be expressed as:

$$Ws_i <= AAC \qquad (11)$$

Harvesting of miombo woodland stock for sale should be in quantities less than or equal to the annual allowable cut (AAC). The basic assumption is that harvesting for household consumption is currently at sustainable levels. Otherwise we can add such consumption to the left-hand side of this equation.

This constraint has to be tied to the buying constraint by the private sector.

A second sectoral policy worth exploring could be the introduction by government of license fees for producers (the rural households in our case) when they harvest forest produce from government forests for sale because in some countries harvesting for household consumption is free. Under such situation the unit profit realized by the household will have to shrink by the unit charge in fees. For instance, in the case of firewood or charcoal, the price will be reduced by a factor, ff. In the objective function reproduced below, Pp_i will have to be reduced by this amount.

$$-\sum_{i=1}^{n}(Pp_i - ff)\,Pr_i - \sum_{i=1}^{n} Tr_i\,Pr_i + \sum_{i=1}^{n} Ws_i\,Pr_i - Mc = 0 \qquad (12)$$

A third policy scenario is the introduction of a penalty to the private sector as well as to the household sector for harvesting any amount above that stated in the license.

This also works through the objective function as an added cost, Fe, which then lowers the net revenues (Ws_i -F).

$$-\sum_{i=1}^{n} Pp_i Pr_i - \sum_{i=1}^{n} Tr_i\,Pr_i + \sum_{i=1}^{n} (Ws_i - Fe)Pr_i - Mc = 0 \qquad (13)$$

The fines are imposed when the harvesting exceeds that allowed in the licence when the condition below prevails (c.f. equation 13):

$$\sum_{i=1}^{n} N_{ti} Tc_i >= AQ \qquad (14)$$

A fourth example relates to national governments' concern on improving the welfare of rural people. As a measure to contain this concern national governments might allow for bigger landholdings for the farmers in order to ensure food security and cash incomes. Therefore, where land is available or can be made available through degazettment of forest reserves or resettlement of people in new adjacent areas, the land constraint can be relaxed to the appropriate size of the land.

$$\sum_{i=1}^{n} X_l >= e \qquad (15)$$

From equation (2) in the household model, we can see that the limitation now becomes one of >= e. In reality the size of farmed land depends on family labour and capital.

If this is enforced and all other conditions are favourable then households will have the potential for surplus agricultural produce, which can in turn be sold. Nevertheless, it has to be noted that despite the good intentions of governments, in practice additional land might come from clearing forests or from grazing land. This could then conflict directly with the sustainable use of resource objective.

Linking the two models with the market involves aggregation of the households in the miombo woodlands as well as determination of the aggregate number of intermediaries (size of private sector) and then linking production and the market. To link to the final consumers it is necessary to estimate the total demand in the urban market, i.e., number of households still using firewood for cooking or poles for construction.

This means that the production activities in the household part of the model would have to be summed up in terms of surplus from the production activities undertaken by the household. The quantity sold wholesale by the private sector would then be a summation of the quantities sold by each player in this sector. In the market place the sum of these wholesale quantities would have to be to be linked to consumer demands.

7. MAJOR LIMITATIONS OF THE MIOMBOGP MODELLING APPROACH

Apart from limitations that are implicit in the basic structure of the functions in the model, the following are some other potential limitations:

- Scarcity of and/or unreliability of data to estimate the coefficients can significantly distort the household organisation and consequently the model results.
- Inability of the decision-makers like farmers and middlemen to list and state in a consistent manner priorities or weights they attach to each target level.
- Making an appropriate choice of the number of variables and constraints capable of producing meaningful results, as well as interpretation that reflects the decision makers' space, i.e., interests, activities, and goals.

ENDNOTES

1. Also available as: Nhantumbo, I. and Kowero, G. 2001 A goal-programming model for planning management of miombo woodlands. *In*: Modelling methods for policy analysis in miombo woodlands. Occasional Paper No. 35, CIFOR, Bogor. pp.5-15.

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17.

A goal programming model for planning management of miombo woodlands: A case study of Chivi and Gokwe communal areas, Zimbabwe

E. Guveya and C. Sukume

ABSTRACT

This paper reports results on the use of a goal-programming model to the management of woodlands in two communities in communal areas of Zimbabwe – one abundant and the other less abundant in woodlands resources. The relatively well-endowed community borders the Mafungautsi Forest Reserve in Gokwe. The less endowed site was Mutangi in Chivi area. The objective of the modelling exercise was to simulate the effects of changes in agricultural policies and demographic changes in farming households on how local households use woodlands under an open access regime and under institutional constraints imposing sustainability concerns.

The findings presented in the paper point to the following basic conclusions: a) households in communal areas are highly differentiated with regards to ability to satisfying family sustenance goals; b) relatively poor households depend on woodlands for a significant part of their income needs but richer families are more efficient in harvesting woodlands; c) increase in agricultural product prices as well as an increase in yields tend to increase woodlands harvesting among the better off and reduce woodland harvests among the poorer households; d) increase in input costs tends to increase reliance on woodlands especially among the poorer households; and e) loss of an adult member of a household increases the degree of poverty especially among the relatively poor with the greatest impacts being realised with loss of female members of households.

Key words: Woodlands, weighted goal programming, communal area, Zimbabwe

1. INTRODUCTION

Indigenous forests and woodlands in Zimbabwe provide a wide range of goods and services that include edible fruits, medicines, honey, poles and fuelwood. About 80% of the population of Zimbabwe depends on woodfuel for their cooking, heating and lighting requirements. There is concern however at the rate of deforestation of the indigenous woodlands in Zimbabwe. Deforestation has led to various environmental problems such as siltation of rivers and dams, soil erosion, flooding, general land degradation and fuelwood shortages. In addition, an estimated 80 000 ha (FAO, 1988) of woodland in Zimbabwe are cleared annually to give way to other land-uses including agriculture and domestic animal grazing which though profitable, have negative externalities.

The need for proper management and conservation of woodlands is an area of high priority. In Zimbabwe there are many policies guiding socio-economic development. Some of the policies target the public sectors while other affect private sector operations. Each of these sectors has ways through which it can respond to the policies. The view of this study is that some current policies lead to inappropriate deforestation, since the people who clear forests and woodlands do not have to pay for the negative externalities associated with their actions, both at the local or national levels. Regardless of the decisions made by woodland users, policy makers should at least be aware of the potential impact of their policies on forest and woodland cover. In rural areas the policies that have potential to impact most on the behaviour of rural households are mainly those associated with agricultural crop production and trade, since the majority of rural people are involved in agriculture. The objective of this paper is therefore to assess how the communal area households of Zimbabwe might respond to agricultural input and output pricing policies and to household labour supply and how this impacts on the use of woodlands.

The study uses a weighted goal programming modeling approach to address this objective. In particular, we follow a specification of the goal programming application to woodlands management developed by Nhantumbo and Kowero (2001). The next section provides a description of two communities of Gokwe and Chivi that were the basis of the study. It is followed by a detailed model description along the lines of the weighted goal programming model developed by Nhatumbo and Kowero (2001). Section 4 presents the data used to run the model while section 5 presents and discusses simulation results of the potential impacts of different policy scenarios on the households in these two communities and their woodland resources. The last section gives a summary of major conclusions from the study.

2. DESCRIPTION OF STUDY SITES

The study sites are Chivi and Gokwe districts of Zimbabwe. The two districts were purposely selected as they have differing agricultural potential, and settlement history. In Chivi district, Mutangi, a dam catchment area 80 km from Masvingo town and 19 km from the Chivi business centre, was selected. Chivi communal area, the major part of Chivi district, covers 3534 km^2 and has been settled since the mid 19th century. The 1992 census shows a total population for Chivi district of 157 428, with a growth rate of 1.98% and a population density of 44.5 people per square km. Mutangi is estimated to have population density of close to 58 persons per km^2 (Campbell *et al.* 2001).

Chivi is a poor area agro-ecologically with a long-term mean annual rainfall of 545 mm (1913-2001). In addition, the amount, intensity and distribution of the rainfall within a season are highly variable, and inter-annual variation is large (Campbell *et al.* 2001). Droughts are recurrent in the area with that of 1991/92 being the worst on record, when only 83 mm of rain fell in some parts of the district. This is compounded by very poor soils within the region.

The dominant vegetation in Mutangi is the woodland that forms an enclave of approximately 360 square kilometres surrounded and shared by about five villages (Campbell *et al.* 2001). The top three dominant tree species found in the area are *Colophospermum mopane*, *Terminalia sericea* and *Acacia tortilis*. Forest products like honey, mushrooms, and medicinal plants also occur in the woodlands. There is very little wild game except for small animals like rabbits that can be found in some parts of the woodland. The woodland is mainly utilised as a grazing area for livestock, source of firewood, construction poles and occasionally as a source of fruits and other non-timber products (NTFPs). Due to high population pressure, the demand for arable land, firewood and construction timber the woodlands are being cleared fast.

In the Gokwe study area, villages within a radius of about 30 km from the western edges of the Mafungautsi state forest were selected. The study site is about 50 km from the Gokwe business centre. These communities have settled in the area for less than 70 years. The families are relatively sparsely distributed.

The mean annual rainfall for the area is around 819 mm. The Mafungautsi State Forest is entirely situated on the Mafungautsi plateau, one of the most northerly extensions of the Kalahari sands in Zimbabwe (Vermeulen 1997). The soils are dystrophic with poor water holding capacity.

Most areas in this survey site are still covered by woodlands. Furthermore the communities have access to the Mafungautsi State Forest, which is a government protected forest covering an area of 82 659 hectares (Vermeulen 1997). Villages located near the boundaries can access a total area of about 600 square kilometres of the forest to graze their livestock, collect dead wood and NTFPs like mushrooms, thatch and broom grass. However, the communities are not allowed to cut down trees, collect honey or hunt for game. Fishing is only allowed if it is done using fishing rods as use of fishing nets is prohibited.

The forest is very dense with a lot of tall and old trees. The dominant tree species is *Terminalia sericea*, while important timber trees like *Baikiea plurijuga* and *Pterocarpus angolensis* are also abundant. Wild game especially warthogs and antelopes still occur in large numbers in the forest.

Data was collected in a series of random sample surveys and participatory rural appraisals (PRA) in the period 1999 to 2000 in the two sites. A descriptive summary of the survey is reported in Siziba and Mutamba (2002). For the purposes of this study, the households in each study area are distinguished into draft owning and non-draft owning households. The rationale for this distinction being that the two types of households' utilization of woodland is hypothesized to be different. Households with draft animals tend to be larger and efficiency of collection of woodlands products and farming operations tend to be higher due to a higher degree of mechanisation in the processes.

3. MODEL SPECIFICATION AND DATA

3.1 Objective function

We model a household that allocates labour and other productive resources to agriculture, household chores and woodlands harvesting activities so as to minimize simultaneously the weighted sum of deviations from two goals – food security and income targets. This optimization problem is considered under two regimes, namely a regime where utilization of forest resources are restricted to be within sustainable levels and under a regime where this restriction is relaxed, i.e. an open access situation. How the sustainability requirement is modeled is discussed under woodland use constraints.

From surveys in both Gokwe and Chivi more households ranked the achievement of food security above income maximization in their decision-making. In the two-goal model considered in this study, giving equal weight to positive and negative deviations from goals, the weighted goal programming (WPG) objective function can be specified as,

$$\text{Min } \{(w_1n_1+w_1p_1)+(w_2n_2+w_2p_2)\} \quad (1)$$

where w_i is the weight associated with the goal i, and n_i and p_i are negative and positive deviations in the achievements of goal i; and i = 1, 2.

Ranking of goals by households is translated into weights using the transformation:

$$w_i = \frac{\frac{1}{r_i}}{\sum_j \frac{1}{r_j}} \quad (2)$$

r_i is the ranking of goal i.

Using the above transformation, the food security goal (goal 1) has a weight of 0.67 while that for income (goal 2) is 0.33.

Household food security goal

Given this background, the household food security goal can be expressed as:

$$e_{mz}\ CsMz + e_{gn}\ CsGn + e_{sg}\ CsSorg + e_{mk}\ CsMk + e_{bf}\ CsBf + n_1 - p_1 = E \quad (3)$$

where,

e_{mz}, e_{gn}, e_{sg}, e_{mk}, and e_{bf} are per unit calorie content for maize, groundnuts, sorghum, milk and beef, respectively,

CsMz, CsGn, CsSorg, CsMk, and CsBf are respectively units of maize, groundnuts, sorghum, milk and beef consumed by the household in a year, and E is the recommended minimum household calorie requirement per year.

The food security goal is to strive to get enough food to satisfy yearly requirements for energy. According to University of Minnesota (2002) the average minimum daily kilo calorie requirements are 2944 for a man, 2180 for a woman and a child's daily requirement are 2048. For a household the requirements for men (HHcM), women, (HHcW) and children (HHcChn) in a year would equal the target (E) calorie intake, and this is expressed as:

$$E = 365(2944\ HHcM + 2180\ HHcW + 2048\ HHcChn). \quad (4)$$

The per unit energy content of different food commodities are given in Table 1.

Table 1. Energy contents of different food types

Food type	Energy content [kilo calories/kg]
Maize	3450
Groundnuts	5700
Sorghum	3450
Milk	660
Meat	2350

Source: USDA 2002.

Household income goal

The income goal for the household is the residual income. The residual income is gross household income after taking into account costs of inputs, hired in labour, money spent on buying extra food (maize, groundnuts, sorghum, milk and beef). The residual or target income (I) was obtained from maximizing a linear programming model of the representative household in each site. The income goal is then stated as:

$$CrR + LvR + Wg + DftR + FwR - CrCst - DftCst - LabCst - FdCst + n_2 - p_2 = I \quad (5)$$

We define the components of this function as follows:

(a) Revenue from sale of crops

In the above equation CrRv is crop revenue computed from the product of crop price and the quantity of maize sold in wet and dry season (SgMzW, SgMzD), groundnuts in the wet and dry seasons (SgGnW, SgGnD), sorghum (SgSorgD, SgSorgW), cotton (SgCtn) and sunflower (SgSun). That is

$$CrR = P_{mz}\ (SgMzD + SgMzW) + P_{gn}\ (SgGnD + SgGnW) + P_{ct}SgCtn + P_{su}SgSun + P_{sg}(SgSorgD + SgSorgW) \quad (6)$$

where P_{mz}, P_{gn}, P_{ct}, P_{su} and P_{sg} are farm gate prices of maize, groundnuts, cotton, sunflower sorghum in both wet and dry seasons.[1]

(b) Revenue from livestock

Similarly, LvR is revenue from sale of livestock and livestock products. Thus LvR is the sum of products of unit price and the units of goats sold (GtSg), cattle sold (CaSg), donkeys sold (DkSg) during the year, and milk sold during wet and dry seasons (SgMkW, SgMkD),

$$LrR = P_{gt}GtSg + P_{ca}CaSg + P_{dk}\ DkSg + P_{mk}\ (SgMkD + SgMkW), \quad (7)$$

where P_{gt}, P_{ca}, P_{dk}, and P_{mk} are prices of goats, cattle, donkeys and milk, respectively. For households with neither cattle nor donkeys, selling of cattle, donkeys and milk is restricted to zero to contain possible unrealistic computational solutions where households can buy and sell these within a year, situations which were not encountered in the Gokwe and Chivi households.

(c) Revenue and expenditure related to labour and draft power

The income, Wg, the household gets from hiring out labour is the product of labour (HrOutLab) days hired out and the wage rate (w),

$$Wg = w \ HrOutLab. \tag{8}$$

In the case where a household hires in labour, it incurs payments (LabCst) equal to the product of labour days hired in (HrInLab) and the wage rate (w),

$$LabCst = w \ HrInLab. \tag{9}$$

Similarly, the household can either hire out draft power to generate revenue (DftR) or hire in draft services and incur expenditures (DftCst). In either case the revenue generated or the payment incurred is the product of draft-days hired in (HrOxIn, if oxen, and HrDonkIn, if donkeys) or out (HrOxOut, if oxen, and HrDonkOut, if donkeys) and the rate/price for hiring draft animals (r_{ox}, if cattle and r_{dk}, if donkeys). As is explained later in this section, differentiation between oxen draft and donkey is due to the differences in rates/prices as well as efficiency of draft services. Thus

$$DrftR = r_{ox} \ HrOxOut + r_{dk} \ HrDonkOut \tag{10}$$

$$DrftC = r_{ox} \ HrOxIn + r_{dk} \ HrDonkIn. \tag{11}$$

(d) Revenue from woodland products

Even though institutional constraints exist limiting the shipment of timber and fuel wood from communal areas to areas outside, sale of poles and fuel wood goes on between households within the areas in the form of contract cutting and carting. Prices of wood products sold in these ways are not well defined in form of amount paid per volume of wood. One way of going around this problem is to express the value of the sales in terms of value of time spent gathering and carting wood for payment. Using this approach, revenue from wood harvesting for sale (FwR) is the product of the wage rate (w) and the time devoted to collecting wood for sale (ClFwSLab). That is,

$$FwR = w \ ClFwSLab \tag{12}$$

(e) Household expenditure on farming and food

The major farm household expenditure item is on crop production (Crest). It is the sum of production expenditure (cost) on each hectare and area cropped to maize (GrMz), cotton (GrCtn), groundnuts (GrGn), sunflower (GrSunf) and sorghum (GrSorg),

$$CrCst = cmz \ GrMz + c_{ct} \ GrCtn + c_{gn} \ GrGn + c_{su} \ GrSunf + c_{sg} \ GrSorg \tag{13}$$

where c_{mz}, $c_{ct,}$ $c_{gn,}$ c_{su} and c_{sg} are per hectare expenditure on materials inputs to the production of maize, cotton, groundnuts, sunflower and sorghum, respectively.

The other major expenditure item was on food, (FdCost), which was the sum of the products of 'buying prices of the food items' and their respective quantities. The major goods bought by households in dry and wet seasons are maize (BgMzD, BgMzW), groundnuts (BgGnD, BgGnW), sorghum (BgSrgD, BgSorgW), beef (BgBfD, BgBfW) and milk (BgMkW, BgMkD) to supplement own production. Expenditure on food is thus

$$\begin{aligned} FdCst = & P_{b,mz} (BgMzD + BgMzW) + P_{b,gn} (BgGnD + BgGnW) \\ & + P_{b,sg} (BgSrgD+BgSorgW) + P_{b,bf} (BgBfD + BgBfW) \\ & + P_{b,mk} (BgMkW + BgMkD) \end{aligned} \quad (14)$$

where $P_{b,mz}$, $P_{b,gn}$ Pb,sg, $P_{b,bf}$ and $P_{b,mk}$ are buying prices of maize, groundnuts, sorghum, beef and milk, respectively.

The goals are expressed in monetary values (for income) and in kilo-calories (for food security). To facilitate ease of interpretation of the results each goal is normalized so that the target is 100 percent by multiplying both sides of the goal equation by 100 and dividing by the nominal value of the target.

Coefficients utilized in the models for Gokwe and Chivi study areas are summarized in Table 2.

It is important to note that goals will differ between farmers of varying resource endowments and in varying agro-ecological environment. In the above model, target energy requirements differ between households in the different areas due to differences in size and composition of the households. Income goals differ in that these are the product of maximization of residual farm income after taking into account food consumption needs. Differences in feasible cropping mixes between farmers in diiferent areas and with different resource endowments imply that attainable incomes will also differ.

3.2 Model constraints

The weighted goal-programming problem is optimized subject to constraints on:

- Land availability,
- Availability of ready cash to finance inputs and services,
- Draft power availability,
- Supply and utilisation of food crops,
- Labour availability,
- Minimum dietary requirements,
- Maximum livestock production potential, and
- Forest products availability/supply.

3.2.1 Land constraints

Land allocated to growing maize, cotton, groundnuts, sunflower and/or sorghum should not exceed the average area, A^T, available to the representative household in a site. Thus

$$A^T - GrMz - GrGn - GrCtn - GrSunf - GrSorg \quad 0 \quad (15)$$

Table 2. Parameters in the goal functions

Category	Coefficient	Gokwe		Chivi	
		Draft	No-draft	Draft	No-draft
Target	E ('000 kcal)	6701	4845	5920	4879
	I (US$)	998	135	870	128
Selling prices	P_{mz} (US$/kg)	0.13	0.09	0.09	0.07
	P_{gn} (US$/kg)	0.28	0.24	1.22	0.30
	P_{ct} (US$/kg)	0.45	0.42	0.34	0.37
	P_{su} (US$/kg)	-	0.09	0.10	0.08
	P_{sg} (US$/kg)	-	-	0.08	0.04
	P_{gt} (US$/goat)	13.16	13.16	13.16	13.16
	P_{ca} (US$/beast)	105.00	105.00	105.00	105
	P_{dk} (US$/beast)	53.00	53.00	53.00	53.00
	P_{mk} (US$/litre)	0.52	52	0.65	0.65
Buying prices	$P_{b,mz}$ (US$/kg)	0.14	0.10	0.10	0.09
	$P_{b,gn}$ (US$/kg)	0.31	0.26	1.34	0.33
	$P_{b,bf}$ (US$/kg)	2.00	2.00	2.00	2.00
	$P_{b,mk}$ (US$/litre)	0.52	0.52	0.65	0.65
	$P_{b,sg}$ (US$/kg)	-	-	0.09	0.09
Wage	w (US$/day)[a]	0.44	0.44	0.44	0.44
Costs of production	c_{mz} (US$/kg)	15.39	16.29	24.60	15.03
	c_{ct} (US$/kg)	35.31	47.26	43.13	37.24
	c_{gn} (US$/kg)	25.00	25.00	15.50	21.31
	c_{su} (US$/kg)	-	4.50	5.42	4.23
	c_{sg} (US$/kg)	-	-	1.84	2.47
Draft hiring rates	r_{ox} (US$/day)	4.21	4.21	4.21	4.21
	r_{dk} (US$/day)	3.95	3.95	3.95	3.95

Source: Field Survey Data: 1999-2000; [a] stipulated wage for farm labourer (Commercial Farmers Union, pers. Comm.).

Average land holdings for sampled households were 2.31 and 1.92 hectares respectively for draft and non-draft animal owning households in Chivi. Corresponding figures for Gokwe were 5.11 and 3.6 hectares for draft and non-draft animal owning households, respectively.

3.2.2 Cash constraints

Availability of income to finance inputs and services at the inception and during the crop-growing season is a major constraint to most farmers in rural Zimbabwe. High interest rates following removal of credit subsidies brought about by economic reforms have exacerbated the liquidity constraint. To reflect this problem we include in the model a constraint requiring that households must have, as a minimum, the cash C for producing all crops as well as other requirements including hiring in labour or draft services. This budget constraint can be expressed as:

$$- c_{mz}\,GrMz - c_{ct}\,GrCtn - c_{gn}\,GrGn - c_{su}\,GrSunf - c_{sg}\,GrSorg - 0.44{*}HrInLab + C \quad 0 \quad (16)$$

Per-hectare costs of production for the four representative households modeled are given in Table 2.

3.2.3 Draft animal hire

A significant proportion of households in both Chivi and Gokwe do not have enough number of cattle or donkeys to perform farm operations such as ploughing, mechanical planting, cultivating and transporting. Only 41% of households in Chivi and 47% in Gokwe have enough cattle for use as draft (Mutamba and Siziba 2002). Those without have to hire draft from those with animals especially for the critical task of ploughing. Given a pair of oxen or donkeys can plough 1 hectare of land over 4.5 days (Guveya 1995) and that the critical period in the planting season when draft is required is only two months, there only about 44 days available for hiring out draft animals for those households with animals. Thus the number of days that draft hiring out can be offered by a household with draft (HrOxOut in the case of oxen, or HrDkOut for donkeys) should be 44 days less the time the household needs the draft to prepare its own fields.

$$44 - 4.5(GrMz + GrGn + GrCtn + GrSunf + GrSorg) - (HrOxOut + HrDonkOut) \quad 0. \quad (17)$$

Households without draft animals will need to hire in enough draft services (HrOxIn/ HrDkIn) to plough all their fields,

$$HrOxIn + HrDonkIn = 4.5(GrMz + GrGn + GrCtn + GrSunf + GrSorg). \quad (18)$$

This means that there is virtually minimal farm preparation using hand hoe.

3.2.4 Crop production and utilization

The two cash crops grown in the project sites – sunflower and cotton – are sold soon after harvesting at the beginning of the dry season. In both areas farmers may sell some of their produce, store some for consumption during the wet season, or buy some food crops to supplement own production (Mutamba and Siziba 2002). How much is consumed, sold and stored during the dry season should not exceed what is harvested and bought by the household in the season. Similarly, during the wet season how much is consumed and sold should not exceed the amounts bought during the season and how much was stored taking into account storage losses. Storage losses for sorghum and maize were assumed to amount to 4 percent while those for groundnuts were assumed not to exceed 2 percent.

If $YIELD^{Mz}$, $YIELD^{Gn}$, $YIELD^{Ctn}$, $YIELD^{Sunf}$ and $YIELD^{Sg}$ are yields of maize, groundnuts, cotton, sunflower and sorghum, respectively, and StMzD, StGnD and StSorgD are respective quantities maize, groundnuts and sorghum carried over (stored) into the wet season, the following relationships capture the constraints implied by the above:

Maize

$YIELD^{Mz}$ GrMz - SgMzD - StMzD + BgMzD - CsMzD   0 (19)

0.96 StMzD - SgMzW + BgMzW - CsMzW   0 (20)

Sorghum

$YIELD^{Sg}$ GrSorg - SgSorgD - StSorgD + BgSorgD - CsSorgD   0 (21)

0.96 StSorgD - SgSorgW + BgSorgW - CsSorgW   0 (22)

Groundnuts

$YIELD^{Gn}$ GrGn - SgGnD - StGnD - CsGnD   0 (23)

0.98 StGnD - SgGnW - CsGnW   0 (24)

Cotton

$YIELD^{Ctn}$ GrCtn - SgCtn = 0 (25)

Sunflower

$YIELD^{Sunf}$ GrSunf - SgSunf = 0 (26)

In both Chivi and Gokwe sites, households with draft animals tended to be self sufficient in maize production and no household was observed buying maize in the dry season for the purposes of selling during the wet season. To add realism in the household model further restrictions were added to take into account these two observations.

Table 3. summaries the average yields of the different crops in the two study sites and the draft and non-draft animal owning representative households.

Table 3. Crop yields (kg/ha) by survey site

	Gokwe		Chivi	
	Draft	Non-draft	Draft	Non-draft
Maize	911	754	1413	916
Cotton	834	689	1512	546
Groundnut	535	446	604	491
Sorghum	-	-	1053	722
Sunflower	667	384	875	834

Source: Field Data, 1999-2000.

3.2.5 Labour constraints

Members of the household – men, women and children - in the communities studied contribute to activities undertaken with different degrees of specialization. Activities undertaken on the farm that demand labour include crop production, livestock tending, paid farm work at other households within the community, harvesting fuel wood and timber for domestic use and for sale, working with hired draft animals, as well as domestic chores around the homestead such as fetching water, laundry, cooking, cleaning and taking care of infants. For each class of household members (men, women or children), labour input into all activities must not exceed maximum labour available from the members in the class plus any labour hired in to supplement the class' labour. That is

$$TotLab_i - CropL_i - LiveL_i - HireOutL_i - WoodlandsL_i - DomL_i \quad 0 \qquad (27)$$

where j=1,2,3 for men women and children respectively.

Total labour (TotLab) consists of labour from the gender class/category of household members (number of days in a year available to each category of household member (D) multiplied by the number of members in that labour category, $L_{i,}$) and hired labour days allocated to supplement requirements by gender/class (i.e. the fraction, , of hired labour allocated for the gender class or category) multiplied by total labour hired by the household (HrInLab)). That is

$$TotLab_i = D\ L_i \ + \quad (HrInLab) \qquad (28)$$

Labour input by a household class into crop production (CropL) is defined as

$$CropL_i = \ (L_{mz,i}\ GrMz + L_{gn,i} GrGn + L_{ctn,i}\ GrCtn + L_{sunf,i} GrSunf + L_{sorg,i} GrSorg\ ) \qquad (29)$$

where $L_{mz,i}$, $L_{gn,\ i}$, $L_{ctn,i}$, $L_{sunf,i}$ and $L_{sorg,i}$ are labour input per hectare and by a household gender category in the production of maize, groundnuts, cotton, sunflower and sorghum, respectively.

Labour input by a household gender category in livestock related activities ($LiveL_i$) consists of labour required to tend animals and labour use in working with hired out draft animals. Working with hired draft animals is generally considered a preserve of men in the household and so the following constraint applies to men only

$$LiveL_i = L_{lv}(0.8\ Ca + 0.04\ Gt + 0.6\ Dk) + \quad (HrOxOut + HrDonkOut) \qquad (30)$$

where: Ca, Gt and Dk are numbers of cattle, goats and donkeys owned by the households.

L_{lv} is the household male labour input per livestock unit into livestock operations. is an indicator variable taking on a value 1 if a household works with hired draft animals and zero otherwise.

In addition, households may supplement incomes through selling of labour (HrOutLab) to other households' farming operations. In the communities studied adult members –men and women - of the household mostly do this. In the model we assume equal sharing of this activity between men and women in the household and exclude children. Children are excluded since they go to school and their little labour is available during school holidays and largely not hired out. Thus the proportion of male and female labour to total hired out labour, HireOutL, available in the household can be represented as

$$HireOutL= \quad HrOutLab \qquad (31)$$

where takes on a value of 0.5 for men, 0.5 for women and zero for children.

In the communities studied households harvest woodlands for firewood and non-timber forest products mainly for domestic use with very little for sale directly (Mutamba and Siziba 2002). However, firewood collection and use statistics mask activities related to harvesting of firewood for brick making and beer brewing, activities that generate incomes for some households and this is therefore an indirect way of selling firewood. The total labour supplied to woodlands harvesting (WoodlandsLi) by a household gender class (i) is modelled as

$$WoodlandsL_{i} = (L_{nt,i}\ NtFp + L_{fw,i}\ ClFw + {}_{i}\ ClFwSLab) \qquad (32)$$

where $L_{nt,i}$ and $L_{fw,i}$ are respectively labour inputs into collection of non-timber forestry products and fuel wood for home consumption by gender class i, and ${}_{i}$ is the proportion of household labour used for collection of fuel wood for sale (ClFwSLab). NtFp and ClFw are indicator variables taking on a value 1.

Lastly, each gender class' contribution to domestic activities ($DomL_{i}$) is specified as:

$$DomL_{i} = L_{dom,i} DomA \qquad (33)$$

where $L_{dom,i}$ is the number of days of the year gender class i is involved in domestic chores. DomA is a scaling constant, taking on a value 1/8 to indicate that a member of a household only works one hour in an eight-hour day on such activities.

On total labour time available, the overriding assumption is that adults work for 260 days in a year while each child provides labour during the 95 days of the year they are on school holidays and week ends. Also all labour inputs of children are in adult equivalent assuming children labour input is 50 % of adult labour. Each child can only make available 47.75 labour days to the household labour pool. Table 4 summarises the labour constraints parameters used in the four models analysed in this study

3.2.6 Dietary constraints

The types of foods households consume greatly affect their food production and purchasing decisions. Thick porridge of maize and/or sorghum (locally known as sadza) forms the base of most meals consumed by households in Gokwe and Chivi and is the main source of energy. The meals are complemented by relish consisting mostly of boiled or partially fried vegetables (from gardens or forests) in vegetable oil or peanut butter. Depending on affluence and opportunity households also consume meat (bush meat, chicken, goat, or beef), fresh and dried fish, butter, milk and pulses (beans and pigeon peas). Little research has been done on the nutritional composition of these meals. Discussion with food scientists at the University of Zimbabwe's Food Science Department in 1999 indicate that almost all of the energy requirements of households in communal areas of Zimbabwe come from consumption of maize, groundnuts, milk products, meat and sorghum with maize contributing a minimum of 50 percent of the energy. These food commodities are also estimated to contribute at least half of the protein intake of households with the rest coming from vegetables as well as other foods.

Household energy demand in the dry season (EnDD) and in the wet season (EnDW) are equivalent to the sums of half yearly energy requirements for the men (HHcM), women (HHcW), and children (HHcChn) in the household, based on recommended daily intake. Thus

$$EnDD = EnDW = 0.5\ (365)\ (2944\ HHcM + 2180\ HHcW + 2048\ HHcChn)/1000 \qquad (34)$$

where EnDD and EnDW are measured in thousands of kilocalories.

Table 4. Values of parameters in labour constraints

Parameter		Gokwe		Chivi	
		Draft	Non-draft	Draft	Non-draft
L_l	Men (HHcM)	2	1	2	1
	Women (HHcW)	2	1	1	2
	Children (HHcChn)	4	4	4	3
D	Men	260	260	260	260
	Women	260	260	260	260
	Children	47.75	47.75	47.75	47.75
	Men	0.4	0.4	0.4	0.4
	Women	0.4	0.4	0.4	0.4
	Children	0.2	0.2	0.2	0.2
L_{mz}	Men	20.81	23.44	23.4	24.83
	Women	20	23.44	35.28	37.59
	Children	19.4	11	41.23	41.45
L_{gn}	Men	23	37	27	33.1
	Women	77.78	37	48.23	61.24
	Children	20	17	62.57	64.33
L_{ctn}	Men	151.79	142	107.38	162
	Women	149.25	142	117.81	149
	Children	67.82	65	112.25	111.5
L_{sunf}	Men	16	16	13.57	11
	Women	16	16	18.14	18.14
	Children	14.34	7	25.57	25.57
L_{sorg}	Men			23.4	33.9
	Women			35.3	43.33
	Children			41.23	50
L_{lv}	Men	3.89	12	3.65	22.1
	Women	2.57	18.5	1.97	18.2
	Children	0.02	0	1.64	2.9
	Men	1	1	1	1
	Women	0	0	0	0
	Children	0	0	0	0
	Men	0.5	0.5	0.5	0.5
	Women	0.5	0.5	0.5	0.5
	Children	0	0	0	0
L_{nt}	Men	59.3	58.1	87.4	99.1
	Women	27.3	16.7	10.1	7.1
	Children	22.3	23.5	40.2	26.2
L_{fw}	Men	8.4	6.7	6	5.1
	Women	22.9	39.5	43.6	35.6
	Children	15.3	11.6	22.3	16.7
	Men	0.5	0.5	0.5	0.5
	Women	0.2	0.2	0.2	0.2
	Children	0.3	0.3	0.3	0.3
L_{dom}	Men	5.7	1.9	12.8	11.1
	Women	95.7	97.5	320.6	238.8
	Children	94.1	93.5	190.4	138.2

Energy supply on the other hand is the sum of contribution of the amounts consumed by the household from produced and purchased foodstuff. Contributions of each major energy source (maize, sorghum, groundnuts, milk and meat) are given in Table 1. Thus the relationships for household energy supplied in the dry and wet seasons are, respectively,

EnSD = (3450 CsMzD + 5700 CsGnD + 2350 CsBfD+ 660 CsMkD
+ 3450CsSorgD)/1000 (35)

EnSW = (3450 CsMzW + 5700 CsGnW + 2350 CsBfW+ 660 CsMkW
+ 3450 CsSorgW)/1000 (36)

where EnSD and EnSW are measured in thousands of kilocalories.

If the identified major crops supply all the energy required by the household, then the supply and demand constraint requires that demand should be less than or equal to energy supplied. That is,

EnSD EnDD (37)
EnSW EnDW (38)

That a minimum 50 percent of energy comes from food grains (maize and sorghum) implies that in the two seasons,

3.45(CsMzD + CsSorgD) 0.5 EnDD (39)
and
3.45(CsMzW + CsSorgW) 0.5 EnDW (40)

Given that recommended average daily intake of protein are 0.057 kilograms for men, 0.048 kilograms for women and 0.051 kilograms for children (University of Minnesota 2002), household demands for protein in dry (ProtDD) and wet (ProtDW) seasons are,

ProtDD = ProtDW = 0.5 (365) (0.057 HHcM + 0.048 HHcW + 0.051 HHcChn) (41)

Similarly, given that maize supplies 0.1 kilograms, sorghum 0.1 kilograms, groundnuts 0.25 kilograms, meat 0.180 kilograms per kilogram of food taken while milk supplies 0.035 kilograms per litre consumed (USDA 2002), the protein supplied by the major food products in the two seasons, ProtSD (dry) and ProtSW (wet) are:

ProtSD = 0.100 (CsMzD +CsSorgD) + 0.250 CsGnD + 0.180 CsBfD
+ 0.035 CsMkD (42)

ProtSW = 0.100 (CsMzW +CsSorgW) + 0.250 CsGnW + 0.180 CsBfW
+ 0.035 CsMkW (43)

Thus, if the major foods provide for a minimum of roughly 55 percent of protein required by the household, the protein supply and demand constraint in the two seasons becomes:

ProtSD 0.55 ProtDD (44)
ProtSW 0.55 ProtDW (45)

In an effort to reflect the consumption habits in study areas constraints requiring a minimum consumption of 0.5 kilogram of meat per household per week as well as maximum groundnut consumption limitation per half a year were imposed on the models.

CsBFD 0 (46)
CsBFW 0 (47)
30 CsGnD (48)
30 CsGnW (49)

3.2.7 Livestock grazing constraints

Feed for livestock in study areas is provided by pastures in the agricultural areas (fallow land and non-arable land between fields), accessible forest areas as well as stover from harvested fields during the dry season. Since fallow land is only available in seasons in which farmers plough less than their total agricultural land, the availability of this land is transitory. The guaranteed or minimum grazing land available is the forest portion the households have access to, while the maximum grazing land is the combined area of this forest portion and the average fallow land when it is available.

Natural pastures in communal areas of Zimbabwe are estimated to yield 1800 kilograms of dry matter (DM) per hectare per year (Guveya 1995). Stover from grain production on the other hand is estimated to yield about 423 kilograms DM per hectare annually. An animal weighing 500 kilograms (i.e. 1 livestock unit) requires about 8 kg DM per day or 2.92 tonnes per livestock unit (LU) per year (Guveya 1995). Livestock unit equivalents of cattle, goats and donkeys, the major classes of animals kept in study areas, are respectively, 0.8, 0.04 and 0.6 LUs.

Based on the above information, feed supply (FeedS) from stover and natural grassland (Graz) is

$$\text{FeedS} = 0.253\ (\text{GrMz} + \text{GrSorg}) + 1.8\ \text{Graz} \qquad (50)$$

where FeedS is measured in tonnes of DM.

Feed demand for each animal type/class is equivalent to feed requirement per livestock unit multiplied by the livestock unit equivalence of the animal and the product multiplied by the number of animals in the class. Thus, total feed demand becomes:

$$\text{FeedD} = 2.92\ (0.8)\ \text{Ca} + 2.92\ (0.04)\ \text{Gt} + 2.92\ (0.6)\ \text{Dk} \qquad (51)$$

where Ca, Gt and Dk are respectively the number of cattle, goats and donkeys owned by the household at the start of the year.

Supply and demand constraints for feed require that feed demanded is less than or equal to available feed,

FeedS FeedD (52)

3.2.8 Livestock production and utilization constraints

Apart from draft services, livestock provides a number of benefits including income from their sale, capital gains from reproduction, income from sale of milk as well as direct consumption benefits. Capital gains due to reproduction will depend on the number of females in the herd as well as the calving/kidding rate net of mortality. Data collected in the study areas did not include this information. For the purposes of the modeling exercise we resorted to national estimates for the communal sector reported in Guveya (1995). Calving/kidding rates net of mortality are estimated to be 45% for cattle and donkeys and 120% in the case of goats. Percent of females in national herd are estimated to be 56% for cattle, 67% donkeys and 75% goats.

Given these statistics end of year stocks of livestock can be specified as

Cattle: $Ca_f = 0.45\ (0.56)\ Ca + Ca$ (53)

Goats: $Gt_f = 1.2\ (0.75)\ Gt + Gt$ (54)

Donkeys: $Dk_f = 0.45(0.67)Dk + Dk$ (55)

where Ca, Gt and Dk are beginning stocks of cattle, goats and donkeys.
and $Ca_{f,}$ Gt_f and Dk_f are end of year stocks for the respective animals.

To maintain a stable herd size, we assume that livestock sold cannot exceed livestock born. Thus,

$0.45\ (0.56)\ Ca - CaSg \quad 0$ (56)

$1.2\ (0.75)\ Gt - GtSg \quad 0$ (57)

$0.45\ (0.67)\ Dk - DkSg \quad 0$ (58)

where CaSg, GtSg and DkSg are numbers of cattle, goats and donkeys sold, respectively.

Most of the households with draft animals milked cows for household consumption and sale even though the yields were quite modest. In Mutangi, Chivi district, households got an average of 253 litres per year while in Mafungautsi, Gokwe district, they got about 294 litres per year (Mutamba and Siziba 2002). Given that average cattle holdings by households with draft animals in Chivi and Gokwe study areas were 6 and 8, respectively, the proportion of cows in the herd and the assumed calving percentage lead to milk yield per milking cow of 167 and 144 litres in Chivi and Gokwe, respectively. Availability of better forage in the wet season implies that most of this yield will be obtained during the wet season. It is estimated that dry season production is half of that during the wet season. Thus in Chivi a milking cow is estimated to yield about 56 litres in the dry season compared to 111 litres during the wet season. In Gokwe a milking cow produces 48 litres in the dry season and 96 litres during the wet season.

The seasonal milk production constraints are then:

$MyieldD\ (0.45)\ (0.56)\ Ca - PrMkD \quad 0$ (59)

$MyieldW\ (0.45)\ (0.56)\ Ca - PrMkW \quad 0$ (60)

where MyieldD and MyieldW are milk yield during dry and wet seasons, and PrMkD and PrMkW are household milk production during dry and wet seasons, respectively.

Milk produced is either consumed or sold. How much is consumed and/or sold in a season is assumed not to exceed the volume of milk produced. That is,

PrMkD - CsMkD – SgMkD 0 (61)
PrMkW - CsMkW - SgMkW 0 (62)

where CsMkD and CsMkW are litres of milk consumed during the dry and wet seasons, and SgMkD and SgMkW are litres sold during the dry and wet seasons, respectively.

Since no household milking cows were reported the purchase of milk to supplement own production and that consumed by the household was limited to be at most equal to the amount produced. That is

PrMkD - CsMkD 0 (63)
PrMkD - CsMkD 0 (64)

3.2.9 Household fuelwood consumption and sales constraints

In addition to labour allocated to domestic and farming related activities, households devote labour time to collection of fuelwood and poles for household use as well as for sale. Across the two sites, average per capita consumption of fuelwood was 1.56 cubic metres. Assuming a woodland stocking of 50 cubic metres per hectare, the area of woodlands harvested to satisfy household needs for fuelwood and poles (StkMioH) should at least be equal to household needs divided by woodland stocking. That is

StkMioH 1.56 (HHcM +HHcW+ HHcChn)/50 (65)

Very little of direct marketing of woodland products was observed in the two study sites. The insignificant commercial harvesting was for use as inputs into other income generating activities, such as beer brewing and brick curing. In this study we assume that the value of the harvested firewood and poles is equal to the opportunity cost of labour utilised to harvest these products. How much is collected for income generation is then equal to how much the household can allocate to harvesting for sale (ClFwSLab) multiplied by how much the household can harvest per unit of labour input. How much a household can collect per labour-day – a form of firewood and poles collecting efficiency measure (EfCoef) – is estimated by dividing domestic needs of these products by the time the household devotes to collecting them. That is,

$$EfCoef = [1.56*(HHcM + HHcW + HHcChn)]/(\;^{3}_{j=1} L_{fw,i}) \qquad (66)$$

where $_{i} L_{fw,i}$ is the sum of labour allocated to collecting firewood and poles by men, women and children in the household for domestic use. Area of forest used to satisfy harvests for income generation (StMioS) is therefore:

StMioS EfCoef ClFwSLab (67)

Total area, Areamio, of woodland harvested by the household is thus

Areamio = StkMioH + StMioS (68)

Government conservation regulation enforced through chiefs and village heads in the study areas is that no harvest for poles and firewood from communal areas should be for sale outside the areas of origin. This is an imperfect way of ensuring that woodland harvest is as close as possible to biological sustainable harvest, if we assume that harvesting for household consumption does not degrade the woodlands significantly. To try to mimic this policy we introduce into the model a constraint limiting the amount harvested by a family to be less than its share of regeneration of the woodland stock in the community. The communities in Gokwe and Chivi can access 60,000 hectares and 5670 hectares of woodlands respectively. A 3 percent regeneration rate for woodland is assumed in the two sites. Given that the number of households in Gokwe and Chivi are 4558, and 453 families, respectively, the per household maximum biologically sustainable harvests (Miomax) are estimated at 0.40 and 0.38 hectares in Gokwe and Chivi, respectively. The woodland biological sustainability requirement can be specified thus,

$$\text{Miomax} \quad \text{StkMioH} + \text{StMioS} \qquad (69)$$

4. RESULTS AND DISCUSSION

The model allows us to answer a number of questions about the likely effects of changes in the socio-economic environment in which the Gokwe and Chivi communities under study reside. Specifically, we scrutinise the likely impacts on levels of achievement of a weighted household goal combining food security and income, resulting from woodlands use, crop mix, labour utilised in woodlands related activities relative to agriculture, among others, under the following scenarios:

- Current price and cost structure with no sustainability restrictions,
- Current price and cost structure with sustainability restrictions,
- Changes in all agricultural commodity prices,
- Changes in agricultural productivity,
- Changes in agricultural input prices, and
- Restrictions on household labour availability, e.g. through death or institution of laws preventing use of child labour in production.

4.1 Baseline results

Tables 5 and 6 present the base case results from the model simulation runs. With the exception of non-draft owners in Gokwe, all other representative households were shown to potentially achieve fully their food security and income goals as well as harvest timber within sustainable harvest levels identified in section 3.2.9. In those households that harvested woodlands unsustainably, simulations showed forcing sustainable harvesting entails more than proportionate loss in achievement of income goals. For non-draft owning households in Gokwe, a 32 percent reduction (0.71 to 0.40 hectares) in harvest forced by sustainability restrictions led to an increase in income deficit of 61 percent compared to baseline predictions.

The baseline results seem to support the view that natural resource degradation tends to occur in areas with abundant resources. Baseline simulation results clearly show higher levels of woodland use in Gokwe compared to Chivi, a resource poor community. Draft owning households in Gokwe harvest 0.25 hectares compared to 0.22 hectares harvested by their counterparts in Chivi, while non-draft owning households in Gokwe harvest 0.71 hectares compared to 0.20 in Chivi. In addition, as expected draft owning households tend to crop more land compared to non-draft owning households in both project sites.

Table 5. Baseline results of simulations in Chivi

		Chivi—Draft owners			Chivi—Non-draft owners		
		No-Env[a]	Env[b]	Change	No-Env	Env	Change
Food security goal	N1	0	0	0	0	0	0
	P1	0	0	0	0	0	0
Income goal	N2	0	0	0	0	0	0
	P2	0	0	0	0	0	0
Labour allocation to woodlands (%)		59.37	59.37	0	61.13	61.13	0
Labour allocation for woodlands for sale (%)		0	0	0	3.73	3.73	0
Area of woodlands harvested (ha)		0.22	0.22	0	0.20	0.20	0
Area under food crops (ha)		2.15	2.15	0	0.83	0.83	0
Area under cash crops (ha)		0.00	0.00	0	1.09	1.09	0
Total cropped land (ha)		2.15	2.15	0	1.92	1.92	0
Dual price of agricultural land		0	0	0	0	0	0

[a] No-Env implies that no environmental restrictions like in an open access situation.
[b] Env implies that environmental restrictions are enforced.

Table 6. Baseline results of simulations in Gokwe

		Draft owners			Non-draft owners		
		No-Env	Env	Change	No-Env	Env	Change
Food security goal	N1	0	0	0	0.00	0.00	0.00
	P1	0	0	0	0.02	0.02	0.00
Income goal	N2	0	0	0	1.55	62.70	61.15
	P2	0	0	0	0.00	0.00	0.00
Labour allocation to woodlands (%)		46.6	46.6	0	219.9	122.0	-97.9
Labour allocation for woodlands for sale (%)		0	0	0	162	64	98
Area of woodlands harvested (ha)		0.25	0.25	0	0.71	0.40	-0.32
Area under food crops (ha)		2.16	2.16	0	0.95	0.95	0.00
Area under cash crops (ha)		0.77	0.77	0	0.42	0.42	0.00
Total cropped land (ha)		2.93	2.93	0	1.37	1.37	0.00
Dual price of agricultural land		0	0	0	0.00	0.00	0.00

4.2 Effects of an increase in output prices

To assess the impact of a general increase in output prices that could be brought about by for instance improvement in road infrastructure, setting up of marketing infrastructure closer to the community, devaluation of an overvalued exchange rate or removal of explicit government taxes on outputs, we simulated the Gokwe and Chivi models with output prices set at 25 % more than the current prices. Tables 7 and 8 report the changes from base model results obtained for the two study sites. As expected, simulation results indicate that a general output price increase has potential to improve the attainment of income and nutrition goals. Draft owners in Chivi and Gokwe and non-draft owners in Chivi fully satisfied both goals under the with- and the without environmental concerns scenarios. Gokwe non-draft owners under unrestricted forest access manage to fully achieve both goals. Even with a sustainability constraint (Env), Gokwe non-draft owning households improve achievement of the income goal by about 16 percent.

Table 7. A 25% output price increase of simulations in Chivi

		Chivi—Draft owners				Chivi—Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	0	0	0	0
	P1	0	0	0	0	0	0	0	0
Income goal	N2	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0
Labour allocation to woodlands (%)		59.4	0	59.4	0	57.4	-3.73	57.4	-3.73
Area of woodlands harvested (ha)		0.22	0	0.22	0	0.19	-0.01	0.19	-0.01
Area under food crops (ha)		2.02	-0.13	2.02	-0.13	0.86	0.02	0.86	0.02
Area under cash crops (ha)		0.00	0	0.00	0	1.07	-0.02	1.07	-0.02
Total cropped land (ha)		2.02	-0.13	2.02	-0.13	1.92	-2.1E-07	1.92	-2.1E-07
Dual price of agricultural land		0	0	0	0	0	0	0	0

Why not cultivate more cash crops when prices increase and additional land is available? A close look at the model results points to two major constraints to increasing cash crop production. The first is the high labour and cash input requirement of the major cash crop, cotton, which makes the liquidity constraint binding. The second is the draft power constraint in a situation of limited draft leasing.

Table 8. A 25% output price increase of simulations in Gokwe

		Gokwe—Draft owners				Gokwe—Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	0.00	0.00	0.00	0.00
	P1	0	0	0	0	0.02	0.00	0.02	0.00
Income goal	N2	0	0	0	0	0.00	-1.55	47.12	-15.58
	P2	0	0	0	0	0.00	0.00	0.00	0.00
Labour allocation to woodlands (%)		46.57	0	46.57	0	235.6	15.8	122.0	0.00
Area of woodlands harvested (ha)		0.25	0	0.25	0	0.76	0.05	0.40	0.00
Area under food crops (ha)		2.09	-0.06	2.09	-0.06	1.10	0.15	0.95	0.00
Area under cash crops (ha)		0.79	0.02	0.79	0.02	0.34	-0.08	0.42	0.00
Total cropped land (ha)		2.88	-0.04	2.88	-0.04	1.44	0.07	1.37	0.00
Dual price of agricultural land		0	0	0	0	0	0	0	0.00

A priori, we would expect a general increase in output prices to make returns to labour in agriculture to rise relative to returns from woodlands activities leading to more land and labour being demanded for agriculture and reduced reliance on woodlands, at least in the short-run. Using data from 19 Tanzanian regions Angelsen *et al.* (1999) observed significant increases in cropped area with increases in agricultural output prices. A study by Deininger and Minten (1999) using satellite imagery information from Mexico found a significant and positive relationship between forest area converted to agriculture and agricultural output price increases. Similar results were found in two separate studies on deforestation in Thailand by Cropper *et al.* (1997) and Panayotou and Sungsuwan (1994). However, in Zimbabwe, a study by Chipika and Kowero (2000) found a weak positive relationship between agricultural land expansion and crop output price increases.

Results from simulations in the two sites and for the two household type models provide evidence both supporting and refuting the above observations. The results show a decrease in woodlands area harvested with increase in output prices. Draft owners in Chivi and Gokwe show no change in labour use in woodlands from baseline while non-draft owners in Chivi and Gokwe register decreases in both labour use in woodlands and total area of woodlands harvested. Further, in all areas with the exception of the no-draft owners in Gokwe that predicted no change, a general decrease in total area cropped under both with and without sustainability concerns were predicted. These results tend to suggest that improvement in output prices over a situation where both food security and income goals are met would reduce the need to over-achieve these goals through expansion in either agriculture or woodland harvesting with households preferring to enjoy more leisure. In households where agriculture is currently failing to satisfy income requirements and woodlands are already making a significant contribution to household income, the 25 percent improvement in selling prices of commodities would lessen dependency on forests. In the case of non-draft owners in Gokwe, however, the improvement would not be large enough to wipe out the deficit in achievement of the income goal, thereby making reduction in agriculture in favour of more leisure an unaffordable luxury.

4.3 Effect of an increase in agricultural productivity

In general, we would expect the changes in crop productivity to have an indeterminate direction of impact on woodland use. This indeterminacy on the impact of productivity on deforestation is borne out in empirical research. On one hand, an increase in productivity that does not have an appreciable impact on commodity prices and labour demand could lead to an increase in agricultural profitability and hence promoting a shift from harvesting of woodlands towards agriculture. On the other hand, yield improvements may trigger declines in prices affecting agricultural profitability promoting harvesting of forests (Kaimowitz and Angelsen 1998). Studies by Deininger and Minten (1996) and Panayoutou and Sungsuwan (1994) showed that increase in agricultural yield was associated with a reduction in deforestation while studies by Angelsen *et al.* (1996) and Katila (1995) reported an increase in deforestation with productivity improvement. Yet studies by Barbier and Burgess (1996) and Chakraborty (1994) showed no significant effect of yield changes on deforestation.

To assess the impact of general increase in agricultural productivity, we simulated the Gokwe and Chivi models with yields increased by 25 %. Crop yields increases could be due to use of improved seed, fertilizers and pesticides. Table 9 and 10 report the changes from base model results obtained for the two study sites. As expected, yield improvements promoted achievement of both food security and income goals. In all areas under both 'with' and 'without' environmental concern scenarios, there is full achievement of the nutrition and income target levels.

Table 9. A 25% yield increase simulations in Chivi

		Chivi – Draft owners				Chivi – Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	0	0	0	0
	P1	0	0	0	0	0	0	0	0
Income goal	N2	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0
Labour allocation to woodlands (%)		132.19	72.82	101.94	42.67	57.4	-3.73	57.4	-3.73
Area of woodlands harvested (ha)		0.49	0.27	0.38	0.16	0.19	-0.01	0.19	-0.01
Area under food crops (ha)1.67		-0.48	1.67	-0.48	1.29	0.46	1.29	0.46	
Area under cash crops (ha)		0.00	0	0.00	0	0.00	-1.09	0.00	-1.09
Total cropped land (ha)		1.67	-0.48	1.67	-0.48	1.29	-0.63	1.29	-0.63
Dual price of agricultural land		0	0	0.00	0	0	0	0	0

Table 10. A 25% yield increase simulations Gokwe

		Gokwe– Draft owners				Gokwe – Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	0.00	0.00	0.00	0.00
	P1	0	0	0	0	0.02	0.00	0.02	0.00
Income goal	N2	0	0	0	0	0.00	-1.55	0.00	-1.55
	P2	0	0	0	0	0.00	0.00	0.00	0.00
Labour allocation to woodlands (%)		46.57	0	46.57	0	252.1	32.2	122.0	-97.9
Area of woodlands harvested (ha)		0.25	0	0.25	0	0.82	0.10	0.40	-0.32
Area under food crops (ha)		1.68	-0.48	1.68	-0.48	1.19	0.24	1.03	0.08
Area under cash crops (ha)		0.91	0.14	0.91	0.14	0.20	-0.22	0.38	-0.04
Total cropped land (ha)		2.59	-0.34	2.59	-0.34	1.39	0.02	1.41	0.04
Dual price of agricultural land		0	0	0	00	0	0	0	0

On woodlands use, simulation results seem to support the indeterminacy hypothesis. Draft owning households in Chivi were predicted to increase the labour allocated to harvesting woodlands while their counterparts in Gokwe were predicted to have no change in woodlands related activities under the with- and without environmental concern management regimes. On the other hand, non-draft owning households in Chivi projected a reduction while those in Gokwe projected an increase in labour allocated to woodlands harvesting under the without environmental concern scenarios. Evoking sustainability (i.e. enforcing the environmental constraint) would lead to a reduction in labour for harvesting woodlands with crop yield increase in households without draft animals.

As the case with output price increases, and possibly for the same reason, crop yield increases would induce declines in total area cropped with the exception of non-draft owners in Gokwe. This tends to suggest that household decision-making is largely guided by the principle of satisfaction of minimum requirements rather than maximizing surplus. To test whether this result is due to the structure of the model we ran the model without the requirement of minimising positive income deviation. The results for both categories in Gokwe showed insignificant sensitivity to this modification.

4.4 Effect of an increase in input prices

Increasing the prices of inputs is likely to lead to two opposing effects (Kaimowitz and Angelsen (1998). On one hand, an increase in crop input prices will lead to a decrease in agricultural profitability and could promote the harvesting of woodlands for sale to compensate for loss in crop income. On the other hand, subsistence farmers following a “safety-first” food production strategy could substitute cash inputs with land if input prices were increased, and this could lead to an increase in agricultural labour relative to that for harvesting woodland. The net effect would most probably be indeterminate. In a number of CGE modelling efforts that looked at the impact of lowering agricultural subsidies – which is the same as increasing input prices – this indeterminacy seems to be supported. A study by Mwanawina and Sankayan (1996) in Zambia estimated that an increase in input prices tends to increase the area under agriculture, while a similar study in Tanzania showed no effect due to input price increases. A study by Coxhead and Chively (1995) in the Philippines estimated a reduction in deforestation due to input price increases.

Another dimension that may affect how responsive a community’s woodlands use is to input price increases are the initial levels of cash inputs and the cropping patterns. Communities that use a lot of cash inputs and are involved in cash crop production such as cotton (that tend to demand more cash inputs such as fertilisers, seed and agrochemicals) would tend to exhibit more inelastic response to changes in prices compared to communities that traditionally use little bought inputs. Thus we would expect the response to be more muted in Gokwe where cotton growing is a major enterprise compared to Chivi which is relatively more subsistence oriented.

To assess the impact of general increase in cash input prices we simulated the Gokwe and Chivi models with cash input prices increased by 25 %. Tables 11 and 12 report the changes from base model results obtained for the two study sites.

For the relatively well-off draft owning households in both sites, an input price increase would not affect the achievement of both food security and income goals. For non-draft owning households however there would be a reduction in ability to meet goals. In Chivi they would underachieve the nutrition goal by 1.5% while in Gokwe they would underachieve the income goal by 14 percent (or by 75% if environmental sustainability is enforced).

Table 11. A 25% input price increase simulations for Chivi

		Chivi—Draft owners				Chivi—Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	1.53	1.53	1.53	1.53
	P1	0	0	0	0	0	0	0	0
Income goal	N2	0	0	0	0	0	0	0	0
	P2	0	0	0	0	0	0	0	0
Labour allocation to woodlands (%)		59.37	0	59.37	0	61.75	0.62	61.75	0.62
Area of woodlands harvested (ha)		0.22	0	0.22	0	0.20	0.00	0.20	0.00
Area under food crops (ha)		1.89	-0.26	1.89	-0.26	0.81	-0.03	0.81	-0.03
Area under cash crops (ha)		0.00	0	0.00	0	1.11	0.03	1.11	0.03
Total cropped land (ha)		1.89	-0.26	1.89	-0.26	1.92	1.5E-07	1.92	1.5E-07
Dual price of agricultural land		0	0	0	0	0.03	0.03	0.03	0.03

Table 12. A 25% input price increase simulations for Gokwe

		Gokwe—Draft owners				Gokwe—Non-draft owners			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	0.00	0.00	0.00	0.00
	P1	0	0	0	0	0.02	0.00	0.02	0.00
Income goal	N2	0	0	0	0	15.48	13.93	77.00	75.45
	P2	0	0	0	0	0.00	0.00	0.00	0.00
Labour allocation to woodlands (%)		154.7	108.2	73.7	27.1	219.9	0.0	122.0	-97.9
Area of woodlands harvested (ha)		0.83	0.58	0.40	0.15	0.71	0.00	0.40	-0.32
Area under food crops (ha)	3.65	1.5	4.64	2.55	0.95	0.00	0.95	0.00	
Area under cash crops (ha)		0.00	-0.77	0.00	-0.79	0.42	0.00	0.42	0.00
Total cropped land		3.65	0.73	4.64	1.76	1.37	0.00	1.37	0.00
Dual price of agricultural land		0	0	0	0	0	0	0	0

Response to the reduced economic prospects due to higher agricultural input cost differs in all areas. In Chivi, draft owning households would respond through a shift in the composition of their food crop mix towards higher value, and high labour demanding crops such as groundnut and reducing maize without increasing harvesting of woodlands and actually reducing total area cropped. However, draft owning households in Gokwe, probably due to ease of obtaining woodland products in Gokwe, would respond to high agricultural costs by harvesting poles and firewood. The non-draft owning households in Chivi suffering reduced food security would respond with an increase in harvesting woodland products and an increase in area under production emphasising cash crops. The increase could be higher as the positive dual price of land suggests. Very limited options seemed to be available for non-draft owning households in Gokwe. The already high labour allocation to woodlands resource harvesting (220 days) leaves little scope for cropland expansion under the without environmental sustainability constraint. Unsustainable baseline harvest levels would imply that the household could not expand forest related employment to counter poor agricultural returns under the sustainability constraint scenarios. Further, input buying related liquidity constraints could force farmers to reduce plantings.

4.5 Impact of loss of some household members

The HIV/AIDS epidemic has reached unprecedented levels in Zimbabwe. In 1999 an estimated 1.5 million people were living with AIDS representing an adult prevalence rate of 25.1 percent and leading to 160,000 AIDS related deaths (UNAIDS 2000). According to a recent FAO/UNAIDS (2001) study, agricultural output of small farmers in some parts of Zimbabwe may have fallen by as much as 50 percent in the past five years, mainly because of AIDS. The study attributed to AIDS over 50 percent of deaths - 78 percent of which were men - in the areas studied (UNAIDS 2001).

The problems of HIV/AIDS in farming communities begin as soon as the first adult in the household becomes sick. Those suffering need the help of their kin, so the family loses not only the labour of the sick but also of other relatives. The situation worsens if other household members get the disease. The family budget is squeezed to pay for medical bills and, ultimately, funeral costs thereby reducing money available to buy seeds and other inputs, and forcing the sale of livestock and other assets. Further, one would expect labour shortages due to HIV/AIDS to cause a range of farm changes, including a reduction in land under cultivation, a decline in crop yields and a shift from cash crops to subsistence crops. Labour shortages may also lead to shifts towards much easier coping strategies for the household such as harvesting woodlands for sale.

To gain insight into the likely impact of AIDS and other common diseases like malaria, on the household's welfare we model situations where a household loses an adult (woman/man) or a child. Tables 13 and 14 report the potential impacts in the two study sites.

Table 13. Simulation of effects of loss of household member in Chivi

		Chivi—Draft owners (loss of child labour)				Chivi—Non-draft owners (loss of a woman)			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	74.36	74.36	74.36	74.36
	P1	0	0	0	0	0	0	0	0
Income goal	N2	0	0	0	0	306.1	306.1	306.1	306.1
	P2	0	0	0	0	0	0	0	0
Labour allocation to woodlands (%)		86.93	0.00	86.93	0.00	57.4	-3.73	57.4	-3.73
Area of woodlands harvested (ha)		0.27	0.00	0.27	0.00	0.16	-0.04	0.16	-0.04
Area under food crops (ha)		2.07	0.16	2.07	0.16	1.23	0.40	1.23	0.40
Area under cash crops (ha)		0.00	0.00	0.00	0.00	0.00	-1.09	0.00	-1.09
Total cropped land (ha)		2.07	0.16	2.07	0.16	1.23	-0.70	1.23	-0.70
Dual price of agricultural land		0	0	0	0	0	0	0	0

Losses of child labour through the death of a child, or alternatively through enactment of laws preventing employment of child labour, was modelled for draft owning households in Chivi and non-draft owning households in Gokwe. For Chivi draft owning households, loss of a child did not prevent satisfaction of both food security and income goals. Simulations also show that there was no effect on area of woodlands harvested. However, since loss of a child means demand of woodland products for domestic use goes down, it implies harvest of timber for sale goes up. Simulations for Gokwe non-draft owning households however showed dramatic impacts of loss of a child. Simulations show a worsening failure to achieve both food security (15 percent) and income (10 percent) goals. Labour allocated to woodlands harvesting drops by 97 labour days while total land cropped also drops. Results also show a shift in production towards cotton (cash crop) production, a labour intensive activity, explaining why there was a drop in cropped area accompanied by an increase in land under crops.

Loss of one woman's labour in a household was modelled for Chivi non-draft owning households (Table 13). Simulation results show dramatic impacts on the household. The household fails to attain food security goal by 74 percent and by more than 100 percent the income goal. The household significantly reduces area cultivated and even stops growing cash crops altogether shifting efforts toward food production. Despite these impacts, simulations show surprising little reduction in labour used on woodland harvesting with only 4 days reduction in woodland harvesting labour. However, there was noted a slight decrease in area of woodland harvested, while the opposite was observed in Gokwe when there was a loss of adult male labour (Table 14).

Table 14. Impact of loss of household member in Gokwe

		Gokwe—Draft owners (loss of a man)				Gokwe—Non-draft owners (loss of child labour)			
		No-Env	Change	Env	Change	No-Env	Change	Env	Change
Food security goal	N1	0	0	0	0	15.41	15.41	15.41	15.41
	P1	0	0	0	0	0.00	-0.02	0.00	-0.02
Income goal	N2	0	0	0	0	11.48	9.93	11.48	9.93
	P2	0	0	0	0	0.00	0.00	0.00	0.00
Labour allocation to woodlands (%)		74.78	28.21	73.69	27.13	122.50	-97.40	122.50	-97.40
Area of woodlands harvested (ha)		0.40	0.15	0.40	0.15	0.33	-0.38	0.33	-0.38
Area under food crops (ha)		4.79	2.63	4.79	2.69	0.81	-0.14	0.81	-0.14
Area under cash crops (ha)		0.00	-0.77	0.00	-0.79	0.49	0.08	0.49	0.08
Total cropped land (ha)		4.79	1.86	4.79	1.91	1.30	-0.07	1.30	-0.07
Dual price of agricultural land		0	0	0	0	0	0	0	0

All in all the results indicate substantial increase in poverty due to diseases like HIV/AIDS that can constrain availability of labour. The total absence of adult female labour in the household due to such diseases has potential to adversely affect both income and food security by mainly to disrupting agricultural productivity, and could increase woodland harvesting for sale as this would remain an important income source for households during this predicament.

5. MAIN FINDINGS AND CONCLUSIONS

This paper modeled woodland use in four representative households: draft animal owning households and non-draft animal owning households in a woodland abundant area and a woodland poor area. The results indicate that woodland use tends to be higher in wood abundant areas compared to the resource poor areas and that woodland resources are important sources of household income for the poor in resource abundant regions compared to households in the resource poor areas.

The study also simulated the likely impacts of agricultural incentives and effects of absence of labour from productive members, for example due to death from diseases such as HIV/AIDS and malaria. The results indicate varied woodland use response depending on household characteristics. Basically three household types emerge that are likely to influence household response to policy or situation change stimuli:

- Type I households are those fully satisfying both food security and income goals from current agricultural activities with woodlands resources only used for domestic requirements. In this category falls draft animal owning households in Gokwe and Chivi.
- Type II households are those fully satisfying both food security and income goals from current agricultural activities with some supplementary income coming from harvesting woodlands over and above domestic requirements. However, woodland resource harvest is still within sustainable levels. In this category are non-draft animal owning households in Chivi.
- Type III households are those currently failing to satisfy either of their food security or income goals from current agricultural activities even with supplementary income coming from harvesting woodlands over and above domestic requirements and beyond sustainable levels. This category describes non-draft animal owning households in Gokwe.

The characteristics of the households described above are found to be closely linked to how households respond to external shocks. In the event of drastic reductions in agricultural incentives (e.g. reduction in yield or increase in input prices) Type I households have some room to restructure agricultural activities to satisfy goals before turning to harvesting woodlands for income. Type II households have less opportunities compared to Type I households to restructure agriculture to counter adverse conditions. However, because they are currently harvesting within sustainable levels, they have room to increase harvests from the forests to increase incomes and be better able to achieve goals. Type III households however are in a difficult situation. Because they are unable to satisfy goals from agriculture and from devoting maximum possible labour to harvesting woodlands, these households are likely to respond to adverse agricultural incentives by turning even more to woodland harvesting in an open access situation. However, under strict environmental sustainability enforcement, and because Type III households exceed sustainable harvest under free access baseline condition, they cannot respond to adverse agriculture activities by resorting to woodland harvesting.

Better agricultural incentives (from say an increase in agricultural product prices) should allow Type I and II households to satisfy goals with less agricultural land freeing up labour to either boost woodland harvesting or improvement in leisure. Type III households, because they are not satisfying goals in the baseline and due to improvement in relative returns to agriculture, are predicted to respond to improvement in agricultural incentives by allocating more land and labour to agriculture and less to woodland harvesting.

Loss of household members were shown to make the relatively poorer non-draft animal owning households poorer while draft owning households could absorb the losses without losing their standards of living. Poorer households, already depending on woodland resources to a significant level tend to reduce labour allocated to woodlands and increase land under food crops in the event of loss of household members. The richer households could increase dependence on woodland resources in the event of a loss in a household member. The results also indicate a strong gender bias in effects of household member loss. The loss of a woman member induces debilitating decline into abject poverty compared to other gender classes highlighting the central roles women play in the household production process.

The above conclusions demonstrate the strong effect on woodland use of agricultural policies, HIV/AIDS related diseases, and institutional arrangements protecting forests. As Zimbabwe proceeds with its second - and much expanded - phase of the land reform and redistribution exercise, it is important that issues of protection of the woodlands are not ignored. Of particular concern is the lack of consideration for development of local level institutions governing the use of forest resources in the current land redistribution exercise. The model presented here provides a tool for potential use in crafting new policies and institutions governing woodland resource use in the newly settled areas.

ENDNOTES

1. Even though prices are held constant across seasons due to government price controls, separating wet and dry season takes care of possibilities of storage losses, labour limitations during wet season as well as differences in milk productivity across season, etc.

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18.

Management of miombo woodlands in Malawi: An application of goal programming

H. Tchale, R. Kachule and C. Mataya

ABSTRACT

Miombo is a local name for African woodlands prevalent in seven eastern and southern African countries, namely Angola, Democratic Republic of Congo, Malawi, Tanzania, Mozambique, Zimbabwe and Zambia. The woodlands are surrounded by subsistence farmers who largely depend on them for their livelihood. Unfortunately, there is no guarantee that the utilization of the resources from the miombo woodlands is sustainable in the long-run, mainly due to the absence of effective control and management of these vast resources.

In an effort to come up with a methodology for planning woodland management and use, a model called MIOMBOGP based on the weighted goal programming (WGP) method is employed. This methodology is used to evaluate how the various principal woodland stakeholders respond to some macro-economic and sectoral policies in ways that satisfy the achievement of their goals. We identify households, the private sector and governments as the main stakeholders in the woodlands, who often have interests that conflict with each other. This has potential to reduce the sub-optimization of the benefits they derive from the woodlands as well as adversely affecting the woodland condition.

Using this model on the data collected from the communities surrounding Dzalanyama, Chimaliro and Mdeka forest reserves, the results imply that use of the miombo woodland resources is mainly influenced by prices of agricultural commodities, technological changes in agriculture, labour supply changes and prices of firewood and other energy sources. Thus when planning to change any of these variables, there is a need to quantify the impact on the woodland resources because any pressure on agriculture holds potential to negatively affect woodland resource condition as well as the benefits that flow from them.

Key words: Goal programming, miombo woodlands, Malawi

1. INTRODUCTION

Miombo woodland characterise most of the African woodlands which are mainly dominated by species of *Brachystegia*, either in pure stands or in association with those of *Julbernadia* and/or *Isoberlinia* (Lind &Morrison 1974; White 1983). These woodlands are most prevalent in seven eastern, central and southern African countries namely Angola, Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe (White 1983). They occupy an area of about 2.7million km^2 and support over 40 million people. The people live in the vicinity of the woodlands, while some reside in woodlands that are in public domain. They rarely live in the woodlands set aside as government forest reserves, but do encroach on them for several demands. Where the woodlands occur outside forest reserves, their clearing for agriculture has taken place over the years.

These woodlands are surrounded mostly by subsistence farmers who largely depend on them for their livelihood in the form of energy sources, poles for the construction of dwellings, thatch, food in the form of fruits, fungi, indigenous vegetables, insects and grazing ground for livestock. Given this extensive dependence on these resources, there is need to ensure that the resources are managed and used sustainably because the very existence of the communities depends on them. Apart from the communities, there are also other stakeholders like the private sector, the government and the international community that have commercial and conservation interests in the woodlands.

All the countries with miombo woodlands are implementing economic reforms that seek to restructure their ailing economies. The policies and strategies employed affect all the miombo woodland stakeholders differently and in ways that are not clear but with potential effects on woodland based rural livelihoods and the forest condition.

The objective of this paper is to present a methodology for planning woodland management and use, by evaluating how the various principal woodland stakeholders respond to some key macroeconomic and sectoral policies in ways that satisfy the achievement of their goals. The satisfaction of some of these goals exerts pressure on the woodland resources. It is this pressure and the extent to which it manifests itself in the woodlands that the paper seeks to address, and especially the sustainable satisfaction of the needs of the key stakeholders.

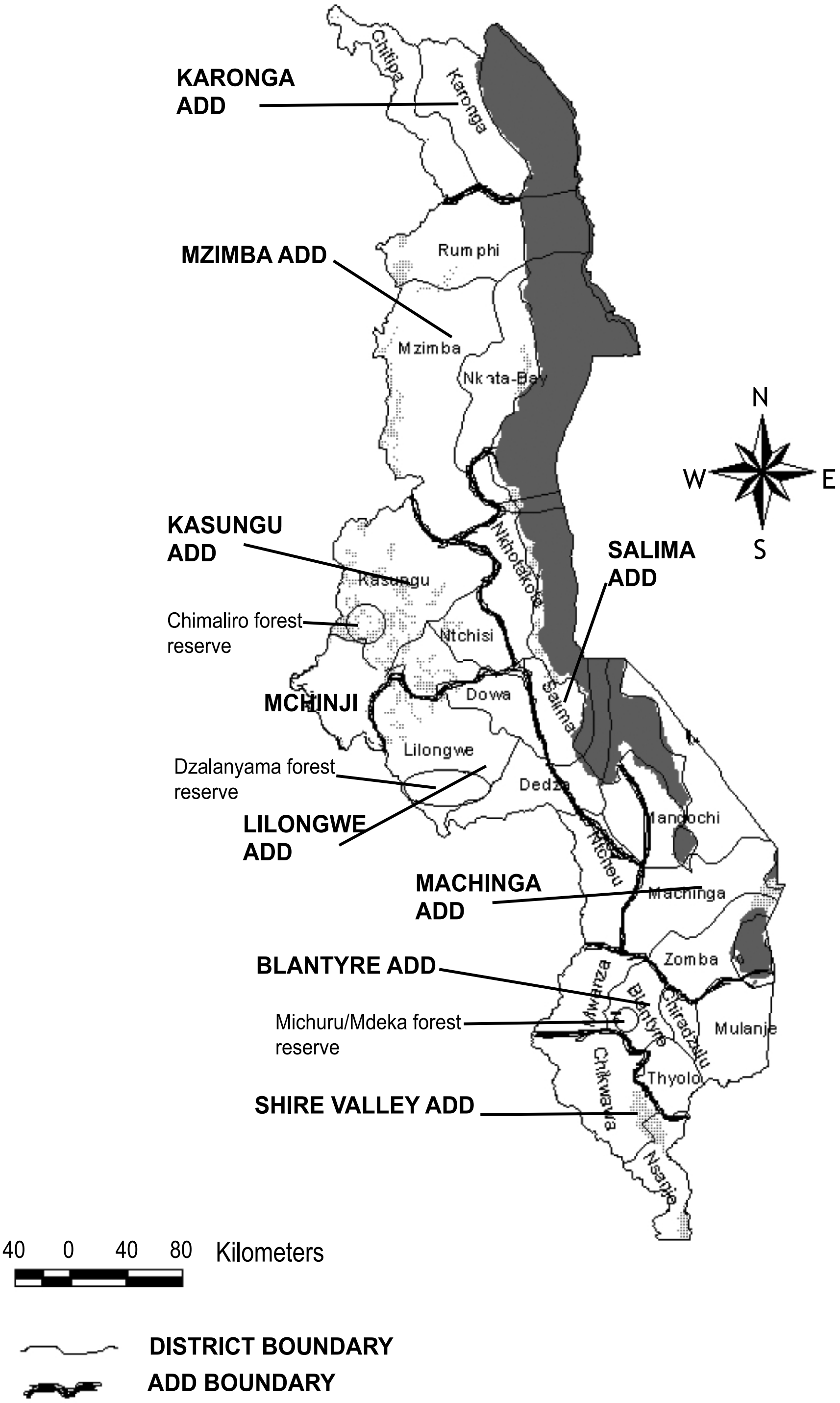
This paper presents the results derived from a weighted goal programming model (MIOMBOGP) based on data collected from communities living around three forest reserves in Malawi namely Chimaliro in Kasungu district, Dzalanyama in Lilongwe district and Michiru in Blantyre district.

The paper is arranged as follows: it starts with a description of the study sites, presentation of the goal programming model adapted for Malawi, the baseline results, the discussion of results from the sensitivity/alternative scenarios analysis, and finally conclusions and recommendations. The basic goal programming model is presented in Nhantumbo and Kowero (2001) and Annex1 presents the data used in building the models for the three study sites while Annex 2 presents the variable definitions and units of measurement.

2. DESCRIPTION OF THE STUDY SITES

The research was conducted in three different sites namely, Chimaliro and Dzalanyama in the central region of the country and Mdeka in the South of the country (Figure 1). This section describes the characteristics of these sites.

Figure 1. Map of Malawi showing the survey districts and the forest reserve sites



2.1 Chimaliro

Chimaliro is a gazetted forest reserve with tree species of *Brachystegia* and *Jubernardia* as the predominant woodlands. The reserve is wholly indigenous, i.e. there is no plantation of exotic species. The reserve was declared a protected area in 1926 with an initial area of 98 square kilometres. All villages in the vicinity of the reserve were closed except one which acted as a caretaker. The people of this village were allowed to cultivate specific areas within the reserve. At the time the reserve was declared a protected area, there were plenty of indigenous trees on the customary land such that there was no need or motivation for the villagers to go to the reserve for wood and other forest supplies/products. In 1945, the Forest Department prohibited cultivation in the reserve since the agricultural practices were considered detrimental to the woodlands. In 1952, the government began to employ people to manage the forest. At that time, encroachment on the forest reserve had already started. The boundary of the reserve was then changed to its present position. Currently the reserve stretches over an area of 160 km^2 from the north east Zambian boarder (Lowore *et al*. 1995).

Food crops grown in the area include maize, groundnuts and beans, with tobacco as the major cash crop. However, maize and groundnuts surpluses are also sold for cash. Livestock form another source of income through sales of milk, eggs, chickens and occasionally the stock itself. Minor sources of income include local beer brewing, moulding of bricks and sale of firewood. The traditional form of agriculture practised was shifting cultivation which involved clearing some of the miombo woodlands. The minimum fallow period could be as long as 15 years. This allowed rejuvenation of soil fertility and re-growth of some tree species. Increasing land pressure due to population growth has led to a sedentary form of agriculture with continuous cultivation on the same piece of land that eroded soil fertility. Due to increasing importance of the tobacco crop and also due to the liberalization of tobacco production by allowing smallholder farmers to also grow it, there has been a considerable conversion of the forest to cropland by estate and smallholder farmers.

All along, management and control of the reserve has been under the Forest Department. Communities surrounding the reserve were never allowed access into the forest reserve for any forest products. However, beginning from the late 1990s, the concept of co-management was introduced along certain stretches of the reserve. Communities are now allowed access to the forest for non-timber products such as wild fruits, honey, grass and caterpillars. The estate sector is occasionally allowed access for poles and fuel wood.

2.2 Dzalanyama

Dzalanyama forest is gazetted as a protected forest reserve and it is designated as public land under the Land Act of Malawi. The reserve lies on the Dzalanyama range stretching over a distance of 65 km. It covers a total area of 98,909 ha and runs through three districts; Dedza to the south covering 35,600 ha (bordering Mozambique); Lilongwe to the center covering 61,909 ha (about 40 km to the west and south west of Lilongwe city) and Mchinji to the north covering 1,400 ha (bordering Mozambique & Zambia).

The indigenous component of the reserve covers 45,420 ha and the remaining 53,489 ha is a plantation with *Pinus* and *Eucalyptus* as the dominant species. Ultimate management and control of the forest and its resources lies with the Department of Forestry. Management focus has been on protection against fire, over-exploitation and encroachment. Firewood, poles and timber are legally obtained by licenses (for the plantation only). Prior to 1987/88, the commercial sector was allowed to salvage dead wood from the indigenous forest for sale in the city of Lilongwe. Due to abuse, this privilege was removed because it was discovered that when dead wood was getting scarce, people started felling live trees for eventual use as firewood. Illegal procurement of forest products especially fire wood by the commercial sector occurs around the boarder of the reserve.

The indigenous part of the forest reserve is composed of tree species of *Julbernadia* and *Brychystegia* with the dominant species being *Julbernadia paniculata, Uapaca kirkiana, Uapaca sensabarica, Parinari curatellifolia* and *Brachystegia spiciformis*. Dense grass growth dominates throughout the reserve with *Hyparrhenia, Andropogon, Themeda, and Digitaria* being the most common grass types.

By 1921, most of the reserve was cleared for agricultural purposes and this led to serious deforestation. Tobacco is the main cash crop in the area with maize as the major food crop. Since the reserve was constituted, it has been under the management and control of the Forest Department and management of the reserve has primarily aimed at protecting the reserve to conserve water and soil. Generally, management of the reserve has been carried out on a minimal budget for implementation of the Forest Department's fire policy, protection against overexploitation and encroachment. From the late 1990s, the Forest Department embarked on a co-management approach whereby communities in the vicinity of the reserve are encouraged to participate in management of the reserve. In turn, the communities are allowed access to the indigenous forest to collect dead wood, thatch grass, and other non- timber forest products.

2.3 Mdeka

The Mdeka site lies near the Michiru forest reserve and is about 30 km south of Blantyre city, a major commercial city in Malawi. The area is neither gazetted as protected area nor designated as public land (i.e. open access). Despite the fact that rules and regulations regarding management of the indigenous forest are there from the Forest Department, virtually no elements of management by the local communities exist in this area. The indigenous forest is largely under customary tenure system whereby the local leaders are the custodians of the land and resources available on the land. Construction of a major bitumised road which passes through Mdeka and connecting the cities of Blantyre and Lilongwe has encouraged overexploitation of the indigenous woodland by the communities living within the forest area. The communities largely cut wood for sale as fuelwood and for purposes of producing charcoal. The bitumised road has eased transport between Mdeka and Blantyre city thereby increasing trafficking of wood and charcoal into the city. Furthermore, growth of the construction industry in the city of Blantyre has also contributed to degradation of the natural forest in this area because people harvest wood from this area for purposes of curing bricks.

3. THE MODELLING APPROACH

3.1 Description of the typical household

The model is based on analysing the decision making process of a typical household using data[1] derived from a broader and detailed field survey that was conducted in the three-study sites. The sites were selected in consultation with the Department of Forestry and the Forestry Research Institute of Malawi (FRIM) who have good knowledge of the forest reserves and related issues around these sites.

The typical household was defined by taking a mean of the sample which comprised a total of 300 households (100 households from each study site). Simple random sampling was used in identifying the households. The sampling frame was developed together with forest assistants and agricultural field assistants from each study site. The sampling design also provided for at least 30 female-headed households based on the understanding that 30 percent of the rural households in Malawi are female headed.

Subsistence agriculture predominates the activities of the households in all the sites. As shown in Table 1, the main cash crop is tobacco and the predominant cropping system is inter-cropping of maize with beans and groundnuts. However other minor crops such as cassava and sweet potatoes are also planted as sole crops, especially when planted as a second crop soon after harvest.

Table 1. Crops commonly grown in the study sites (%)

Crop	Mdeka	Chimaliro	Dzalanyama
Maize	92.1	77.3	83.3
Sweet potato	6.0	9.0	15.9
Cassava	22.8	-	14.5
Beans/pulses	12.6	9.1	16.5
Groundnuts	17.2	20.3	19.0
Tobacco	8.3	45.1	30.8

The key household activities were food production and consumption including the collection, consumption and selling of forest products such as firewood and fruits. Each of these activities uses the labour available to the household. The core of the household's decision making is based on best allocation of the labour in ways that will ensure the satisfaction of its production and consumption goals.

3.2 Key descriptive statistics

The following information characterise the typical household on whom the goal programming model is based.

Table 2. Key descriptive statistics for typical households

Variable	Dzalanyama	Michiru/Mdeka	Chimaliro
Land coefficients (hectares)			
Maize	0.91	0.35	0.72
Tobacco	0.53	0.20	0.53
Average land holding size per household	1.44	0.55	1.25
Yield coefficients (kg/hectare)			
Maize (intercrop)	1277.14	695.60	1569.44
Beans (intercrop)	168.06	100.00	197.14
Groundnuts (intercrop)	366.08	318.88	529.66
Tobacco (monocrop)	666.04	643.40	1250.00
Total mandays/year (agric. season)	112.5	112.5	112.5
Total mandays/year (other activities)	200.5	200.5	200.5
Family size (3 working adults and 2 children)	5	5	5
Livestock ownership			
Cattle	3	1	3
Goats	4	2	7
Firewood demand (m^3/season/household)	4.39	2.80	5.48
Consumption (wet season)	3.29	3.72	3.62
Consumption (wet season) Selling (dry season)	4.35	5.40	2.94
Selling (wet season)	3.30	6.44	2.83
Dietary requirements (%)			
Maize	70	70	70
Beans	20	20	20
Groundnuts	5	5	5
Others	5	5	5
Income target (USD per household)	538.00	284.10	364.90

Note: The dry and wet seasons in Malawi are on average, 7 and 5 months long, respectively. The agricultural season is assumed to be approximately 3 months.

3.3 The basic goal programming model[2]

The objective in the weighted goal programming (WGP) model is to minimise the sum of deviations, both positive and negative, from the target levels set by the decision-maker. In this case the decision-maker is the household. The objective function of the WGP is the simultaneous minimisation of the sum of weighted deviations, and is given as:

$$\text{Min} \sum_{i=1}^{k} ({}_i n_i + {}_i p_i) \qquad (1)$$

The weights ($_i$ and $_i$) are associated with the goals of food security, household income and environment conservation and positive (p_i) and negative (n_i) deviations from the goals. This means that the household has to set targets it wishes to attain with respect to the goals. Sections 3.4.1 to 3.4.3 explore this further.

Constraints

As with any other programming model, the attainment of the goals is subject to a number of constraints. In this particular model, the constraints are on arable land, labour, dietary requirements, requirements for livestock grazing and the demands for forest products for both food and domestic energy needs.

Land constraint[3]

The total land holding (ß) has to satisfy the demand for arable land by a household for the various crops denoted by Xi.

$$\sum_{i=1}^{n} X_i <= ß \qquad (2)$$

Total demand (by season j) for each crop is used to satisfy the selling (S_{ij}), storage (A_{ij}) and consumption (C_{ij}) needs, where j=1, 2 represent dry and wet seasons respectively. This total demand is met through production (X_{ij}) and buying (B_{ij}).

$$-\sum_{i=1}^{n} y_i X_{ij} + \sum_{i=1}^{n} S_{ij} + \sum_{i=1}^{n} A_{ij} - \sum_{i=1}^{n} B_{ij} + \sum_{i=1}^{n} C_{ij} <= 0 \qquad (3)$$

Production Selling Storage Buying Consumption

Labour constraint

The total labour demand for crops (Li), livestock (LA), off-farm (LN) and domestic (LD) activities should not exceed that available in the household (L_k); and is given as follows:

$$\sum_{k=1}^{n} L_{ik} + \sum^{n} LA_k + \sum^{n} LN_k + \sum^{n} LD_k - \sum^{n} L_k <= 0 \qquad (4)$$

Tie constraints (labour)

L_k = 5. This is based on the assumption of an average household size of 5,

with k=1,2,3 for adult male, adult female and children respectively.

Dietary constraints

Energy supply (E) per crop to the household

$$-\sum_{k=1}^{n} E_i + E_{kj} <= 0 \qquad (5)$$

where Ei denotes energy supply sources and Ekj denotes energy demands.

The calorific figures that have been used in the model are based on the dietary recommendations for healthy living of males, females and children (Latham 1979).

Protein supply (P) per crop to the household

$$-\sum_{j=1}^{n} P_j + P_{kj} <= 0 \qquad (6)$$

where Pi denotes protein supply sources and Pkj denotes protein demands.

Livestock grazing
The demand for feed for cattle (g tons of dry matter per head) should at least be satisfied by the amount of available pasture (p tons dry matter per ha) in a specified grazing area.

$$gC - pF <= 0 \qquad (7)$$

where:
C = cattle stock numbers.
F = land area for natural production of feed for cattle.

Forest products constraints
The standing forest stock (SS) should at least satisfy the demand for household consumption (WdCh - charcoal and FwC- firewood) and for firewood sale (SFw).

$$-SS + FwC + WdCh + SFw <= 0 \qquad (8)$$

3.4 The MIOMBOGP for Malawi

In modelling the interaction of the communities and the *miombo* woodlands in the case of Malawi, the following observations were taken into account. First, the State, household and the private sector have stake in the *miombo* woodlands. Second, the household's goal is to maximize food security or to minimize the occurrence of food insecurity. Third, the private sector's goal is to maximize income from sale of woodland products or to minimize the lack of it. Fourth, the goal of the state is to ensure that the woodlands are managed and used in ways that give maximum benefits to the households and the private sector while ensuring that the environment is not compromised. Fifth, the interaction of these sectors determine the extent to which each one of them satisfies its own goals given that they all depend on the resource.

It was observed from the ranking done by the households that a typical household would aim at maximising food security as a priority goal. The other goals of securing income and environmental conservation were ranked second and third respectively.

(a) The household food security goal
The food security goal for the typical household assumes a crop mix comprising maize, beans and groundnuts. In terms of the goal programming model, the household aims to minimize the negative deviations from the minimum amount of energy, measured in kilocalories, required for an active and healthy life for all household members. Although maize is the main staple for most of Malawi, the other crops are used, some as relish or sold to get money with which to buy relish. At smallholder level, which is the sector typical of most households in Malawi, these crops are key and they take up over 80% of the cropland.

(b) The income goal
Most rural households derive income from a combination of subsistence activities including selling of crops, livestock and labour to other farms. They also harvest and sell forest products, mostly firewood and poles, charcoal and other non-timber forest products such as mushroom and fruits. The objective of the household is to maximize the

income realized from these sources. In this analysis, the target income level was calculated using a linear programming model developed for each site.

(c) The environmental protection goal

From field data, the typical household in Malawi places little weight on environmental conservation. This is manifested in the way they encroach on the woodlands for agriculture and other sources of livelihood. Ensuring the attainment of this goal is largely the responsibility of the government through appropriate policies. In this analysis, the environmental goal is evaluated in terms of the amount of firewood that is extracted annually and used for household domestic use and for sale. It is therefore essentially a fuelwood goal. Harvesting the woodlands for fuelwood is the main household demand on these resources. The extent to which fuelwood becomes sustainably available would reflect the attainment of this goal. If fuelwood supplies are not sustainable, then degradation of the woodlands is inevitable leading to the total disappearance of the woodlands in the long-run. The best measure of the extent of environmental degradation would have been woodland depletion or deforestation. However, absence of data on how this has been going on precludes its adoption.

The model syntax and the variable definitions and units of measurement appear in Annex 2.

4. BASELINE RESULTS AND DISCUSSION

Tables 3-9 present the results from the base runs. The results highlight the attainment of household goals, crop and livestock production, food consumption, sale of food production as well as consumption and sale and forest products.

4.1 Attainment of household goals

The results in Table 3 show that the food security and income goals are fully satisfied since the negative and positive deviations from them are zero. However in all the three sites the environmental goal is not fully satisfied. In all the communities under the study, the priority goal is food security, followed by income. The fuelwood goal was modeled as the amount of firewood that the household needs for household consumption in both the wet and dry seasons. As the results indicate, this goal is not attainable in all the three sites. This implies that if firewood runs out then the woodlands would have been fully depleted, an environmentally unacceptable outcome.

Table 3. Baseline Results: Attainment of goals

Objective value	Sites		
	Mdeka	Chimaliro	Dzalanyama
Food security goal (n1)	0.00	0.00	0.00
Income goal (n2)	0.00	0.00	0.00
Environment /Fuelwood target (p3)	96.84	99.70	99.04
LP target income (US$/year)	284.10	364.90	538.00

Given the resources and constraints available in a typical household in the three sites, a linear LP model was run to determine the level of disposable optimal income that can be achieved per year. The results in Table 3 indicate highest income in Dzalanyama and lowest income in M'deka. This reflects the differences in the level of income earning opportunities among the sites. For example tobacco and legume production in Dzalanyama and Chimaliro is considerably higher than in M'deka. These results actually do reflect the existing disparities in terms of income distribution in Malawi. Various research studies including the more recent Integrated Household Survey have indicated low household incomes on average among households in the Southern region compared to the other two administrative regions.

4.2 Crop and livestock production

In terms of crop production, less than half as much land is allocated to maize, groundnuts and bean intercrop in M'deka compared to Dzalanyama and Chimaliro (Table 4). This reflects the differences in the land holding sizes as households in M'deka have on average the lowest land holding compared to those in Dzalanyama and Chimaliro.

Although the land allocated to tobacco production is not very different across the three sites, there are significant differences in productivity as a result of the differences in inputs applied. It was observed from a questionnaire survey for this study that input application was much lower in M'deka compared to Dzalanyama and Chimaliro. This could possibly be the result of the differences in current and potential income earnings (Table 2).

Table 4. Baseline Results: Crop production (ha)

Activity	Mdeka	Chimaliro	Dzalanyama
Maize, groundnuts and bean intercrop	0.35	0.76	0.94
Tobacco	0.09	0.20	0.27
Total cropland	0.44	0.85	1.21
Total landholding	0.55	1.25	1.44

4.3 Food consumption

The consumption levels for maize, groundnuts and beans are as shown in Table 5 for both dry and wet seasons. These are optimal consumption levels given the resources and constraints that characterise the typical household in the three sites. The results indicate that in the dry season, maize consumption level is much lower in M'deka compared to Chimaliro and Dzalanyama. In fact, given an average household size of 5 people, most households in M'deka hardly meet the consumption requirement.

The wet season consumption levels are not very different across sites as these reflect the buying and not the actual own-farm production. For groundnuts and beans the consumption levels are slightly lower in M'deka. It was noted that these consumption levels are mostly normalized through buying from the local markets as production levels for these crops are typically lower compared to the other two sites (Table 6).

Table 5. Baseline Results: Food consumption (kg/household)

Food commodity	Mdeka		Chimaliro		Dzalanyama	
	Dry	Wet	Dry	Wet	Dry	Wet
Maize	432.79	360.67	717.36	363.07	717.36	363.07
Groundnuts	67.52	0.00	75.00	75.00	100.00	75.00
Beans	98.56	91.16	100.00	75.00	100.00	75.00
Beef	7.00	5.00	14.00	5.00	18.02	15.00
Goat meat	16.52	9.05	17.57	9.30	36.00	15.05

Table 6. Crop sales (kg/household)

Food commodity	Mdeka		Chimaliro		Dzalanyama	
	Dry	Wet	Dry	Wet	Dry	Wet
Tobacco	128.68	0.00	181.96	0.00	181.96	0.00
Maize	0.00	0.00	0.00	0.00	0.00	0.00
Groundnuts	0.00	0.00	254.25	0.00	191.08	0.00
Beans	0.00	0.00	0.00	0.00	0.00	0.00

4.4 Trade in food products (buying, selling and storage)

Tobacco is the dominant traded crop (Table 6) with quantities sold lowest in M'deka and similar in the other two sites. Given that pan-territorial selling prices were used in the model, the differences in the levels of crop sold cold only reflect the differences in the production levels. Tobacco production is dominant in the central region. The results from a questionnaire survey for this study indicate that almost all households interviewed in Dzalanyama and Chimaliro grew tobacco either on their own farms or through some form of contract or out-grower scheme with other farmers or estates. For M'deka (located in the non-tobacco zone in the southern region) less than 20% of the households grew the crop.

As can be seen in Table 7, storage activity is zero for almost all crops[4], except maize in the dry season in M'deka, while small quantities of other crops (maize, groundnuts and beans) are actually stored in the dry season by households in Dzalanyama and Chimaliro. As a result, most of the buying (Table 8) done in M'deka is to replenish food stocks in wet season that result from low production that leaves nothing, or insignificant amounts for storage during the dry season.

All the households meet their demand for livestock products from the market (Table 8) since most of them have very few livestock (goats and cattle). Even the consumption levels are far lower than the recommended consumption levels especially due to the lower budget shares allocated to these commodities.

Livestock rearing is limited to an average of 2 cattle and 4 goats per household in Dzalanyama and one cattle and two goats for households in M'deka. Households in Chimaliro have on average 3 cattle and 7 goats. These low stocking levels are

Table 7. Food storage (kg/household)

Food commodity	Mdeka		Chimaliro		Dzalanyama	
	Dry	Wet	Dry	Wet	Dry	Wet
Maize	95.60	0.00	472.80	0.00	477.22	0.00
Groundnuts	0.00	0.00	72.41	0.00	76.34	0.00
Beans	0.00	0.00	49.50	0.00	57.20	0.00

Table 8. Food purchases (kg/household)

Food commodity	Mdeka		Chimaliro		Dzalanyama	
	Dry	Wet	Dry	Wet	Dry	Wet
Maize	0.00	284.93	0.00	0.00	0.00	0.00
Groundnuts	0.00	229.90	0.00	0.00	0.00	0.00
Beans	63.56	95.36	0.00	39.55	0.00	34.75
Beef	7.00	5.00	14.00	5.00	18.02	15.00
Goat meat	16.52	9.05	17.57	9.03	36.00	15.05

characteristic of most households in Malawi where livestock levels are generally low, except for some few districts in the Northern region. However, we have used standard or average animal unit values that might not always be consistent with the averages in the specific study sites. The consumption of beef and goat meat has been calculated based on the breeding, calving and kidding rates of the Malawi stock[5].

4.5 Consumption and trade in forest products

The results on firewood consumption and selling (Table 9) indicate lower consumption quantities in M'deka compared to the other sites. However, the quantities sold are substantially higher in M'deka reflecting increased firewood sales. This could stem from the increased demand for firewood and charcoal in M'deka to supply the city of Blantyre. Also the woodlands in M'deka have for a long time been under free access as there was no regulation from the government. This could probably explain why the site is more depleted in terms of wood resources as compared to Dzalanyama and Chimaliro which are gazetted forest reserves regulated heavily by the government. For Dzalanyama[6] and Chimaliro, the potential for depletion of the woodland resources is also high as a result of the escalating demand in the nearby Lilongwe city and Kasungu towns, respectively.

Table 9. Firewood consumption and sales (m^3/household)

Activity	Mdeka		Chimaliro		Dzalanyama	
	Dry	Wet	Dry	Wet	Dry	Wet
Consumption	2.80	3.72	5.48	3.62	4.39	3.29
Selling	5.40	0.80	0.00	1.20	0.00	0.18

The selling of firewood by individual households features relatively low in Dzalanyama and Chimaliro. Firewood collection and selling is quite low in these areas i.e. on average about 4 to 6 cubic meters of wood are used for household energy needs per household per year. Between 1 and 2 cubic meters of wood are also extracted and sold to other households in the semi-urban areas per household per year. The wood used in the dry season, whether for household consumption or sale, is consistently lower than that used in the wet season in all the sites[7].

In general the results based on the slack[8]/surplus and the shadow prices[9] indicate that to a large extent, most of the constraints have been satisfied. The results are also consistent with the ranges of the coefficients on the right hand side of the constraint equations presented in Annex 1.

It may not be the case however that Malawi, in general, has excess capacity in resources to satisfy all the constraints in the model. Malawi is already at the edge in terms of resource endowment. The national average land holding size is 0.8 hectares and over 55% of the households have less than 1 hectare of land. Labour is also a constraint particularly for most crops other than maize and tobacco. However, other studies also argue that labour is not a constraint given that most people are willing to sell their labour even at wage rates far below the market rate (Zeller *et al*. 1996).

The argument that labour could be in surplus may be plausible given that agriculture is seasonal. Therefore, any slack labour has potential for employment in other off-season activities that could not be identified in the model like grazing, gardening, social work and even leisure.

5. SENSITIVITY ANALYSIS/POLICY EXPERIMENTS

A number of sensitivity analyses have been performed in order to find out the potential impact of both the endogenous and exogenous shocks as a result of policy changes within and outside the forestry sector. This is done to demonstrate the capacity of MIOMBOGP in creating alternative development scenarios based on changes in selected policy levers or instruments. In this way, the MIOMBOGP could be used as a planning tool by decision makers in demonstrating the potential impact of various decisions and policies and selecting the strategy that produces the most favourable outcome. It must be pointed out that the outcomes of the sensitivity analysis are dependent on the underlying assumptions in constructing the MIOMBOGP and the quality of the data used in generating the baseline results on which the analysis is based.

These analyses have been made in the context of the policy environment in Malawi. The country has been implementing economic reforms as a result of the adoption of the Structural Adjustment Program (SAP)[10] since the early 1980s. Due to the inter-linkage between the agricultural and forestry sectors, most of the policy reforms that have been implemented in the agricultural sector could have impacted the forestry sector. Also the policies that have been implemented in the forestry sector could have had some impact on the agricultural sector. As such most of the sensitivity analysis revolve around the agricultural or forestry policies.

The selected sensitivity analyses performed are presented in Table 10. Of particular importance within the forest sector, is gauging or evaluating the potential impact on the sector arising from fluctuations in the price of agricultural commodities for example due to weather or policies that influence crop production and markets. Also of interest to the forest sector is the potential impact on the sector due to changes in agricultural crop yields that could result from policies that influence agricultural technologies like use of improved seeds, pesticides and fertilizers or even mechanisation.

We also examined the potential impact of changes in household labour. Apart from land, labour is the only other resource the communities have, and in abundance. We note that household labour is mobile, with the youth emigrating from rural to urban areas in search of employment. Further, strict observation of labour laws would constrain availability of child labour, which is common in rural areas. Also diseases like HIV/AIDS and malaria constrain availability of labour (and other resources) by diverting healthy members of the household to attending the sick and funerals, as well as by making less or none of the labour of those affected by these diseases because of associated morbidity and eventual death.

Table 10. Description of the sensitivity analyses

Simulation No.	Scenario	Changes made to basic model
1	Increase in prices of major inputs and crop output	25% and 75% increase in seed and fertilizer prices; output price
2	Increase/decrease in yield of major crops	25% and 75% increase / decrease in yield of maize and tobacco
3	Changes in household labour supply	i) M, F, C labour and ability to hire ii) M, F, C labour and inability to hire iii) FHH, no male labour iv) No female labour v) No child labour
4	Increase/decrease in price of firewood	50% increase/decrease in price of firewood

Note: M= male; F= female; C= child; FHH= female headed household.

With respect to forest sector policies consideration was also given to policies that aim at arresting or curbing deforestation, for example through increases in prices of woodland products.

5.1 Potential impact of changes in crop input and output prices

(a) Changes in crop input prices

When crop input prices are increased by 25%, there is a less than 25% contraction in cropland hectarage, especially for tobacco, while for crops like maize, groundnuts and beans, the levels of production do not seem to respond to the increase in input prices. Being the main food security crops, this should not be very surprising since the households primarily devote their resources to the production of food crops and would therefore cut down on the production of non-food crops such as tobacco, when faced with escalating input prices. The model response would imply that food crops are fairly inelastic to changes in input prices most probably due to the risk-averse behaviour of smallholder farmers in the study sites and perhaps Malawi in general.

On the other hand, when crop input prices are reduced by 25%, there is a corresponding increase in production levels of all crops, especially for tobacco. However, as in the previous case the firewood consumption levels remain the same in all sites.

(b) Changes in crop output prices

When the selling price of maize and tobacco is increased by 25%, there is a corresponding marginal increase in consumption requirements especially for maize in the wet season. While it would be expected that an increase in price would reduce the demand for that commodity, it should be noted that at community level the extent to which this could conform depends on whether the people are net food buyers or sellers. Where communities are net food buyers, an increase in the farm-gate prices would mean an increase in the market prices for the same and this could reduce their demand for the same commodities. However, in the case of net food sellers, an increase in prices of cash crops and food commodities would act as an incentive for them to increase production and therefore income. This could increase their share of consumption since they have additional income for more food purchases. This scenario would apply to Dzalanyama which lies within the country's food basket.

The impact of an increase in the output prices was also reflected in the amount of crop that people were willing to sell. It was noted that when the selling price for all the crops was increased by 25%, the sales of maize, beans and groundnuts were realized while in the base run they were virtually zero. Higher output prices could provide an incentive to sell.

5.2 Potential impact of changes in the yield of major crops

(a) Potential impacts due to increase in yield

(i) On cropland

The land allocated to the various crops increased with a yield increase by 25%. As shown in the Table 11a, compared to the base the land allocated to maize, groundnuts, bean intercrop and tobacco increases consistently in all sites.

Table 11a. Impact of a 25% yield increase on maize and tobacco production

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	0.96	5.3	0.27	0.29	7.4
Chimaliro	0.76	0.84	10.5	0.2	0.25	25.0
Mdeka	0.35	0.42	20.0	0.09	0.13	44.4

However, households in Mdeka are more constrained with land (Table 2), their response to yield improvement in terms of cropland expansion is very modest even when yield increases were set at 75% (Table 11b). However, households in the other two sites put more land under crops with increased yields.

Table 11b. Impact of a 75% yield increase on maize and tobacco production

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	0.98	7.7	0.27	0.31	14.8
Chimaliro	0.76	0.87	14.5	0.2	0.28	40.0
Mdeka	0.35	0.44	25.7	0.09	0.14	55.6

With yield increases as low as 25% all land in Mdeka is put under crops while a small portion remains for Dzalanyama and Chimaliro, even with a 75% crop yield improvement. In all sites farmers do not cut down on the area under food crops, but allow a faster growth of the area under cash crops (tobacco in this case) so as to increase incomes. Rural incomes are low and most of the households live below the poverty line, so any incentive to increase their income would be welcome.

It would therefore appear that households in Mdeka would probably encroach on more land (or the woodlands), if it were available, to take advantage of crop yield increases, while those in Dzalanyama and Chimaliro do not appear to have exhausted their arable land and therefore do not pose immediate pressure on the surrounding woodlands.

(ii) On firewood demand

A 75% increase in yield of maize and tobacco could result into a relatively high response in terms of the decline in firewood extracted in both dry (D) and wet (W) seasons from the woodlands in all areas (Table 12).

Table 12. Impact of 75% increase in yield on firewood demand

Site	Base (m^3 per household)	CSFWD (m^3 per household)	% change	Base (m^3 per household)	CSFWW (m^3 per household)	% change
Dzalanyama	4.39	3.95	-10.0	3.29	3.04	-7.6
Chimaliro	5.48	4.45	-18.8	3.62	3.14	-13.3
Mdeka	2.8	1.95	-30.4	3.72	3.15	-15.3

However, proportionate declines are high for Mdeka and Chimaliro compared to Dzalanyama. The former two sites are more constrained by land and forest resources than Dzalanyama and would logically be more sensitive and responsive to policies that target these two natural resources. In fact the quantities of firewood demanded for sale would still remain high in Michiru even with a substantial increase in crop yield. This means that while there are indications that increases in agricultural yields have potential to relieve the pressure on the woodlands, for woodland rich areas like Dzalanyama the effect is unlikely to be great because households have the woodlands in relative abundance making the benefit from increased crop yield unlikely to change their firewood collection habits especially when markets for such products are small and firewood collection is mainly for household consumption.

(b) Potential impact of a decline in crop yield

(i) On cropland

A decrease in crop yield has potential to reduce the area put under crops (Table 13). The decrease in crop yield could be due to drought, low output prices and/or use of inadequate inputs like fertilizers.

Table13. Impact of 25% decrease in yield on production of maize and tobacco

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	0.84	-7.7	0.27	0.23	-14.8
Chimaliro	0.76	0.65	-14.5	0.2	0.18	-10.0
Mdeka	0.35	0.27	-22.9	0.09	0.04	-55.6

From Table 13 we see that the response to modest decline in crop yields is stronger in Mdeka and Chimaliro, areas more constrained by land than Dzalanyama. However, for Mdeka and Dzalanyama the reduction in cropland is relatively higher for tobacco, the cash crop, than for the food crops.

A 75% decrease in yield has a correspondingly substantial impact on the area allocated to the two crops. In all areas there is a substantial shift (up to 40%) of land to maize, since the decrease in land planted with tobacco is more than that of maize. As a food security precaution, risk-averse farmers would want to increase the amount of land under maize in order to offset the decline in yield.

(ii) On firewood sales

The loss of income from reduced crop area appears to be compensated by relatively higher increases in firewood sales and especially from Mdeka and Dzalanyama that made relatively big cuts on cash cropland (Table 14). These trends are even more pronounced when crop yields decline by 75%.

Table 14. Impact of 25% decrease in yield on firewood sales.

	Base (m^3 per household)	SGFWD (m^3 per household)	% change	Base (m^3 per household)	SGFWW (m^3 per household)	% change
Dzalanyama	0	1.2	-	0.18	0.52	188.9
Chimaliro	0	1.43	-	1.2	1.80	50.0
Mdeka	0.8	1.1	37.5	0.8	1.40	75.0

Firewood is one main sources of income for the households living close to the forest reserves, therefore changes in the yield of the key agricultural crops would influence the amount of firewood that could be extracted for sale. This is because in the absence of adequate income from agricultural production, households would most probably resort to forest income for their needs. It would appear that the impact would be more pronounced in the wet (W) season as compared to the dry (D) season when the crops would still be in the field and probably with insignificant or no crop storages from the dry season.

5.3 Potential impact of changes in household labour supply

(a) On crop production and trade

Rural households have two main resources, land and their own labour. The latter is increasingly constrained by education as children go to school (making child labour less available), the youth emigrate to urban areas in search of jobs, and diseases like malaria and HIV/AIDS. Such diseases constrain labour availability through sickness and/or death, and for the healthy through attending the sick and funerals. They also affect the allocation of household resources. All this potentially impact on the attainment of household goals.

For example, when there is no adult male labour in the household and it is not possible to hire such labour the results indicate a substantial cut in the production of tobacco while the production of the food crops increases moderately (Table 15). Women provide most of the labour for growing tobacco, however they mainly do that with the male counterparts. Tobacco marketing is an activity that is mainly in the domain of men and when adult male labour is absent in the household sales decline significantly in all sites (Table 16).

However lack of adult female labour in the household and with no possibility of hiring such labour not only affects production for tobacco, but also that of all the food crops. Mkandawire *et al.* (1990) and Diagne *et al.* (1995) report that women contribute over 70% of the labour in agricultural production in Malawi making female labour critical in agriculture.

Table 15. Impact of lack of adult male labour on crop production

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	1.04	14.3	0.27	0.14	-48.1
Chimaliro	0.76	0.85	11.8	0.20	0.12	-40.0
Mdeka	0.35	0.38	8.6	0.09	0.04	-55.6

Further, as shown in Tables 15 and 16, absence of adult male labour makes the family to increase production of food crops in all three sites. Trade in food crops also increases, except in Mdeka.

We experimented with making 30%, 50% and 70% of male and female adult labour available, a constraint that could be due to sicknesses, attending the sick, funerals, and/or occasional migration to the urban areas. In the case of crop production the tobacco area was reduced slightly (by less than 10%) when only 30% adult male labour was made available. However the reduction was substantial (by over 30%) when only 30% of adult female labour was made available. The reduction in crop production increased with decreased labour availability, but was more affected by constraint on adult female labour availability. This reinforces the observation by Mkandawire *et al.* (1990) that most of the rural farming is done by women.

However, the implications of labour constraints on attaining household goals and improving household welfare in general are very serious because the HIV/AIDS scourge

Table 16. Impact of lack of male labour on firewood collection

Site	Base (m^3 per household)	CSFWD (m^3 per household)	% change	Base (m^3 per household)	CSFWW (m^3 per household)	% change
Dzalanyama	4.39	4.41	0.5	3.29	3.31	0.6
Chimaliro	5.48	5.49	0.2	3.62	3.64	0.6
Mdeka	2.8	3.2	14.3	3.72	3.78	1.6

tends to reduce female labour supply more than that of males because women appear to be more infected than men and that women are the traditional caretakers of the sick.

(b) On firewood consumption and sale

Changes in either adult male or female labour supply do not appear to significantly affect consumption of firewood in both wet and dry seasons (Table 17). This is mostly due to the way firewood is used in the household, the same quantity is used for cooking meals when the full family is there or one or two members are missing. Further, children also participate extensively in firewood collection, cushioning the family from firewood shortages in case the mother is sick or absent. Therefore when there are fluctuations in the supply of household labour members of the households adjust their activities in ways that minimize adverse impact on firewood collection.

Table 17. Impact of lack of adult male labour on crop sales

Site	Base(kg)	SGTOB(kg)	% change	Base(kg)	SGBND(kg)	% change
Dzalanyama	181.96	39.54	-78.3	52.2	63.20	21.1
Chimaliro	185.89	45.67	-75.4	49.5	56.70	14.5
Mdeka	125.68	25.43	-79.8	0	0.00	0.0

However, when adult household labour is absent, the results indicate an increase in the amount of firewood that is extracted and sold. This is probably because absence of an adult male reduces household incomes and this compels the other members of the household to collect more firewood for sale in order to compensate for the income loss that arises primarily from reduced tobacco production and sale. This was noted to be more pronounced in the wet season with sales potentially increasing by 50%, 17% and 13% in Mdeka, Dzalanyama and Chimaliro respectively. Also households could increase production and sale of food crops.

When there is completely no adult labour in the household an infeasible solution is obtained. This is an indication of the total collapse of the activities of the household as defined in this model. When adult household labour availability is constrained to 30%, 50% and 70% due to reasons explained earlier, the results indicate a slight reduction on firewood collected for consumption if only 30% of the adult female labour were made available. A reduction in firewood sales begun if the adult male labour available dropped to below 70%. This could be attributed to the fact that firewood collection for domestic use is dominated by females while collection for sale is mainly done by males.

5.4 Potential impact of changes in price of firewood

(a) On firewood demand/consumption

It is often argued that one way for containing deforestation is to increase prices of forest products. In government-controlled forests, like the forest reserves in these three study sites, the prices can be regulated administratively as a way to implement a sectoral policy or strategy of this nature. This strategy was tested and the results (Table 18) indicate that there is a potential increase in the demand for firewood for sale when there is an increase in its price.

Table 18. Impact of change in the price of firewood on its demand

Site	Base (m^3 per household)	CSFWD (m^3 per household)	% change	Base (m^3 per household)	CSFWW (m^3 per household)	% change
Dzalanyama	0.0	1.4	-	0.18	0.48	166.7
Chimaliro	0.0	1.6	-	1.20	1.56	30.0
Mdeka	0.8	1.5	87.5	0.80	1.7	112.5

The result was expected because in open access forests the price signals an incentive for people to extract more firewood for the market. However, the response to price increase only starts when the increase is at least 50% of the prevailing price. This indicates that firewood demand and the requirement for land for forestry is less responsive to the changes in the prices of firewood. Actually when firewood price increases, the households that used to buy the commodity from others resort to own collection from the forests.

(b) On cropland area

For Dzalanyama and Chimaliro, increasing the price of firewood by 50% has potential to marginally reduce cropland area, as farmers decide to engage most of their labour in the more lucrative business of collection and selling firewood (Table 18). The impact appears to be high for Mdeka, where most households have traditionally relied on firewood sales for their livelihood.

Table 18. A 50% increase in firewood price: changes in cropland

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	0.9	-1.1	0.27	0.26	-3.7
Chimaliro	0.76	0.76	0.0	0.2	0.19	-5.0
Mdeka	0.35	0.32	-8.6	0.09	0.06	-33.3

On the other hand a 50% reduction in the price of firewood could slightly increase the scale of production, especially tobacco (Table 19). Again, this could be attributed to shifts in labour away from firewood collection and trade to tobacco production.

Table 19. A 50% decrease in firewood price: changes in cropland

Site	Base(ha)	PRMZGN(ha)	% change	Base(ha)	PRTOB(ha)	% change
Dzalanyama	0.91	0.91	0.0	0.27	0.28	3.7
Chimaliro	0.76	0.76	0.0	0.2	0.22	10.0
Mdeka	0.35	0.36	2.9	0.09	0.09	0.0

It should be noted that the magnitude of the changes would strongly depend on the relative prices in the agricultural sector. Thus, these results would only be plausible if we assume no change in agricultural input and output prices. Most households in these sites depend on both agricultural and woodland products not as substitutes but mainly as complementary products. There is a narrow range in which they can be substitutes, and this is especially in relation to excess that is marketed. Consequently the demand for firewood for sale is less responsive to some agricultural and forestry policies. The type and extent of the response would largely depend on whether a community is a net buyer or seller of firewood as well as the relative prices of the different products.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

The impact of the agricultural policy scenarios expressed through changes in output and input prices and technological improvements are manifested in increases in food consumption and selling requirements. Given that food security is the primary goal, it is unlikely that there could be any marked response in terms of required consumption levels. However, as shown in the sensitivity analyses, there is a marked impact on the levels of requirements for selling as a result of an increase in the output prices and yield improvements. The increase in production is reflected in the surplus commodities especially, maize and groundnuts which increase the storage requirements thereby necessitating the need to sell the surplus.

Increases in agricultural output through yield improvements could have substantial impact on crop production levels when the yield increases are in excess of 50%.

Firewood consumption and selling requirements increase as a result of the increase in firewood prices, more especially when the price increases are over 50%. This can only be the case in communities where people are net firewood sellers. Also it largely depends on the relative increase in the prices of firewood compared to agricultural prices. Otherwise communities that are net buyers of firewood would respond negatively to increases in prices of firewood. From the study, it would appear that the demand elasticity of the communities to firewood prices is very inelastic, implying that a marked response can only be triggered with very high increases in firewood prices.

The increase in output prices and yield improvements have potential to reduce cropland and therefore alleviate pressure on the woodlands. In so far as there is no increase in agricultural land requirements, which could trigger encroachment into forests, the results seem to support the hypothesis that incentives in agriculture, be they price or technology related, tend to reduce the likelihood of deforestation by shifting the pressure and dependence away from the forests to the more lucrative agricultural production.

These findings serve to highlight the type of policy responses that need to be critically examined in the light of their impact on the resources. The results from this research indicate that the main factors that seem to impact on resource use decisions include: prices of agricultural commodities, technological changes in agriculture, labour supply changes and prices of firewood and other energy sources.

Given the ever-existing conflict and complimentarity between agriculture and forestry in supporting human existence, the harmonization of these policies requires sound scientific knowledge. This modeling exercise has the potential of providing such knowledge which is very important in decisions management, use and conservation of the resources.

There are still a number of fundamental policies that need to be critically examined further. For example, there is need to assess the impact of the increases in the prices of alternative energy sources. In Malawi, the notable case would be the impact of the rapidly increasing prices of paraffin and electricity, considering that these are the major alternative sources of energy in the rural and urban sector, respectively. The impact of some forestry policies that encourage the development of alternative and more efficient energy technologies are examples of typical instruments whose impacts need to be examined as well.

Despite its potential robustness given the availability and reliability of the data, the MIOMBOGP has only one major weaknesses in that as a static model, it does not account for the dynamism that characterize resources use in the ideal world. However, it might be possible to project the values of the various variables into the future and run the model to correspond to those future points thus allowing for a possibility of tracing the changes in the variables of interest over time.

ENDNOTES

1. Both a household survey and a Participatory Rural Appraisal (PRA) exercise were undertaken in each of the sites namely Dzalanyama and Chimaliro in the central region and Mdeka in the Southern region. The PRAs provided some socio-economic description of the three sites and a separate PRA report was compiled.

2. Detailed description of the basics of the goal programming model including examples of relevant applications can be found in, but not limited to, Nhantumbo and Kowero (2001), Romero (1991), Romero and Rehman (1989), Rehman and Romero (1993), Mendoza and Sprouse (1989) Hazell and Norton (1986), Day (1963), McCarl (1992) and Yoon and Hwang (1995).

3. In terms of the constraint equations in the Malawi models, the actual data on the constraints is presented in Annex 1 (1A - 1D).

4. In reality farmers harvest and sell, and seldom store large enough quantities for long periods of time. They then buy the same products in small quantities from local markets on a regular basis especially during the post harvest season. It is therefore possible to have storages of small or insignificant quantities on a weekly or monthly basis and not for the whole season.

5. The assumed calving rate net of mortality for cattle is 45%, kidding rate for goats net of mortality is 300%, breeding rate for cows and goats are 40% and 75% respectively. A cattle unit is estimated at 450kg live-weight while that for goats is estimated at 50 kg live-weight.

6. It should be noted that while the forests are still relatively thick in Dzalanyama, mostly due to the fact that these areas are protected areas, the rate at which people are harvesting wood for various uses is quite high. In the long run, these areas could be degraded as is the case with

Mdeka. This could among other factors be exacerbated by increased resettlement of people in this area and expansion of agricultural estates that surround these areas. The increasing demand for wood resources in the urban areas, as result of the increase in the prices of conventional energy providing petroleum products, could trigger increased exploitation of the resource by both long term residents and new settlers. This is an area that needs to be given adequate attention by government, in view of balancing the community needs for energy and household income and the need to conserve the forests.

7. It is logical that firewood demand should be higher in the wet season because of the increasing uses compared to the dry season. In most areas, firewood is also used for heating during the lower temperatures experienced in the wet season. Another reason could be that the efficiency of wood is higher in the dry than wet season due to the high humidity levels in the wood during the wet season.

8. Slack variable refers to a variable that accounts for any unused, or idle amounts of a resource (Forgionne 1981).

9. Shadow price refers to the change in the objective value that results from a marginal (one-unit) change in the amount of a constraint (i.e. the value on the right hand side).

10. The Malawi government with financial and technical support from the World Bank and the International Monetary Fund (IMF) embarked on SAPs in 1981 in order to address both domestic and external economic imbalances. Following the economic crises that Malawi experienced in the late 1970s resulting from external shocks such as rising interest rates and fuel prices, droughts, regional political instability and deteriorating terms of trade, the government resorted to adopting the SAPs whose primary objectives included: (i) economic stabilization (ii) accelerating agricultural growth, (iii) diversifying the export base, (iv) increasing the efficiency of import substituting enterprises and parastatals, and (v) improving the mobilization and management of public resources.

The major goal of the SAPs were to provide incentives for stimulating production of tradable goods, for rationalizing government tax base and expenditure and for strengthening key sectors and institutions. So far more than seven Structural Adjustment Loan facilities have been adopted. i.e. SAL I (1981); SAL II (1984); SAL III (1986); ITPAC (1988); ASAC (1990); ASAP (1991); etc.

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ANNEX 1. TABLES OF SOME DATA FOR BUILDING THE MALAWI MODEL

1a. Average land holding (ha) by site

Crop	Dzalanyama	Chimaliro	Mdeka
Maize, beans, groundnuts intercrop	0.91	0.72	0.35
Tobacco	0.53	0.53	0.20
Average land holding	1.44	1.25	0.55

1b. Land distribution by site (%)

Land area (ha)	Dzalanyama	Chimaliro	Mdeka
< 0.5	13.9	8.0	32.0
0.5 – 1.0	31.8	37.0	38.0
>1.0 – 2.0	36.1	35.0	19.0
> 2.0	18.2	20.0	11.0

1c. Total man-days per site per season.

Category	Mdeka	Dzalanyama	Chimaliro
Adult males	1983.00	1872.00	1003.00
Adult females	356.00	744.00	459.00
Children	42.00	86.00	103.00
Total	2381.00	2702	1565

1d. Average number of livestock kept by household

	Mdeka	Chimaliro	Dzalanyama
Cattle	1.1	3.2	3.6
Goats	2.5	6.6	3.9
Chicken	15.7	8.5	9.8
Pigs	-	7.7	4.6
Ducks	6.3	4.1	3.6
Pigeons	5.1	9.1	6.0

ANNEX 2. VARIABLE DEFINITIONS AND UNITS OF MEASUREMENT

The definitions, activities and units of measurement of the variables that are presented in this report:

Variable	Unit of measurement	Definition/Activity
PRMZBNGN	Kg per hectare	Production of maize, beans and groundnuts in an intercrop
CSMZD	Kilograms	Consumption of maize in the dry season
CSMZW	Kilograms	Consumption of maize in the wet season
MZSD	Kilograms per hectare	Maize seed rate
CSBND	Kilograms	Consumption of beans in the dry season
BGBNW	Kilograms	Buying of beans in the wet season
BNSD	Kilograms per hectare	Bean seed rate
STGND	Kilograms	Storage of groundnuts in the dry season
CSGND	Kilograms	Consumption of groundnuts in the dry season
CSGNW	Kilograms	Consumption of groundnuts in the wet season
BGGNW	Kilograms	Buying of groundnuts in the wet season
GNSD	Kilograms per hectare	Groundnut seed rate
CSFWD	Cubic meters	Consumption of firewood in the dry season
CSFWW	Cubic meters	Consumption of firewood in the wet season
SGFWD	Cubic meters	Selling of firewood in the dry season
SGFWW	Cubic meters	Selling of firewood in the wet season
CSMSHW	Kilograms	Consumption of mushroom in the wet season
CASG	Number of herds	Selling of cattle
GTSG	Number of herds	Selling of goats
GRAZ	Hectares	Grazing area for livestock
CSBFD	Kilograms	Consumption of beef in the dry season
BGBFD	Kilograms	Buying of beef in the dry season
CSBFW	Kilograms	Consumption of beef in the wet season
CSGTD	Kilograms	Consumption of goat meat in the dry season
BGGTD	Kilograms	Buying of goat meat in the dry season
CSGTW	Kilograms	Consumption of goat meat in the wet season
BGGTW	Kilograms	Buying of goat meat in the wet season
FORES	Hectares	Forest area per household

19.

Linear and goal programming models for analysis of policy impacts on livelihoods in miombo woodlands of Mozambique

I. Nhantumbo, G. Mlay and G. Kowero

ABSTRACT

An analysis of potential impacts of selected sectoral and extra sectoral policies on miombo woodlands was conducted in the Mozambican districts of Dondo, Nhamatanda and Gondola-Manica. A Weighted Goal Programming model was developed that took into consideration household goals in the context of a set of activities and resources constraints on land, labour, food production, access to forest resources and others. Policy experiments were carried out through sensitivity analysis.

Results indicated that harvesting forest products was the main off-farm source of income and employment for the household. The non-availability of adult male or female labour in the household, due to sicknesses like those from HIV/AIDS, emigration or other reasons is catastrophic to the household. This also emphasizes the need to consider the HIV/AIDS pandemic in all rural socio-economic plans.

Further, moderate decrease in crop yield seriously constrained the achievement of household goals, indicating that these households could be very vulnerable to factors that reduce crop yield like drought, floods, pests and high prices of agricultural inputs; and with adverse consequences on conservation of the woodlands. Therefore, the solutions to problems such as deforestation do not rest within the forestry sector alone; rather, an integrated rural development planning holds more promise.

Key words: Policy impact, linear programming, goal programming, miombo woodlands, rural development, Mozambique.

1. INTRODUCTION

Miombo woodland is one of the most extensive dry forest vegetation types in Africa, occurring in seven countries in eastern, central and southern Africa; namely Angola, Malawi, Mozambique, Tanzania, Democratic Republic of Congo, Zambia and Zimbabwe

(White 1983). The woodlands are dominated by the legume family Caesalpiniaceae with the most important tree species being those of *Brachystygia sp.*, either alone or in association with *Julbernardia sp.*, and *Isoberlinia sp.* (Celander 1983; Lind and Morrison, 1974; White 1983).

Although no proper surveys have been carried out to determine the number of people who depend on the miombo woodlands, estimates as high as 100 million people have been made while others put direct and indirect support at 40 and 15 million respectively, in the rural and urban areas (Campbell, *et al*. 1996). Sustainable use of miombo woodlands can offer a long-term perspective for the direct and indirect users. However, current unsustainable agricultural practices such as use of fire for land clearing, inadequate fallow systems, overgrazing, and intensive harvesting of wood for firewood and construction material threaten the increasingly scarce resources. These activities are rapidly diminishing the environmental significance and ecological diversity of the miombo ecosystem. The economic consequences are obvious as the miombo woodlands are a source of food security, employment and income from the sale of wood and non-wood forest products.

In Mozambique there are three forest categories: protected, productive and multiple use areas. Most of the miombo woodlands fall under the latter category. In the first two categories, the primary managers are respectively the state and the private sector. On the other hand, in the multiple use areas, there is competition over resource between the communities that depend on this resource for their livelihood and a large number of small scale private sector operators that have simple licenses for harvesting wood products. Furthermore, there is high competition for different land uses such as relatively large-scale agriculture for cotton, sunflower, and cashew, as well as industrial roundwood harvesting.

The communities are the main producers of cash crops as well as being largely responsible for harvesting wood and non-wood products. However, they are less advantaged in terms of gains from these activities due to their low bargaining power with middlemen and final users of these products.

The relative importance of the miombo woodlands attracts many stakeholders. The government raises revenues from those harvesting products, besides its interest in conserving the woodlands. The private sector is interested in the woodlands for commercial products that they extract. Communities living inside and bordering the woodlands are interested in deriving their livelihoods. The woodlands are important to them as they provide self-employment as well as being sources of income, goods and services.

In Mozambique there exist resource-use conflicts among the different land uses and users of the miombo woodlands. Land use policies and practices have failed with respect to sustainable use and management of the woodlands. If these conflicts are not addressed immediately, they are likely to escalate, and in turn accelerate encroachment and degradation of the woodlands. The consequence of this will be food insecurity, environmental instability, and deterioration of the livelihood opportunities of miombo inhabitants.

The study reported in this paper was a modest attempt to contribute to the on-going debate on sustainable economic development of rural communities in developing countries, basing its case on the compatibility of environmental concerns with farmers' preferences in selected villages in the districts of Dondo, Nhamatanda, Gondola and Manica in Mozambique.

The study was undertaken from 1998 to 2002 and makes use of Weighted Goal Programming (WGP). A modeling framework was constructed where both technical and socio-economic goals were incorporated in order to deal with food security, forest product supplies and household incomes within an integrated land use context. In this way, the study analysed the compatibility of demands by various stakeholders on the woodlands with household goals on one hand and rural development goals on the other.

The paper is organized as follows: section 2 presents the background to the analytical tools; section 3 presents the main characteristics of the study sites and the typical household used for the analysis of the various policy scenarios; section 4 analyzes the main features of the analytical tool used in this study; section 5 summarizes the main WGP results including the impact on the household of a set of policy experiments. Finally, section 6 highlights the main findings and recommendations.

2. MULTIPLE CRITERIA DECISION MAKING TOOLS

One of the challenges in managing miombo woodlands is the sustainability of the various interventions both at the policy level and at land use sphere influenced by daily decisions made by the users. The decision environment appears to be mainly influenced by socio-economic factors and less so by environmental concerns or even efficiency in natural resource use.

The natural resources value is determined mostly by labour invested for their extraction. Royalties paid to the government still undervalue the resources and this contributes to making the selling price of various forest products very low. Therefore, it would be useful to develop analytical tools which can help explain the potential impacts of short-term goals vis-à-vis sustainable development.

Hermanides and Nijkamp (1998) present three building blocks for measuring and judging sustainability: indicators, normative reference values, and impact assessment methodology. These authors define indicators as numerical representations of observed and measurable phenomena. The normative reference values or critical threshold values are defined on the basis of the concept of "Environmental Utilization Space", i.e., the safe maximum and minimum levels that the ecosystem can absorb without being damaged. Examples of the normative reference values are enforcement of the allowable cut when harvesting wood products, and the frequency of fires which have positive impact on the generation of the ecosystem and its growth. Finally, impact assessment is done through ad hoc or structured methods. The latter includes quantitative techniques such as econometric or statistical models that seek to establish in a methodical form the effects of policy measures on pertinent policy variables. This is done by providing an objective set of criteria for analyzing the impact of policy on the farm household organization as well as on the miombo ecosystem. This is the approach pursued in this paper.

As explained earlier, the primary land uses, users of miombo woodlands, and conflicts of goals and priorities are endogenous to the decision environment. There are several approaches to reconcile conflicting demands on resources. Multicriteria decision analysis seeks compromise solutions for the various goals, hence it has potential application in the context of the miombo woodlands problem.

As indicated in Nhantumbo *et al.* (1997), Rehman and Romero (1993) define Goal Programming (GP) as one of the Multiple Criteria Decision Making (MCDM) tools that is based on the geometric definition of 'best' that is regarded as a model which operationalizes the Simonian approach of 'satisfaction' to the fulfillment of the decision makers' objectives. GP has two variants: Lexicographic Goal Programming (LGP) which is based on pre-emptive ordering of goals and priorities by the decision maker, and Weighted Goal Programming (WGP), based on a simultaneous consideration of goals and minimization of the sum of weighted undesired deviations from the targets. The sequential consideration of goals in lexicographic goal programming provides a high probability of the last goals becoming redundant. In this paper, WGP was chosen so that the goals of the different stakeholders could be considered jointly, thus avoiding giving preference to one goal to the detriment of the other.

However, WGP requires a large amount of data from the decision makers, and in this case mainly the households. Such data is used for determining the objectives, targets, weights, and priorities, in addition to estimating the technical coefficients of the decision variables. This is a particularly important limitation in developing countries where planning in subsistence farming is made difficult by lack of farm records and where lack of co-ordination between agriculture and forestry is likely to reduce the reliability of information provided by the decision makers. However, Rehman and Romero (1993) argue that WGP can be applied under such situations because sensitivity analysis can be used to generate information and reduce the amount of data needed from the decision maker. In fact, the method has been applied in Mozambique looking at impact of social forestry in a regional model (Nhantumbo *et al.* 2001).

The WGP model serves as a tool for enhancing planning by providing for the possibility to evaluate various options or scenarios through sensitivity analysis of variables of choice. This is the main thrust of developing these models in the three districts of central Mozambique: to provide alternative means for rural development planning.

3. SOCIO-ECONOMIC CHARACTERISTICS OF THE STUDY SITES

The study sites include the two central provinces of Manica and Sofala selected due to their richness in both the miombo woodlands, and the productive forests and protected areas. In addition, both are along the development corridor (Beira) creating opportunities for development as well as threats since the market for forest products (especially in the towns of Beira and Chimoio) is likely to increase. Further, Beira town is the second largest market for wood for energy and light construction. Manica is a supplier to this market even though at a relatively small scale. Chimoio however, just like any other town in Mozambique, consumes large amounts of firewood. This results from the low purchasing power of alternative sources of energy such as gas and electricity.

The major difference between the two provinces lies in the type of transportation means employed. In Manica there is predominance of use of bicycles. In Sofala, on the other hand, middlemen in the market channel use lorries, and appear to benefit more as demonstrated by a survey done during the study.

3.1 Nature of the households used in the modeling exercise

The household characteristics provide the context under which the results presented in the next section should be understood and discussed.

Table 1. Characteristics of the household

	Size of family		No. of years in the area	Years of education	Dependency ratio
	Male	Female			
Dondo	3	3	6.3	2.8	0.17
Nhamatanda	3	4	5.6	2.1	0.2
Gondola-Manica	3	3	12.3	3.4	0.22

Table 1 indicates that all the three sites have approximately the same size of family and almost a gender balance, except Nhamatanda. There are more children in the household, and this increases the dependency rate as the very young do not engage in agriculture, and if they do, their contribution would be relatively small. Much as Dondo and Gondola-Manica have the same household size, the latter had a higher number of dependants. The population is relatively young and the elderly do not appear as a significant dependant group in the household.

Another important feature of the households is their relative stability in the area, and this is illustrated by the number of years that they have stayed in the study sites. The inhabitants of Manica have been in the area even before the end of the country's civil war in 1992. On the other hand, those of Dondo and Nhamatanda could have experienced the severe effects of the civil war as reflected in their fairly recent resettlement in these two areas.

The scarcity of forest resources in Nhamatanda could also be an indication that this area might have been the main source of fuelwood and construction material for Beira town, even though the population in this area was very mobile. In fact, the people who temporarily resettled largely engaged themselves in harvesting the forest as a ready source of income because agriculture was not always the best strategy during the war. This was because they risked being expelled by soldiers from the area before the crops matured. The soldiers later harvested the crops.

As is the case in practically all rural communities in Mozambique, the adult literacy rate in the study sites was observed to be very low. This could potentially influence opportunities for the socio-economic development of the households.

3.2 Land acquisition

Open access to land still dominates the mode of land acquisition in all study sites. Despite the fact that traditional leadership and local government structures are informed on the intention of opening new land, or harvesting the forest, there was no indication that this is an institutionalized practice. Clearing the forest, inheriting or even purchasing land are the main forms of acquiring land for agriculture and residence. Purchasing land is an interesting feature since the Mozambican Land Law of 1997 does not recognize the existence of land markets, however reality on the ground seems to indicate the contrary. The Land Law opens an opportunity for community land delimitation and the issuing of a land use certificate. However, it was noted during the field surveys that the inhabitants in all sites had failed to take advantage of getting certificates for their land, largely because rural communities have partially or completely not been educated on this legislation. This is compounded by the absence of external facilitators who could assist those who are aware of the legislation to go through the required procedures for acquiring land titles.

3.3 Economic activities

Agriculture, sale of forest products, and some livestock rearing were observed as the main activities undertaken in the three sites. Charcoal was the main forest product that provided employment and income to the households. As far as agriculture is concerned, all sites produce maize and sorghum. However, rice production was only observed in Dondo, while Gondola-Manica was the only study area that produced beans. The absence of beans in the other two study sites raises concerns on the sufficiency of protein foods in the households. The cropping systems include mono-cropping (maize or rice) and mixed cropping.

3.4 The household goals

Multiobjective programming is based on the analysis of tradeoffs amongst different goals (objective plus the target) set by the decision maker, in this case the household. The interviewees in the three sites articulated the household objectives and priorities (Table 2).

Table 2. Household goals (percentage of households interviewed)

Goal	Study site			Priority
	Dondo	Nhamatanda	Gondola-Manica	
Food security	83	73	77	First
Higher income	70	71	67	Second
Environmental protection	73	93	81	Third

However, the targets had to be derived by the researchers. For example, the food security target was derived using the standard FAO nutrition requirements for people of different gender and age. This, together with the size and composition of the household, determined the minimum household nutritional requirements. The income target was determined through linear programming (LP), which allows the analysis of the farm organization and resource constraints to derive the maximum return. Finally, the environmental protection target can be interpreted in various ways, but taking into account that the main environmental concern in the area is due to forest exploitation. First, one could set the exploitation of the forest at allowable cut level. The second option would be to enforce the payment of fees or royalties to achieve some desirable level of harvest. The royalty approach was employed because it was easier to get data. In order to use the allowable cut approach one would require data on the inventory of the forest and growth rate of the various tree species, information that was not available.

In all sites, the household activities and farm organization are managed in ways that seek first to satisfy the family food requirements through allocation of resources (land and labor) to crop production. This is what one would expect from any rural household in Mozambique and elsewhere in Southern Africa.

The bigger the experience with forest resource scarcity, the more sensitive people tend to be towards conservation of the environment as a goal. The decreasing number of households stating this as a goal illustrated such behavior; being highest for Nhamatanda, less for Gondola-Manica and least in Dondo.

4. MAIN FEATURES OF THE MODEL

A generalized weighted goal programming methodology of relevance to the miombo woodlands has been developed by Nhantumbo and Kowero (2001) and the model described in this paper is developed along the same lines. Therefore this section will not dwell on the details of the definition and mathematical expression of constraints, activities, and goals. However, the matrix in Table 3 illustrates the general structure of the model, while Annex 1 presents details on one of the models employed in this study. The other models were structured in a similar way.

Table 3. Planning matrix

	Agricultural activities					Forestry activities		Labor			Sign	RHS
	P	S	B	C	S	P	S	M	F	Ch		
Objective	Minimize positive and negative deviations from the weighted goals											
Land	d											X ha
Labor	d							s	s	s	<=	0
Crop production	s	d	s	d	d						<=	0
Forestry						s	d	d	d	d	<=	0
Consumption	s							d	d	d	<=	0
Food security goal	Normalized supply							Normalized demand			=	100
Income goal	Normalized supply and demand										=	100

P=Production, S=Selling, B=Buying, C=Consumption, M=men, F=women, Ch= children, d=demand, s=supply, RHS=Right hand side.

It is important to highlight some of the decision variables, constraints, and the objective function. As mentioned earlier the household activities revolve around agriculture, forest products, and livestock. However, the latter was excluded from the model since there were no large numbers of livestock, such as goats and cattle, that could take significant labour away from other activities for grazing and that would also produce significant quantities of milk and meat for consumption or sale for cash. Therefore, the model included only activities revolving around agriculture and forest products. The decision variables for each included production, consumption, selling, buying (to supplement deficits), storing food produce from one season to the other, and labor allocation for the different activities.

The main constraints included land for the different crops and cropping systems. The yield for each crop was reconciled with the decision variables for selling and buying. The allocation of produced food (in kilograms) was tied to the energy and protein supply by each of the crop types and the total demand for the same from the household. Another dimension was that the dietary mix as defined by the eating habits was included in the model so that not only the more nutritious products could be consumed but also the habits defined by the culture and level of wellbeing could also be reflected. Labor demand for each activity was limited by the maximum labour available and capacity for hiring it. The constraints were based on a simple principle; that is, the resource demand should not exceed the supply.

The models were run as LP and GP. In the first case, the problem aimed at maximizing the total gross margins according to the set of activities undertaken and resource constraints. This was a single maximization problem. However, as stated earlier the objective of the study was to evaluate options or opportunities for satisfying the different household goals taking into account the different priorities accorded to them (Table 2). Hence the use of WGP was an imperative. Nevertheless, the two methods were complementary in this exercise with LP employed to determine the minimum target for the income goal.

5. MODEL RESULTS

5.1 Linear programming results

Based on the data collected in 1999/2000, the maximum income that the household was likely to earn is shown in the Table 4.

Table 4. Income for the typical household (US$/year)

Site	Gross margin	Disposable income per capita
Dondo	264	44
Nhamatanda	243	40
Gondola-Manica	143	27

It is evident that the level of poverty in the study sites is very high considering that the target household incomes are lower than the average per capita GDP of US$280 for Mozambique. The household disposable incomes are even more distressing, despite the fact that they are net of food requirements since some constraints are built into the model to ensure that the household gives priority to its consumption before selling any food. Even though the per capita income is a distorted measure of distribution of wealth in the country, the reality shows that people in some parts of the country live far below the poverty line. Mozambique has 70% of its people in absolute poverty and the two provinces included in this study are among the poorest areas. The study results demonstrate the severity of poverty in the study sites. This underlines the need to correct the imbalances in resources/wealth distribution not only in the study sites but also throughout the country.

The disposable income when compared with the total land available for agriculture in the three sites (Table 5) on one hand, and the opportunity for harvesting forest resources on the other, would indicate that the forest is a potentially important source of cash for the rural family. Therefore, any restrictions in form of enforcement of allowable cut or introduction of fees is likely to take the households to lower levels of income than the current. This would be contrary to the government policy of poverty reduction. However, the tradeoff in the medium and long term is that the economic basis for the household could be lost as a result of depletion of the natural forest resources. This is the dilemma that the policy maker will have to face in devising measures to sustain the natural forest resources while at the same time alleviating rural poverty using the same resources.

In addition, the results indicate that in Gondola-Manica the preference was for intercropping, which is good in terms of replenishment of the soil fertility through leguminous crops. However, it could in fact be responsible for the relatively low production of each of the crops compared to monocropping, making the produce primarily for consumption with little or no marketable surplus.

Table 5. Land allocation (ha) in the LP model

Crop	Study site		
	Dondo	Nhamatanda	Gondola-Manica
Maize	0.78	0.9	-
Rice	0.64	-	-
Maize & sorghum	0.58	1.7	1.64
Maize & beans	-	-	0.89
Total agricultural cropland	2	2.6	3.5
Forest area harvested	1.71	0.89	0.61

The model provides the shadow prices of key resources such as land and labour (Table 6). It is apparent from the high shadow prices that land is a limited or scarce resource in Dondo and Nhamatanda. The typical household would increase the total gross margin if it expanded the current land for agriculture marginally, i.e., by a hectare. However, this would clearly not be the best option for Gondola-Manica where agricultural intensification would perhaps be a better option for improving productivity and eventually the well being of the household.

The analysis of labor demonstrates that this is also a critical production factor, especially in Gondola-Manica where US$545 could be gained if an extra adult labor (one manday) could be brought into the household at a price of US$2 (i.e. the shadow price of labour in this site).

Table 6. Shadow price of land and labor (US$)

Site	Land (ha)	Labour (mandays)	Rise in household income by one additional adult
Dondo	102	1.11	288
Nhamatanda	93	0.83	168
Gondola-Manica	0	2	545

While land could be limiting in Dondo and Nhamatanda, labor availability would be decisive in Gondola-Manica.

The level of sales shows further evidence of the relevance of the woodlands as a source of income particularly through making and selling charcoal, with as much as 12.5 tones sold per household in Dondo in a year (Table 7). Gondola-Manica households appear to trade more in agricultural produce than those in Dondo and Nhamatanda, though the total sales revenue were meager due to the low prices of these products. Meeting food requirements was the most important objective of production. Table 7 also indicates the level of consumption necessary to meet the FAO nutritional standards.

Table 7. Crop utilization (kg/season)

Site	Crops	Selling		Buying		Consumption		Storage
		Dry	Wet	Dry	Wet	Dry	Wet	Dry to wet
Dondo	Maize	0	98	0	0	472	470	698
	Rice	0	0	0	0	151	151	186
	Sorghum	92	0	0	0	38	38	57
	Charcoal	2500	10 000					
Nhamatanda	Maize	132	0	0	692	648	653	0
	Sorghum	0	0	0	0	142	138	178
	Charcoal	2250	4750	-	-	-	-	-
Gondola- Manica	Maize	619	0	0	0	500	505	634
	Sorghum	92	0	0	0	158	154	193
	Beans	0	48	0	0	26	25	78
	Charcoal	1500	2000					

These results demonstrate what would be the main farm organization if the household were to pursue an income maximization objective. However, as stated earlier, the households are rarely driven by only one objective; they seek a compromise solution between various goals. The following section presents the results of a weighted goal programming model that harmonized the attainment of the three goals on these three sites.

5.2 Weighted Goal Programming results

5.2.1 Base run results

The Weighted Goal Programming model is based on information from the decision maker on the objectives, targets, and priorities to allow calculation of different weights and coefficients. These are then used to evaluate the farm organization and especially how the goals could be satisfied given the farm constraints and a range of activities.

Table 8. shows the comparative results of the three sites.

Table 8. Achievement of goals

Sites	N_1	P_1	N_2	P_2
Dondo	0	10.6	0	0
Nhamatanda	0	2.3	0.2	0
Manica-Gondola	0	3.15	0	0

NB: N_1 and P_1 are negative and positive deviations from the food security goal while N_2 and P_2 are the respective deviations from the income goal.

While the income goal is exactly satisfied in both Dondo and Gondola-Manica (N_2 and P_2 are both zero), in Nhamatanda this is slightly underachieved. In all the three sites there is an overachievement of the food security goal. This means that the households strive to satisfy the minimum food requirements with their production, even though income for other needs is limited. However, there is also some indication that not always the households take such precaution preferring to sell the produce during the harvesting (dry) season and purchase food in the wet season. This producer behavior is responsible for seasonal famine. Besides the need for immediate cash, it was observed that poor storage in the study sites contributes to that farmer's decision.

Table 9 shows that in looking for a compromise solution between the goals of the typical household, there is a change in allocation of land to different crops compared to the maximization situation in Table 5.

Table 9. Land allocation (ha) in the goal programming model

Crop	Study site		
	Dondo	Nhamatanda	Gondola-Manica
Maize	1.3	0.9	-
Rice	0.34	-	-
Maize & sorghum	0.36	1.7	1.64
Maize & beans	-	-	0.89
Total agricultural cropland	2	2.6	3.5
Forest area harvested	2.2	0.93	0.61

In addition, as far as utilization of crops is concerned the consumption does not vary significantly, except in the case of Nhamatanda where less maize is consumed in the wet season (result of higher level of sales in the dry season), hence the need for compensation with sorghum. This apparent stability of the solution results from the fact that restrictions on the energy and protein requirements have been incorporated in the two models.

With respect to use of forest resources the Dondo households will harvest two and three times the forest area that will be harvested by households in Nhamatanda and Gondola-Manica respectively. This will result in the production, in Dondo, of two and four times more charcoal as will be produced in Nhamatanda and Manica respectively

Table 10. Crop utilization (kg/season) for the goal programming model

Site	Crops	Selling		Buying		Consumption		Storage
		Dry	Wet	Dry	Wet	Dry	Wet	Dry to wet
Dondo	Maize	0	0	0	0	472	469	589
	Rice	0	0	128	0	151	151	157
	Sorghum	25	0	0	0	38	38	52
	Charcoal	2500	10 000					
Nhamatanda	Maize	948	0	0	692	648	574	728
	Sorghum	0	0	0	0	142	220	279
	Charcoal	2250	4750	-	-	-	-	-
Gondola-Manica	Maize	633	0	0	12	500	505	619
	Sorghum	92	0	0	0	158	154	193
	Beans	0	48	0	0	26	25	78
	Charcoal	1500	2000					

(table 10). Like in the LP solution, households in Dondo will remain more forest dependent as compared to those in the other two sites.

5.2.2 Policy experiments/sensitivity analysis

Sensitivity analysis enables one to develop scenarios to guide policy analysis and choice. The analysis illustrates how much the current farm organization may be positively or negatively affected by policies and other external factors to the typical household. We evaluated the potential impacts of macroeconomic and sectoral policies in the following areas that appeared to be relevant to the study areas: labour availability, technological change in agriculture, trade in agricultural products, and forest royalties. This choice was based on literature, questionnaire interviews, reconnaissance surveys and participatory rural appraisal (PRA).

The objective of creating scenarios through sensitivity analysis is to provide the decision maker with information and a range of options to guide policy implementation by gauging potential effects on the household and its forest resources. The yardstick for analysis of the effectiveness of government policy would in this case be the poverty reduction through improvement of household incomes, food security and sustainable supply of forest products.

(a) Labour availability

Health related problems, especially those associated with malaria and HIV/AIDS, affect labour supply for various activities, generally constraining the ability of the family to explore a wide range of economic opportunities for generation of household income and subsequent improvement of the living standard. Labour supply could be affected by sickness, attending the sick, death, and attending funerals. The latter is especially important for the rest of the community who have to show solidarity with the family of the diseased, in fact farming is not done for two to three days according to the local customs. This implies that the frequency of death will severely affect the economy of the household and that of the community as a whole.

In addition, strict labour laws on child labour can affect labour supply. Nevertheless these are not enforced in Mozambique and particularly in the study sites where children either go to school after undertaking some farming tasks or even drop out of school to help with farming. Emigration of the rural youth to urban centers in search of jobs also reduces household labour. Further, immigration into the household of relatives retrenched from jobs in urban areas increases household labour.

In Dondo the results indicate that when there was no adult male labour in the household the solution was infeasible, unless there was a possibility of hiring male labour. As Table 11 shows there are negative deviations in both food security and income goals. In the latter case the shortage of cash is more dramatic if the female labour is absent as it affects the crop production. Forest for charcoal and this could cause even greater deforestation that, depending on amount of labour hired, could lead to charcoal production over an area of 12 ha per annum for the typical household. Not all trees in a given area are used for producing charcoal, hence the possibility of making a choice over such an extented area, if there are no restrictions on forest access.

When the household had no adult female labour, even when some could be substituted for by the available child labour, the result was a complete disruption of the household production system. This means that the household has to hire adult female labour, or the man should change his activities and allocate more labour into food production or increase income from harvesting and sale of forest products in order to purchase food to maintain the food security of the household. Further, land is allocated only for pure maize and intercropping of maize and sorghum in respectively 0.24 and 0.22 ha which is far less use of the land available. This is the situation when a female adult is absent, probably due to death. On the contrary, when there is no adult male in the family the land cultivated is slightly higher, being respectively 0.78 and 0.21. In both cases, the solution is infeasible and rice is not cultivated possibly because labour for the crop is not available given that rice cultivation is labour intensive.

Table 11. Achievement of goals given changes in labour supply (Dondo)

Labour scenarios	N_1	P_1	N_2	P_2
No adult male and no hiring	10	0	91	0
No adult female and no hiring	10	0	185	0

The change in labour availability also changes dietary habits (Table 12). For example, when an adult female is absent in the family, there is less consumption of maize, and rice then becomes an important source of energy. In total the typical family would acquire (purchase) 800 kg of rice per year for consumption.

The situation in Nhamatanda and Manica-Gondola was also dramatic since there was insufficient surplus adult female labour to undertake the male activities when the model was run without adult male labour. When the model was run without adult female labour the results indicated that there was no surplus male labour to carry out adult female activities.

The implication of these two scenarios is that labour substitution within the households in these sites appear to be difficult especially in extreme situations when a household looses an adult male or female. Even when substitution was possible through labour hired into the household, it appeared not to be allocated primarily to maize production (the staple food) thus creating an infeasible solution.

Table 12. Crop utilization (kg/season) (Dondo)

	Crops	Selling		Buying		Consumption		Storage
		Dry	Wet	Dry	Wet	Dry	Wet	dry to wet
Base	Maize	0	-	0	0	472	470	589
	Rice	0	0	128	0	151	151	157
	Sorghum	25	0	0	0	38	38	52
No man and no hiring	Maize	0	0	0	0	427	358	443
	Rice	0	0	231	0	115	115	116
	Sorghum	0	0	0	0	29	39	38
No woman and no hiring	Maize	0	0	0	0	175	175	216
	Rice	0	0	800	0	462	335	338
	Sorghum	0	0	0	0	31	31	41

The main finding is that absence of an adult member of the family (either man or woman) adversely affects the ability of the household to meet its food requirements and satisfy its income goal. This also results into putting less land under crops, and therefore there will be less pressure on the forests if this loss cannot be compensated for through labour hiring into the household.

(b) Technological changes and natural disasters

Technological changes in agriculture can increase crop yields (through improved seed, efficiency in use of labour, etc.) and reduce crop losses through improved harvesting methods and better crop storage facilities. Increase in crop production and productivity is one of the government strategies for national socio-economic development highlighted in both the poverty reduction strategy programme (PRSP) and the Agricultural Sector Investment Program (PROAGRI). However, observations in the field indicate that there are no viable extension services to supply subsidized inputs such as improved seed, fertilizers and even equipment. Therefore, the changes assumed here are based on the household's own efforts to improve production.

Also, in relation to crop production we evaluated the effect of natural calamities, especially their potential impact on household welfare. Data was collected just after a drought and the interviewees reported low yields as a result; however during that same year (2000) the reverse happened – excessive rains and massive floods. Such effects are simulated through estimated decreases in crop production.

Improvements in crop yields simulated at 25% or 50% would appear to have little impact on the level of deviation from the goals. This was due to the fact that there was an internal land reallocation that maintained the base solution (Table 13). However, when there was a modest decrease in yields by 25%, the impact was significant with the negative deviation of income (N_2) ranging from 37% for Nhamatanda to an infeasible solution in Gondola-Manica. This could be explained by the fact that the farm performance was lower in Gondola-Manica making household livelihood strategies more sensitive or vulnerable (table 10).

However, as compared with the base results in Table 9, cropland in Dondo declined slightly from 2 to 1.9 and 1.59 hectares with crop productivity increase. The implication is that productivity increase can reduce cropland area and therefore deforestation in the area. However, it has been observed that increased crop productivity has indeterminate effects on forest resources. For example, Katila (1995) argues that marginal productivity of land can encourage deforestation while Jones and O'Neill (1995) reported that increased farm productivity was associated with less forest clearing in the Brazilian Amazon. Also Godoy *et al.* (1997) report that in Honduras indigenous farmers with higher rice yields cleared less forest each year. In the case of Dondo, the forest area to be cleared when crop productivity was increased by 25% remained unchanged. However, when crop yield was increased by 50% cropland area declined while forest area to be cleared increased. The implication is that since these are subsistence farmers, they will get their food from less cropland but will increase forest harvesting for household income because prices of forest products are relatively better than those from agricultural crops. So a crop yield increase that occurs in areas with low crop output prices might not reduce deforestation, especially when the prices of forest products are relatively better.

Table 13. Land allocation (ha) due to yield increase in Dondo

Crop	Yield increase (%)	
	25%	50%
Maize	1.22	1.07
Rice	0.34	0.34
Maize & sorghum	0.43	0.18
Maize & beans	-	-
Total agricultural cropland	1.9	1. 59
Forest area harvested	2.2	5.22

In addition, field observations indicated a precarious storage system where crops are lost due to a variety of plagues. When crop storage loss was estimated at 5% there was no significant change in the base solution, however when crop losses were increased by 15% a moderate reduction in household income, ranging from 5 to 6%, was observed.

The results demonstrate that extension services that result into increases in crop yields and reduction in crop storage losses would be beneficial to the local communities. However, this assumes that these communities have the means to purchase seeds and other inputs. PROAGRI program contemplates both research on the appropriate technologies and extension services that will facilitate the achievement of these aspirations.

(c) Trade in agricultural products

Trade in agricultural products was evaluated. However, the conduct and outcome of trade depend on a number of factors ranging from the quality of the produce to availability of adequate road infrastructure and transportation means to local and distant markets. Access to distant markets was minimal in the three sites.

Crop price increases were expected to augment the positive deviation of the income goal (P_2). This was not the case as shown in Table 14. We have used results from Dondo to illustrate this.

Table 14. Achievement of goals with output price increases in Dondo

Sites	Price increase	N_1	P_1	N_2	P_2
Dondo	25%	0	0	10.6	0
	50%	10	0	10.6	0

Land allocation to crops responds marginally to the change in the prices as shown in Table 15. Also the forest area to be harvested remains relatively unchanged.

Table 15. Land allocations (ha) with price increase in Dondo

Crop	Price increase	
	25%	50%
Maize	0.92	0.9
Rice	0.34	0.34
Maize & sorghum	0.28	0.3
Maize & beans	-	-
Total agricultural cropland	1.54	1. 54
Forest area harvested	2.4	2.41

However, with an output price increase of 25 and 50% there was no change in consumption patterns in all the three sites. Table 16 illustrates the situation for Dondo. Crop prices were observed to be very low and minimally affected sales volumes.

Table 16. Crop utilization (kg/season) in Dondo

	Crops	Selling		Buying		Consumption		Storage
		Dry	Wet	Dry	Wet	Dry	Wet	Dry to wet
Base	Maize	0	0	0	0	472	470	589
	Rice	0	0	128	0	151	151	157
	Sorghum	25	0	0	0	38	38	52
25% yield increase	Maize	0	0	0	0	472	470	579
	Rice	0	0	148	0	151	151	178
	Sorghum	0	0	0	0	38	38	50
50% yield increase	Maize	0	0	0	0	472	470	579
	Rice	0	0	127	0	151	151	156
	Sorghum	6.9	0	0	0	38	38	51

The implication is that with increase in output prices where market infrastructure is poor, as is the case in these sites, food and income needs will be met from less cropland (Table 15). The small marketable surplus does not appreciably change traded volumes in the small local markets. Further, it is common practice that the family will consume the crops that have lower output prices and sell the rest. Such action could affect the satisfaction of dietary requirements and consequently the food security. In addition, this also implies that increasing the price alone for the basic products might not be a sufficient policy measure to improve the household livelihood, but introduction of other cash crops will be required to diminish the risk of malnutrition due to dietary imbalances.

(d) Forest fees

One of the ways the Government of Mozambique could arrest deforestation is to make forest products expensive. Introducing and enforcing fees on roundwood used for making charcoal can do this. However, it is also interesting to evaluate a situation in which fees on forest products are imposed with the possibility of agricultural land expansion offsetting the loss in benefits/income from forest harvesting.

(i) Imposition of forest fees for producers

The current fees for harvesting wood for charcoal are very small, only US$ 0.192 per cubic meter. This compares unfavourably with what it takes to raise the forest to maturity. An upward revision of such fees is therefore desirable, but can the rural households afford to pay such fees? We use the results from Dondo (Table 17) to illustrate the answer.

Table 17. Effect of forest fees in the household goals in Dondo

Fees	N_1	P_1	N_2	P_2
Enforcement*	0	10.6	5.2	0
Increase 10%	0	10.6	5.8	0
Increase 50%	0	10.6	5.9	0
Increase 100%	0	10.6	11	0

*Currently the producer (typical household) does not pay any royalties for harvesting forest products, if such situation was changed, that is the household pays current fees, then the impact on the goals is shown in the first row.

The results demonstrate that the introduction of fees will have a negative effect on the farm income by reducing it by 5.2, 3.3 and 0.14% for respectively Dondo, Nhamatanda and Gondola Manica. The negative effect is higher in Dondo (Table 17) where the household economy relies significantly on sale of forest products. Such dependency decreases progressively as we move to Gondola-Manica where the forest has already been depleted, making the households rely more on agriculture and other activities. Assuming that the fee undervalues the forest resources, its doubling can penalize households in Dondo and Gondola-Manica by reducing by as much as 11% and 0.41% of their incomes respectively.

Another remarkable finding is that despite the proposed increase in fees, the model indicated that households would not be deterred from continuing to harvest the same volume as before. There was also no change in agricultural land allocation patterns. This result is indicative of the few livelihood support options available to households in these areas. Men are supposed to be employed in income generating activities while women usually engage in production of food for consumption and other reproductive obligations.

(ii) Imposition of forest fees and relaxation of constraint on land
In Nhamatanda and Gondola-Manica labour has been demonstrated as the decisive factor for expanding farm area. With additional labour supply in these two sites cropland area will expand, for example, through shifting cultivation where this is possible, or expansion of the household agricultural land in the same areas (if fallow land is available). When the model was simulated with an imposition of fees on forest products, but with a relaxation of the land constraint, the results for Dondo indicated that more land would be allocated to rice production to compensate for loss in forest based revenues. The driver of such behaviour is the high price of rice relative to that of other agricultural and forest products. Nevertheless, further field surveys are required to establish the availability of land suitable for rice production; otherwise, this solution will be unrealistic.

6. CONCLUDING REMARKS

6.1 On methodological issues

(a) The data used to develop the model varied significantly in terms of its accuracy depending on the level of literacy of the respondent and also on accuracy in measuring some parameters like crop yields and labour allocation. Even the selling and buying prices varied.

(b) It was clear from the early stage of sampling that it would be difficult to obtain objective and quantified data for elicitation of targets for the goals stated by the decision makers. Therefore, the approach was to use available technical information to translate the concept of food security into a measurable target, such as the minimum calorific requirement, and use LP model to establish the maximum income that the household could derive from its activities given the resource constraints. The environmental goal was difficult to formulate so a proxy was used. The imposition of forest fees was viewed as one way to regulate harvesting, and through such regulation one could implicitly influence deforestation as well as protect the environment. However, the results indicated that this was not an effective way of regulating woodland harvesting. This means that effective control of deforestation would have to include measures other than those prescribed by the forest policy alone. A better proxy could have been the allowable cut but this pre-supposes the availability of inventory data and information on the growth of all the tree species, both of which were not available.

6.2 On results

(a) The use and management of forest resources cannot be seen in isolation of the rest of economic opportunities in the household such as agriculture, fishing, brewing beer, livestock rearing, and others. These contributions were also investigated and the results indicated that agriculture and forest harvesting are the main sources of livelihoods for the communities in the three sites.

(b) Harvesting forest products was observed to be the most profitable off-farm activity. Imposition of fees on forest products that households harvested, expansion of agricultural land, and increase in crop output prices cannot, in isolation, change the current pattern of the household economy in the three sites. Provision of extension services and inputs for improved agricultural production will complement efforts in regulating harvesting of the forest and materialize in a significant impact on household livelihoods and the forest condition. This underlines the relevance of an integrated development approach for rural areas.

(c) The challenge of diseases like malaria and HIV-AIDS on household economy were demonstrated and the results were dramatic. In short any socio-economic policies that do not address this issue are likely to fail because scarcity of labour will hamper their implementation.

(d) The current model gives a static snap shot of the policy impact on the household. In other words, the model is not dynamic. Despite this limitation the potentialities of the model have been illustrated and it is up to decision and policy makers to decide whether this is a useful planning instrument. A dynamic model could be constructed through recursive or multiperiod programming in which the results for one year would feed into the following year. This would be possible if forest planning was well organized and data collection were available. There is need for a more systematic collection of information to establish trends for a dynamic model. Otherwise, the current framework can be used to simulate the impact of few crucial policies on an annual basis, hence giving a short-term indication of the likely outcomes and allow for incorporation of new strategies. Since central government planning is done during the middle of the year (under PROAGRI), it is therefore possible to experiment with this approach. This will strengthen the current practice in which the national agricultural programme, PROAGRI, is implemented by provincial administrations that have to draw plans for subsequent years without first analyzing the likely impact or performance in the preceding years. This makes planning a partial/incomplete exercise.

(e) The discussions emanating from the demonstration of the models and their results to various fora confirmed that the model results concurred with what other people, i.e. the audience, considered the likely behaviour in the study sites. However, some wanted to see an extension of the model to include non-timber forest products (NTFPs) since these products play an important role in both food security and household incomes. The researchers observed in the field that data for this component could not be fully obtained through a spot survey, but there was need for continuous observation during the different seasons to gauge objectively (and quantify) the role of NTFPs in the household economy. Despite the efforts made by researchers to collect data on NTFPs, the information collected was insufficient and of poor quality and therefore not included in the current model.

(f) The model can be scaled up by extending it to the provincial administrative level, making it a regional or provincial model that incorporates the various activities in each of forest types or agro-ecological zones and link the supply from each of the zones to the main consumer market. This has been tested in Maputo province of Mozambique (Nhantumbo *et al.* 2001) as a more comprehensive planning instrument and at a higher level.

(g) Finally, GIS techniques can provide more illustrative results that are simple to understand and interpret by both the decision maker at farm level and the policy maker. This will bring in another dimension of programming which is fundamental, the interaction with the main actors or interested parties. This would be particularly useful if planning were at provincial or regional level.

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ANNEX 1. A WEIGHTED GOAL PROGRAMMING MODEL FOR ONE OF THE SITES

LINGO software was used.

! The Objective function is to maximise the total gross margin in a Linear Programming Model,;

!In the Goal Programming, however, the farmers look for a compromise solution between food security and income generation, the respective weights are 0.67 and 0.33 and are normalized;

!The objective of the farmers is to simultaneously minimize negative deviations from the food security and income goals;

[Objective] Min= 0.016*n1 + 0.121*n2;

!Land Constraints;
!GrRc is the amount of land allocated to rice;
!GrMz is the amount of land allocated to maize:
!GrMzSgh is the amount of land allocated to growing a mixed (inter) crop of maize and sorghum;

[LandT]GrRc + GrMz + GrMzSgh <= 2;
[LandRc]GrRc <= 0.34;
[LandMz]GrMz >= 0.78;
[LandMzSgh]GrMzSgh <= 0.88;

!Production and utilization;
!The coefficients correspond to the current yield per ha;
!SgMzD, SgMzW, SgRcD, SgRcW, SgSghD, SgSghW represent the quantity of crops (Maize, Sorghum and rice) sold respectively in the dry (D) and wet (W) seasons;
!BgMzD, BgMzW, BgRcD, BgRcW, BgSghD, BgSghW represent buying of maize and sorghum to supplement the internal production, this represents the household deficit;
!MzCsD, MzCsW, RcCsD, RcCsW, SghCsD, SghCsW are variables representing consumption of maize, rice and sorghum during the dry and wet seasons;
!StMzD, StRcD, StSghD are variables showing the transfer of stored produce from the dry season to the wet season, the assumption being that the harvesting takes place at the begining of the dry season. The coefficient reflects the losses that occur during the storage due to insects, rats, etc.;
!MzSd, RcSd, SghSd are variables representing the quantity of seed stored from the harvest;

[MzPrUse]-901*GrMz - 800*GrMzSgh + SgMzD + StMzD - BgMzD + MzCsD <= 0;
[MzUseW]-0.85*StMzD + SgMzW - BgMzW + MzCsW + MzSd <= 0;
[RcPrUse]-531*GrRc + SgRcD + StRcD - BgRcD + RcCsD <= 0;
[RcUseW]-0.99*StRcD + SgRcW - BgRcW + RcCsW + RcSd <= 0;
[SghPrUse]-320*GrMzSgh + SgSghD + StSghD - BgSghD + SghCsD <= 0;
[SghUseW]-0.85*StSghD + SgSghW - BgSghW + SghCsW + SghSd <=0;

```
[AccMzD]SgMzD >= BgMzD;
[AccMzW]SgMzW >= BgMzW;
![AccRcD]SgRcD >= BgRcD;
![AccRcW]SgRcW >= BgRcW;
[AccSghD]SgSghD >= BgSghD;
[AccSghW]SgSghW >= BgSghW;
```

!Labour demand for the household;
!The household members include men-M, women-W, Children in a working age including both boys-Cbw and girls- Cgw and other children - C;
!The coefficients represent the labour allocation for the different activities - cropping (labour contributed per ha by the different members of the household), charcoal production in the dry and wet season (ChPrD and CHPrW), harvesting of firewood and poles for household consumption (FwCs, PlCs respectively), Domestic activities - DoA;

```
[Malabour]42*GrMz + 42*GrRc + 46*GrMzSgh + 45*ChPrD + 45*ChPrW + PlCs - 312*M - HrMl - 66*W<= 0;
[WomLabour]33*GrMz + 40*GrRc + 51*GrMzSgh + 90*DoA + 2*ChPrD + 2*ChPrW + 1.5*FwCs - 187.5*W <= 0;
[Boylabour]14*GrMz + 1.5*FwCs - 104*Cbw <= 0;
[Girlabour]15*GrMz + 90*DoA + 1.5*FwCs - 117*Cgw <= 0;
[AccDomA]DoA=1;
```

!Size of the household;
!Variables for household composition: M for men, W for women, CbW for children (boys) and CgW for children girls both in working age while C denotes both girls and boys before they reach the age of helping their parents;

```
[NoMan]M = 1;
[NoWoman]W = 1;
[Noboyswg]Cbw = 1;
[Nogirlswg]Cgw=1;
[Nochildren]C=2;
```

!Utilization of forest products for energy and construction;
!For - is a variable representing the quantity of forest harvested to produce charcoal for commercial purposes, firewood and poles for consumption;
!ChPrD and ChPrW are the number of kilns of charcoal produced in the dry and wet seasons;
!SgChD and SgChW sales of charcoal in the dry and wet seasons;
!FwCs and PlCs represent the amount of firewood and poles that the typical household consumes per day;

```
[ChPr]-47*For + 15*ChPrD + 15*ChPrW + FwCs + PlCs <= 0;
[ChUseD]-ChPrD + SgChD <=0;
[ChUseW]-ChPrW + SgChW <=0;
[NoKilnsD]ChPrD >=1;
[NoKilnsW]ChPrW >=1;
```

```
[FwCons] FwCs >=5;
[PolesCons]PlCs >=0.6;

!Energy requirement;
!MzCsD, MzCsW, RcCsD, RcCsW, SghCsD, SghCsW represent the quantity of different crops consumed by the household and by season, according to the calories and protein provided by each kg of crop and according to the household minimum requirements per year as established by FAO;
[EnergyD]-3.450*MzCsD - 3.350*RcCsD - 3.350*SghCsD + 538.752*M + 428.22*W + 475.8*Cbw + 385.764*Cgw + 217.221*C <= 0;
[EnergyW]-3.450*MzCsW - 3.350*RcCsW - 3.350*SghCsW + 535.808*M + 425.88*W + 473.2*Cbw + 383.656*Cgw + 216.34*C <= 0;
[ProteinD]-100*MzCsD - 70*RcCsD - 95*SghCsD + 10.431*M + 10.431*W + 13.542*CbW + 12.078*Cgw + 3.66*C <=0;
[ProteinW]-100*MzCsD - 70*RcCsD - 95*SghCsD + 10.371*M + 10.374*W + 13.468*CbW + 12.012*Cgw + 3.64*C <=0;

!Diet balance;
!The diet balance illustrates the fact that the crops included in the model are consumed at different proportions, this avoids the possibility of obtaining unrealistic consumption of only crops that have the highest energy and protein levels. Eating habits are therefore factored into the model;

[MzBalD]-3.450*MzCsD + 0.33*(538.752*M + 428.22*W + 475.8*CbW + 385.764*Cgw + 217.221*C)<=0;
[MzBalW]-3.450*MzCsW + 0.33*(535.808*M + 425.88*W + 473.2*CbW + 383.656*Cgw + 216.34*C)<=0;
[RcBalD]-3.35*RcCsD + 0.224*(538.752*M + 428.22*W + 475.8*CbW + 385.764*Cgw + 217.221*C)<=0;
[RcBalW]-3.350*RcCsW + 0.224*(535.808*M + 425.88*W + 473.2*CbW + 383.656*Cgw + 216.34*C)<=0;
[SghBalD]-3.35*SghCsD + 0.056*(538.752*M + 428.22*W + 475.8*CbW + 385.764*CgW + 216.34*C)<=0;
[SghBalW]-3.350*SghCsW + 0.056*(535.808*M + 425.88*W + 473.2*CbW + 383.656*CgW +216.34*C)<=0;

!Demand for seed;
!MzSd, RcSd and SghSd are quantities of seed of maize, rice and sorghum, respectively, necessary for the cultivated land;
[SdMz]19*GrMz + 18.7*GrMzSgh - MzSd = 0;
[SdRc]12*GrRc - RcSd = 0;
[SdSgh]18.7*GrMzSgh - SghSd =0;

![Food security]3.450*MzCsD + 3.450*MzCsW + 3.350*RcCsD + 3.350*RcCsW + 3.350*SghCsD + 3.35*SghCsW + n1 - p1 = 4 080.335;
!Definition of the food security goal, the RHS shows the absolute target in terms of energy required per year;
```

![Income] Max = 0.12*SgMzD + 0.16*SgMzW + 0.243*SgRcD + 0.25*SgRcW + 0.16*SgSghD + 0.18*SgSghW - 0.13*BgMzD - 0.17*BgMzW - 0.29*BgRcD - 0.293*BgRcW - 0.18*BgSghD - 0.19*BgSghW + 44*SgChD + 47.5*SgChW + n2 - p2 =271.74;
!The income goal has been defined using the information in the expression above, which has been used when the program was run as LP which maximizes the gross margin. This was also important for defining the income target whose deviation is minimised in the goal programming. The coefficients are prices of selling and buying of the different household products;
!Food security goal normalized using percentage normalization;
!n1 and p1 are negative and positive deviations from the food security goal;
[FSecurity]0.0845*MzCsD + 0.0845*MzCsW + 0.0821*RcCsD + 0.0821*RcCsW + 0.0821*SghCsD + 0.0821*SghCsW + n1 - p1 = 100;

!Percentage normalization of the income goal;
!n2 and p2 are negative and positive deviations from the income goal;
[Income]0.0442*SgMzD + 0.059*SgMzW + 0.0894*SgRcD + 0.0919*SgRcW + 0.059*SgSghD + 0.0662*SgSghW - 0.0478*BgMzD - 0.0626*BgMzW - 0.1067*BgRcD - 0.108*BgRcW - 0.0662*BgSghD - 0.0699*BgSghW - 0.367*HrMl + 16.19*SgChD + 17.48*SgChW + n2

20.

Policy impact on woodland resource management, use and conservation in Mozambique: A case study of selected sites in Dondo, Nhamatanda, Gondola and Manica districts

G. Mlay, M. Falcao, I. Nhantumbo and G. Kowero

ABSTRACT

Forest resources play an important role in the economy of Mozambique. They are a significant source of livelihood and food security for rural people. The high rate of deforestation, estimated at 4.2% per year, coupled with land degradation, has been demanding a re-evaluation of the institutions and policies which guide the exploitation and conservation of forest resources. Management arrangements and policies that will meet the needs of stakeholders and at the same time guarantee a sustainable use of the forest resources are complex to devise.

A case study of three sites in the provinces of Manica and Sofala was carried out to analyse (a) the impact of alternative management regimes on the incomes of miombo woodlands users and on woodlands conservation, and (b) the impact of sectoral and extrasectoral policies on incomes for miombo users and woodland conservation under different management regimes. A system dynamics model, MIOMBOSIM, based on game theory and implemented in Powersim, was used for the study.

The results show that regulated management regimes incorporating social concerns or incorporating social and environmental concerns are potentially more beneficial to the household sector than the open access situation. The open access situation is the most beneficial management option for the private sector. Extrasectoral policies intended to promote agriculture have mixed effects on forest development. Modest agricultural price and productivity increases would increase agricultural production through area expansion. Reduction in land clearing for agriculture is only achieved when extrasectoral policies lead to large productivity increases in agriculture.

Key words: Sectoral and extra sectoral policies, management regimes, stakeholders, benefits, system dynamics, Mozambique.

1. INTRODUCTION

Mozambique has been implementing economic reforms in the context of structural adjustment programs since 1987. The pace of reforms accelerated after the signing of a peace agreement between RENAMO (an opposition movement in the country's post-independence civil war that later became a political party) and the government in 1992, followed by multiparty elections in 1994. The reforms have included currency devaluation with subsequent liberalization of the exchange rate, markets, prices and trade. Other measures include increased privatisation, fiscal retrenchment and domestic credit contraction. The implementation of these policies hinges mainly on the dominant role of market forces in guiding economic activities, with government's role directed at creating enabling conditions (infrastructure and market development, regulations and laws to protect property rights and enforcement of contracts, fiscal incentives, public investment in research, etc.).

Although the economic reforms have led to impressive macroeconomic performance as exemplified by a real GDP average annual growth rate of about 8% between 1996 and 1999, an annual growth rate of agricultural production of about 14%, and a reduction of annual inflation from 70.2% in 1994 to 6.2% in 1999, Mozambique continues to be one of the poorest countries in the world. According to a report on poverty assessment in Mozambique about 71.2% of the rural population and 62% of the urban population are below the poverty line (Ministry of Planning and Finance *et al*. 1998). Given that 70.4% of the population lives in rural areas poverty is essentially a rural problem.

The impressive performance of the agricultural sector has come about mainly from area expansion and not from an increase in productivity. The average yields of the main food crops (maize, rice, cassava, and beans) are about half those of sub-Saharan Africa. According to the results of the national household survey carried in 1996/97 by the National Institute of Statistics, only about 20% of the rural households used purchased seeds, none used fertilizer and only 18% of the households had access to technical assistance in the community. These statistics indicate that the present growth performance of agriculture cannot be sustained (since it is based on mining the land/soil) without the use of high productivity technologies that are environmentally friendly.

The Government of Mozambique recognizes that rapid broad based economic growth is necessary to reduce poverty. In this connection, agriculture (which supports the majority of the population) has to play a key role, with emphasis on use of more productive technologies that are environmentally friendly. The high incidence of poverty, and agricultural production characterized by low input use and extensive land use are, two characteristics that favour deforestation and land degradation. As pointed out by Vosti and Witcover (1996), poor households have a short time horizon in which natural resource mining may be the only alternative to meet the short term goals of food and livelihood security. In Mozambique, it is estimated that 4.2% of forest cover is lost annually, the principal causes being conversion of forest land to agriculture, tree felling for energy (charcoal and fire-wood) and construction material. Inadequate agricultural practices based on slash and burn methods, and exploitation of non-wood products using uncontrolled fires, often lead to the destruction of large tracts of forests.

In order to contain the adverse effects of economic development on the environment, the macroeconomic policy reforms have been accompanied by reform or formulation of sectoral policies and instruments to match economy wide policies. The key policy documents relevant to forest management include the agricultural policy and strategy for implementation (Ministério da Agricultura e Pescas 1995), the land law of 1997 (AR1 1997), the trade policy and strategy (Governo de Moçambique 1999), forest and wildlife policy of 1997 (AR2 1997), food security and nutrition strategy (Governo de Moçambique 1998), the national agricultural development program (Governo de Moçambique 1998), and the action plan for the reduction of absolute poverty (Governo de Moçambique 2001).

While land continues to be publicly owned the land, law recognises land use rights under customary law, and has provision for right of occupancy (through title deeds) at community level. The drawing of benefits is guaranteed by the land law, which provides a legal framework of right of occupancy of land at community level. The current forest and wild life policy also provides for a greater role for local community participation in natural resource management. According to Kant and Nautiyal (1993), a cross section study of 28 countries in Africa, Asia and Latin America showed that the main cause of deforestation in these areas is not over exploiting for supply to industry, but the inability of forest owners (often the state) to exclude various user groups from the resource which in theory is under a well defined property regime, leading to resource exploitation in an open access context. The high cost of monitoring coupled with low budgets means that in practice, monitoring and enforcement of government regulations is lax and hence ineffective. The recent interest in promoting community based forest management arrangements is seen as a more promising management alternative to the centralised arrangement.

Although broad policy statements and instruments for the implementation of community based forest management policies are in place in Mozambique, empirical support either to predict their impact or to fine-tune them to reflect the local environment is lacking. This is particularly important given the conflicting objectives of the different actors involved and the trade offs imputed by the extrasectoral policies which impact on the forest sector. The forest and wildlife policy provides for private sector logging under concession arrangements, while the land law allows for the communities to enter into partnership arrangements with the private sector in the exploration of land under community management. These policy provisions create opportunities for cooperation between the private sector and communities in managing the forest. What incentives will promote cooperation and at what level? How will the cooperation impact on community and private sector income and on the woodland resources? These are but a few of the many unknowns.

This paper presents results from a study carried out in Mozambique in the districts of Nhamatanda and Dondo in Sofala province, and those of Gondola and Manica in Manica province. The study was undertaken with the general objective of analysing the impact of selected policies on the incomes of users of miombo woodlands and on the conservation status of the woodlands. The miombo woodland is the most extensive forest formation in Mozambique and is characterised by tree species of *Brachystegia* and *Julbernadia*.

Specifically, the study evaluated the potential impact of five alternative miombo woodland management regimes on incomes of miombo users and on woodlands condition as well as the likely impact of some sectoral and extrasectoral policies on incomes of miombo users and woodlands conservation under the same management regimes. In this way the study sought to predict the impact of the broad government policies on local communities and their environment thus providing an opportunity to fine-tune these policies for maximum impact.

The rest of the paper is organized as follows: section 2 presents a brief review of modelling experiences in forest management, section 3 presents the methodology, while the main results are discussed in section 4. Section 5 presents the summary and main implications of the results on the welfare of rural communities and the forest condition.

2. A BRIEF OVERVIEW OF MODELLING IN FOREST MANAGEMENT

The review focuses on the modelling procedures used to study forest development problems; less emphasis is given to the underlying causes of these problems. These have been reviewed in many studies, including those reported by Mlay *et al.* (2003), Kaimowitz and Angelsen (1998), and Angelsen and Kaimowitz (2001).

Deforestation has serious negative effects on land degradation, climate and biodiversity. In the recent past there has been a rapid growth of studies at micro, meso and macro levels to try to understand and quantify the impact of the underlying causes of deforestation with a view to improving policy formulation and implementation. Kaimowitz and Angelsen (1998) present a rich review of economic models of tropical deforestation, covering studies conducted at micro (household and firm), meso (regional) and macro (national and cross country) levels. Further, Angelsen and Kaimowitz (2001) present a good account on agricultural technologies and tropical deforestation.

The micro level modelling has used household models of two types namely: open economy type models which treat all prices as being exogenous, and Chayonavian models assuming some markets are imperfect or incomplete or absent, leading to inseparability of production and consumption decisions. The empirical implementation of the conceptual models has taken the form of regression analysis, mathematical programming and simulation. These models have been used to study the impact on deforestation of input and output prices, risk, wage rates, off-farm employment land tenure and transport costs.

Regional or meso level models are either spatial or non spatial. The spatial models based on geo-referenced variables can predict where deforestation can occur. The majority of these models use multivariate logit or probit analyses. The non-spatial models are based on regression analysis, and can be used to study the effects of agricultural prices, population growth, transport costs, income and credit on deforestation.

The macro level models are of the general equilibrium type, and their popularity has been promoted for the following reasons (Kaimowitz and Angelsen (1998): they make some prices endogenous, they explore how some underlying variables help to determine decision parameters thus providing an important link to macroeconomic variables and policy instruments, and finally they include the interaction between different sectors and markets. The analytical implementation has mainly been by Computable General Equilibrium Models (GCE). The GCE models have been used to study the impact on deforestation of devaluation, trade liberalisation, export taxes, subsidies to industry, public expenditure, subsidies to agriculture, land taxes and technology (in agriculture and forestry). Trade and commodity models linking production, consumption and trade have been used to study the impact of currency devaluation, population growth, export taxes, wage rates and fertilizer prices on deforestation (Kaimowitz and Angelsen 1998, Pandey and Wheeler 2001).

The choice of modelling approach depends on the research questions and resource availability for implementation. While the models reviewed above address forest development issues at micro, meso and macro levels, they don't provide answers to management issues where potential conflicts exist between stakeholders. Models based on game theory seem promising. White (2000) provides a detailed review of game-theoretic analysis of common property resources. With the exception of fisheries (see Sumaila 1999), the empirical application of game theoretic models for other renewable resources has been limited. McCarthy (2000) presents a single period theoretical model to analyse the effects of production risk on the use of common pool rangelands. The comparative statistic results show that: (a) under a cooperative regime herders are better off in terms of welfare and production as production risk decreases. Stock levels increase as production risk decreases; (b) although under a non-cooperative regime stock levels increase with a decrease in production risk, profit may actually decline; and (c) total stock levels are higher under non-cooperation than under cooperation. According to McCarthy (2000), groups undertake cooperation to the extent that the benefits from cooperation outweigh the costs of making and enforcing agreements. As such, members will weigh the costs and benefits when choosing the level of cooperation.

Unsustainable exploitation of natural forest, land and other resources under open access, stemming from ineffective regulatory instruments (because of high costs of enforcement and conflict between national level objectives on one hand and local needs and objectives on the other) has seen a growing interest in promoting the participation of local communities in joint management programmes. Examples in the region include CAMPFIRE (Community Areas Management Program for Indigenous Resources) in Zimbabwe, largely involving local communities in wildlife ranching; the ADMADE programme (Administrative Management Design for Game Management Areas) of Zambia, another wildlife management initiative with local communities (Forests, Trees and People Newsletter 1991); and Village Natural Resource Management Committees in the Malawi. Other initiatives include Trusts, Conservancies, and Associations as found in Botswana, Namibia, and some villages in Tanzania (e.g. Duru-Haitemba). According to Kant and Nautiyal (1993), joint forest management programmes will only be successful if they include the rights and obligations of both partners, and if the sharing of benefits is perceived to be fair.

Kant and Nautiyal (1993), using a bilateral monopoly gaming approach, show the necessary community share of annual benefits from forest resources to maintain community interest in cooperation with a forest owner in joint forest management. This model is, however, limited in that it does not take into account other employment opportunities opened to local communities (agriculture, off-farm employment). Cardenas *et al*. (2000) examined the effects of external institutions, like rules and regulations imposed from outside the community, on behaviour under an experimental setting. The subjects for the experiment were drawn from rural households who depended heavily on local forests for wood products, and the exploitation of these products affects other aspects of their livelihood adversely (water quality and fish population). The experiment involved the allocation of a given endowment of time between collection of firewood from the forest and providing labour to an unrelated market. They found that when subjects do not face external restrictions and cannot communicate with each other (non-cooperation), their decisions tended to be neither Nash-based strategies[1] nor efficient choices, but somewhere between these extremes. In the absence of regulations, but with communication (cooperation), the subjects made more efficient choices. With external regulations subjects made choices closer to their pure Nash strategies. Consequently, average individual payoffs were lower than in the absence of regulation, and much lower than the payoffs of those subjects who were simply allowed to communicate with each other (cooperation), despite the fact that the regulatory institutions were designed to induce more efficient choices. Their results show that local environmental policies that are moderately enforced are ineffective, and can do more harm than good in comparison to allowing individuals collectively to confront local environmental dilemma without intervention. The reason for the poor performance of external control is that it crowded out group-regarding behaviour in favour of greater self-interest.

3. METHODOLOGY

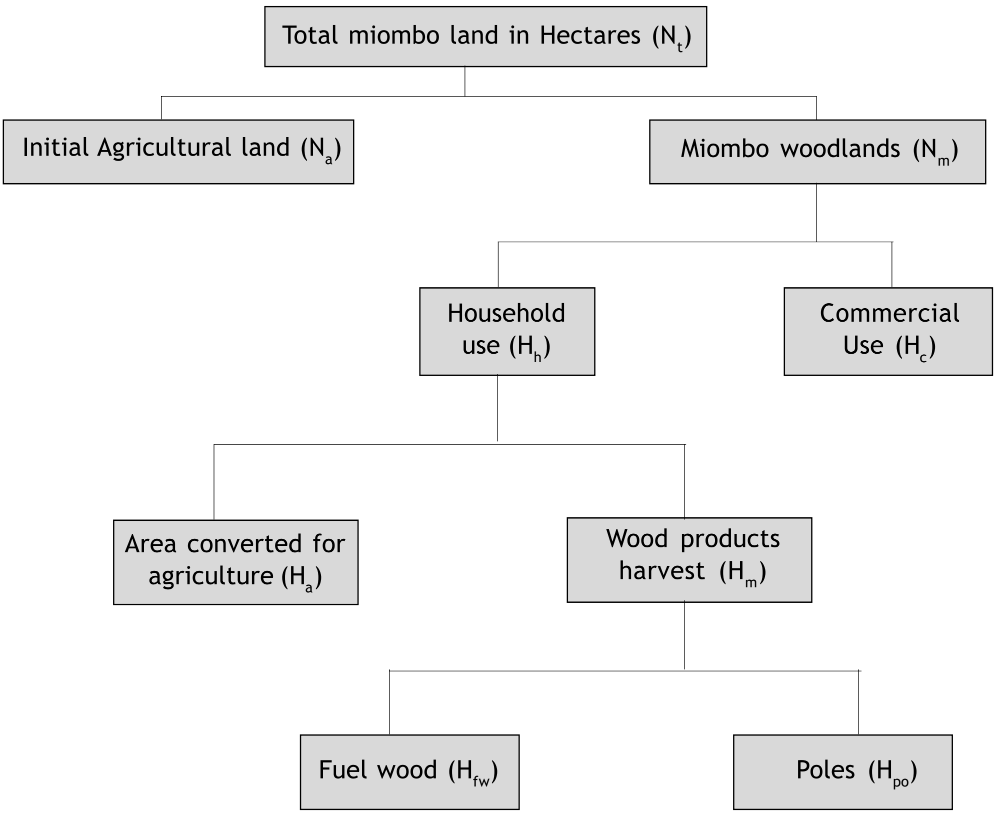
3.1 The model

A system dynamics model, MIOMBOSIM, which is based on game theory, is used in this paper. The conceptual model adapted here is presented in detail in Sumaila *et.al.* (2001). Three groups of stakeholders are identified, namely the government, the private (commercial) sector and the local community. The government's interest in miombo woodlands is based on maximizing society-wide benefits that include environmental protection (biodiversity conservation, protection of catchment areas, mitigation of land degradation and climatic changes), direct economic benefits and social benefits (e.g. preservation of settlement patterns in rural areas). The community's interest in miombo woodlands is based on the benefits that can be derived from wood and non-wood products harvested for consumption and sale, while the private sector's interest is based on the income derived from woodland harvesting, processing and sale activities. Under the existing Mozambican legislation, the land belongs to the state (owner) and the communities and the private sector enjoy user rights as per regulations mandated by the government. Partial enforcement of these regulations has resulted in the woodlands being under open access and therefore overexploited. This has potential for conflicts among the stakeholders due to their divergent objectives. While the private sector carries out selective logging, the household harvesting activities are non-selective, leading to destruction of valuable timber species. In addition, harvesting under concession[2] denies communities legal access to these areas. In the absence of enforcement capacity, these areas will continue to be exploited by communities as if under open access, and this could lead to losses of valuable timber species that have been legally allocated to the concession owner. These conflicts provide a basis for considering cooperation between the private sector and the local communities. A summary of the model that depicts this behaviour is presented in Annex 1. However, the logic leading to the development of the model is described in Figure 1.

3.2 Decision making by household and commercial sectors

The decision rules following the game theoretic games are summarised in Figure 1. It is assumed that at any time, t, there is a fixed woodland area (N_t) available to the communities from which the land area N_a is put under agriculture and N_m is the remaining area under miombo woodlands. The household and commercial sectors have to decide on how to use the land area N_m hectares that are under miombo woodlands. The commercial sector's decision is a one step process involving the determination of area H_c to harvest annually in order to maximize the sum of discounted net benefits. For the household sector, the decision making is a three-stage process. The criterion at each stage is to maximize utility over time. In the first stage a decision is made on how much of the area presently under miombo they should use (H_h) in order to maximize their utility over time. In the second stage a decision is made on how much of the miombo area to be used by households should be cleared for agriculture (H_a) and how much should be used for harvesting miombo wood products (H_m). For the area to be harvested of miombo wood products, the third stage involves its allocation between poles, H_{po}, and fuelwood, H_{fw}, the two main products from the woodlands.

Figure 1. Steps in decision making by the household and commercial sectors



The allocation process is driven by relative prices as shown in equations 1, 2 and 3.

$$H_a = \frac{P_a H_h^*}{P_a + (P_{fw} + P_{po})} \qquad (1)$$

$$H_{fw} = \frac{P_{fw} H_m}{P_{fw} + P_{po}} \tag{2}$$

$$H_{po} = \frac{P_{po} H_m}{P_{fw} + P_{po}} \tag{3}$$

Where: H_h^* = miombo woodland area to be exploited by the household sector
H_a= area to be converted to agriculture
H_m= miombo woodland area to be exploited for wood products (H_m=H_h^*-H_a)
H_{fw} = miombo woodland area to be exploited for fuelwood
H_{po} = miombo woodland area to be exploited for poles
P_a= revenue per hectare of agricultural products
P_{fw} = price per hectare equivalent of fuelwood
P_{po}= price per hectare equivalent of poles

3.3 The game theoretic models

Three principal game theoretic models were employed, namely a command model, a cooperative model and a non-cooperative model. In all models, the maximization of the objective function was over labour since this is the main variable factor in miombo harvesting activities. Each model is briefly described. For definition of symbols see Annex 1.

a) Command model

This model relates to a 'regulator' such as a central or local government, in that ownership and decisions are centralised. In this model, society-wide net benefits are maximized through the choice of the amount of labour to be used by the private and the household sectors in each year over the planning horizon of the model. The harvesting technologies used by both sectors are labour intensive and therefore the amount of labour to be used defines the volume of wood products to be harvested by each sector.

$$\underset{L}{Max} \sum_{t=1}^{T} [B_t] \rho_{t-1} = \sum_{t=1}^{T} \rho_{t-1} [B_c(H_{c,t}) + B_h(H_{h,t}) + B_s(\theta_c H_{c,t}, \theta_{h,t} H_{h,t}) - \phi B_e(H_{c,t} + H_{h,t)}] \tag{4}$$

subject to:

$$N_t = sN_{t-1} + K_t - H_{c,t} - H_{h,t}$$

$$L_t = L_{m,t} + L_{a,t} + L_{n,t} + L_{of,t}$$

where: L_t = total labour available to both household and private sectors at time t.
$L_{m,t}$ = Labour used for harvesting miombo wood products at time t.
$L_{a,t}$ = Labour used in agriculture at time t.
$L_{n,t}$ = Labour used in converting miombo woodland to agriculture at time t.
$L_{of,t}$ = Labour used for off-miombo, off agriculture activities at time t.
s = Natural regeneration rate of the woodlands

Depending on the values assigned to parameters θ_c , θ_h, ϕ different scenarios of the command model can be examined. In this paper we look at three scenarios, namely the scenario in which the regulator (government) is concerned with both social and environmental benefits but favouring or giving more weight to the household sector (θ_c=0, θ_h = 1 and ϕ=1) (scenario 1), the scenario in which only environmental benefits are considered (θ_c=0, θ_h =0 and ϕ=1) (scenario 2), and the scenario that considers only social benefits but favouring the household sector (θ_c =0, θ_h=1 and ϕ=0) (scenario 3).

These three scenarios represent the range of management options that central and local governments normally employ to manage the natural woodland resources. The first scenario corresponds to an advocated option in natural forest conservation that allows limited or controlled exploitation, like in water catchment forest areas that border villages. The second scenario represents a strict biodiversity conservation thrust as usually found in protected areas for important biodiversity, like heritage sites. The third scenario is largely found in most woodlands in the region that are technically under government control, but due to inadequate resources for their management they have almost become open access woodlands.

b) Cooperative model

In some situations some households indulge in commercialisation of the woodland products. Under such a situation, these households could form a 'commercial sector', while those that use the woodland products for own consumption would constitute the 'household sector'. This way one could map and monitor the development of commercial activities at the household level.

In this model it is assumed that the household and commercial sectors have an incentive to cooperate through joint maximization of their discounted net benefits.

$$\max_{L_h, L_c} \sum_{t=1}^{T} [\alpha \rho_{c,t-1} B_{c,t} + (1-\alpha) \rho_{h,t-1} B_{h,t}],\ 0 \le \alpha \le 1$$

subject to:

$$N_t = sN_{t-1} + K_t - H_{c,t} - H_{h,t}$$

$$L_t = L_{m,t} + L_{a,t} + L_{n,t} + L_{of,t}$$

The value assigned to the parameter will reflect the relative weight given to their individual benefits under cooperative management. When is assigned a value of 1, full weight is given to the commercial sector's benefits and a value of 0 corresponds to full weight being given to the household sector's benefits. The value of between the two extremes will permit both sectors to participate in miombo activities, thus the parameter is a measure of their preferences.

c) Non-cooperative model

In this model it is assumed that the two stakeholders (commercial and house hold sectors) operate in the woodlands independently without taking into account the interest of other stakeholders. This model mimics the open access situation, currently the dominant arrangement under which miombo woodlands are being exploited in many parts of Mozambique.

The constrained maximization problem of each stakeholder is as:

(i). Household sector

$$\underset{L_h}{\text{Max}} \sum_{t=1}^{T} \rho_{h,t-1} B_{h,t}$$

subject to:

$$N_t = sN_{t-1} + K_t - H_{c,t} - H_{h,t}$$

$$L_t = L_{m,t} + L_{a,t} + L_{n,t} + L_{of,t}$$

(ii). Commercial Sector

$$\underset{L_c}{\text{Max}} \sum_{t=1}^{T} \rho_{c,t-1} B_{c,t}$$

subject to:

$$N_t = sN_{t-1} + K_t - H_{c,t} - H_{h,t}$$

$$L_t = L_{m,t} + L_{a,t} + L_{n,t} + L_{of,t}$$

Simulation of the models is based on the numerical approach similar to that applied in Sumaila (1995) using system dynamics simulation package Powersim.

3.4 Questions to be addressed

On the basis of the participatory rural appraisal (PRA) and survey results from the study sites the following were identified as the main problems that could be solved with appropriate policy instruments.

a) Inadequate agricultural practices involving use of uncontrolled fires in land clearing and exploitation of non-wood products (honey and wild game).
b) Low or non-use of improved inputs (fertilizers and improved seeds) the result of which is area expansion to increase production or shifting cultivation to maintain reasonable yields.
c) High post-harvest losses of agricultural crops.
d) Incomplete or absent markets for agricultural inputs and products, as a result of poor rural infrastructure.
e) Limited or lack of alternative employment opportunities.
f) Various fees/prices for exploitation of forest products do not reflect their economic values. Cuco (1994) noted that stumpage/royalty fees range from US $1.20 per m^3 for second-class species to US $3.60 per m^3 for precious species.
g) Incomplete property rights on land, with consequent absence of internalisation of the externalities that arise from the exploitation of forest resources. The ineffective enforcement of existing regulation favours the utilization of woodland resources as if under open access conditions.

In addressing the above problems, simulation experiments under the five specified alternative management options were made within the context of the following categories of policy instruments (more details in section 4.2):

a) Policy instruments to create rural markets and improve incentives of market participants: mainly through agricultural input and output prices. For example, we employed a 25% and a 75% increase in agricultural output prices.
b) Policy instruments to promote the use of improved technologies in agricultural and charcoal production: largely through reducing post-harvest losses and increasing crop yields. We experimented with a 25% and a 75% increase in crop yields.
c) Sectoral policies aimed at forest or biodiversity conservation: mainly through fees or royalty charges on the forest products exploited. We experimented with a 30% increase in various fees charged for exploiting forest products for sale.

Table 1. Baseline data

Item	Units	Study site		
		Nhamatanda	Dondo	Gondola-Manica
Average farm size	ha	2.0	2.6	3.5
Discount factor ( )		[0.909;0.89]	[0.909;0.89]	[0.909;0.89]
Household labour efficiency parameter (q_h)		[0.1;0.05]	[0.1;0.083]	[0.1;0.03]
Forest area for community (N_t)	ha	12 000	14 500	25 000
Existing agricultural land (N_a)	ha	4997.2	1890.2	8355
Conversion cost miombo	\$ per m^3	0	0	0
Wage rate (w)	\$ per year	303.72	303.72	303.72
Average price of standing miombo (P_{ave})	\$/m^3	19.30	15.40	11.55
Price of fuel wood (P_{fw})	\$/m^3	3.17	3.06	3.3
Price of poles (P_{po})	\$/m^3	5.2	5	5.4
Purchased inputs		0	0	0
Regeneration (s)		0.012	0.012	0.012
Revenue from agriculture (P_a)	\$/ha	206.03	253.66	134.5
Subsistence income (I_h)	\$	1 095 156	734 561	1 099 930
Survival rate (s)		0.92	0.92	0.92
Social concern parameter ( )		0 or 1	0 or 1	0 or 1
Total potential labour per household	mandays	1273	986	1565
Total labour in the community	mandays	2 446 706	716 822	3 735 655
Parameter to labour cost function (v)		0.5	0.5	0.5
Standing volume of wood (K_t)	m^3/ha	38	47	40
Number of habitants per site		13 454	4 362	14 322
Harvesting cost by commercial sector	\$/m^3	9.75	7.8	5.85
Efficiency parameter for labour for commercial harvesting (q_c)	-	0.05	0.083	0.3
Potential area for commercial harvesting	ha	8 935	1 234	7 282

3.5 Data used

The data used to run the base models are presented in Table 1. The data were obtained from a field survey conducted in 2000 and supplemented with data from secondary sources.

4. RESULTS AND DISCUSSION

4.1 Basic simulation results

The basic results are presented under three categories of management regimes, namely:

a) A scenario in which a central or local government (regulator) determines the annual harvesting levels by household and commercial/private sectors in order to maximize society-wide benefits, which include the direct economic benefits, social benefits and environmental benefits (Command model).
b) A scenario in which the household and commercial/private sectors decide, of their own free will, to cooperate on the harvesting levels for each sector in order to maximise their joint net benefits (Cooperative model).
c) A scenario in which the household and commercial/private sectors act independently, each setting its level of harvesting to maximize own benefits (Non-cooperative model).

4.1.1 Effect of private sector participation (commercialisation) on household benefits

The relative weight assigned to each sector in the cooperative game is reflected by the preference parameter whose value varies from 0 (giving all weight to the household sector) to 1 (giving entire weight to the commercial/private sector). Figures 2 to 4 present the results. These results are compared with those obtained from the non-cooperative model. The top curve (Total household benefits) represents the combined benefits from woodlands and agriculture.

The joint discounted net benefits from woodland products are highest when the private sector or commercialisation is given maximum preference and they are least when total weight is given to the household sector. Given that, in practice, these benefits are not redistributed between the participating sectors, these extreme levels of existence are not practical and therefore define the outermost limits for both sectors; that is, in practice, the private sector and households coexist between these two extremes. It is therefore the responsibility of the decision maker to decide on the appropriate weight to give to each sector and taking into account the monetary benefits, employment creation and eventual forest condition, among others.

In the Dondo site, which is more endowed with miombo woodlands than the other two sites, there is a clear declining trend of household sector discounted net benefits from woodland products and a rising trend of commercial sector discounted net benefits from woodland products as the level of private sector participation or commercialisation increases. The rate of decline slows down when the preference level is between 0.4 and 0.7. The household sector net benefits from combined agriculture and forest activities (the top curve) are also sensitive to changes in preference parameters, showing that forest activities contribute a pronounced share to households' total benefits.

The household sector's net befits from the combined forest and agriculture activities are insensitive to changes in preference parameters in the case of the Nhamatanda

Figure 2. Effect of variation of preference parameter on the stakeholders' net benefits in Dondo

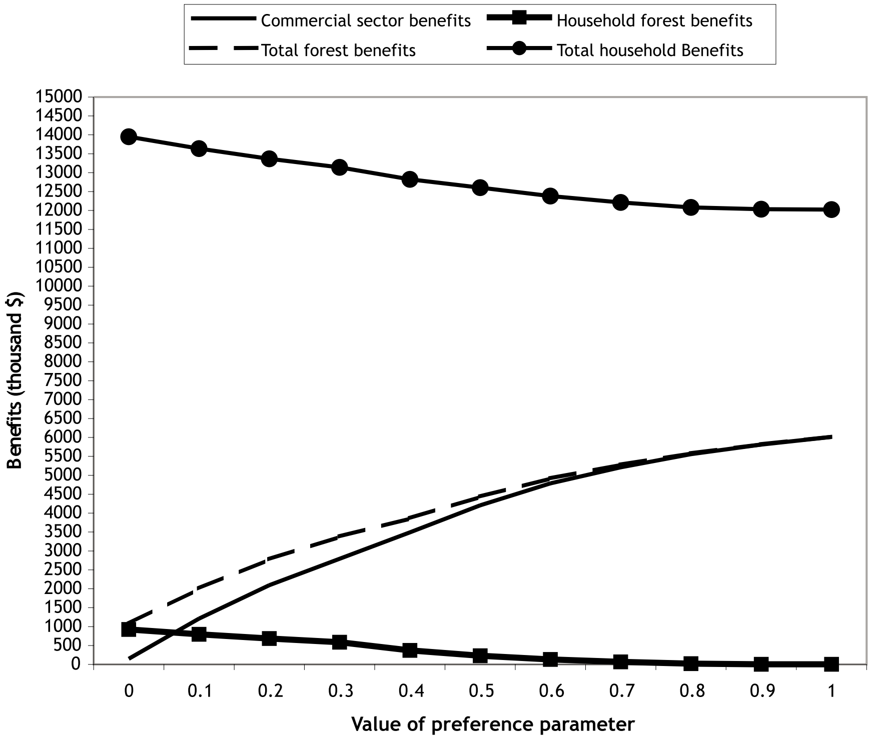


Figure 3. Effect of variation of preference parameter on the stakeholders' net benefits in Nhamatanda

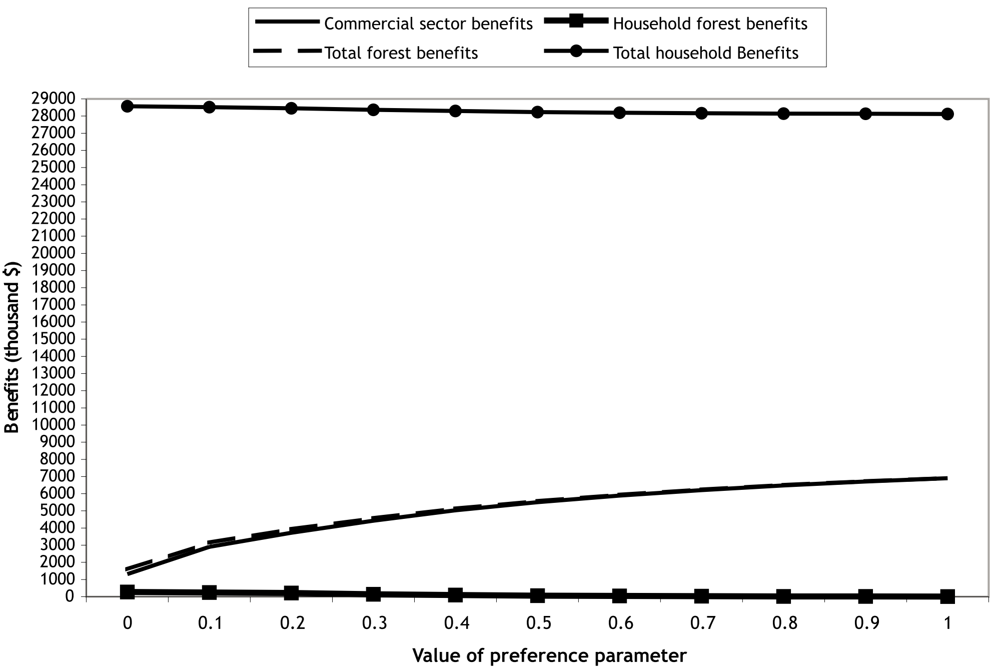
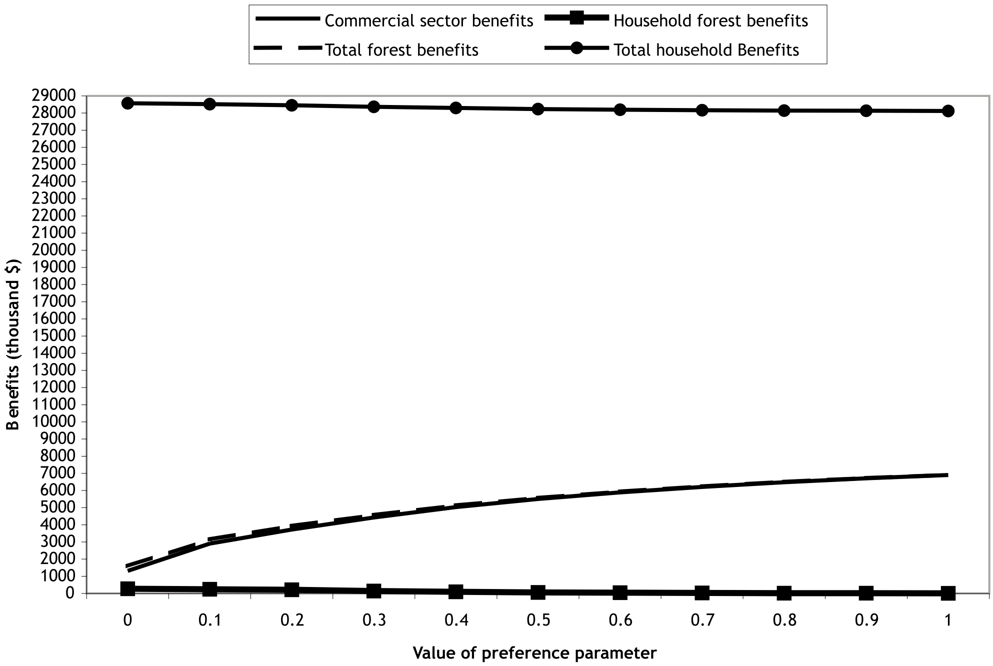


Figure 4. Effect of variation of preference parameter on the stakeholders' net benefits inGondola-Manica



and Gondola-Manica sites, as can be seen from the top curves in Figures 3 and 4. This is because these two sites have few forest resources and the products derived from them make a small contribution to total household net benefits. In these two sites, using income from the woodlands as a strategy (incentive) to households to conserve the forests would most probably be less effective as compared to Dondo. Therefore another strategy has to be devised.

4.1.2. The impact of management regimes on the well-being of stakeholders and on woodland resources

This section will first present the results on comparative analysis of the five management regimes with particular emphasis on their impact on the well-being of stakeholders and on the forest resources. We analyse how alternative management regimes influence the benefits accruing to the stakeholders and how these translate to volume of wood products harvested, labour employment opportunities for miombo activities and the state of forest resources. Given that currently the miombo woodland resources are principally exploited under open access, the non-cooperative model will be used as a reference point in comparing the management alternatives.

4.1.2.1 Impact on stakeholders' net benefits

The effects of management regime on discounted total benefits from miombo activities vary in terms of quantity and distribution between the two sectors (Table 2). The difference in discounted net benefits between the two sectors reflects the difference in harvesting efficiency and market values of the products harvested.

Table 2. Effect of management regime on discounted benefits from sale of woodland products ('000 US $)[a]

Study site	Management regime	Sector		All
		Commercial	Household	
Dondo	Command with social	3578.95 (3)	410.33 (1)	3989.28 (3)
	Command with environment	3227.31 (4)	21.45 (5)	3248.76 (4)
	Command with social & environment	2877.04 (5)	272.77 (2)	3149.81 (5)
	Cooperative	4206.65 (2)	228.65 (3)	4435.30 (2)
	Non-cooperative	5752.07 (1)	87.59 (4)	5839.66 (1)
Nhamatanda	Command with social	3069.08 (3)	180.53 (1)	3249.61 (3)
	Command with environment	2471.97 (4)	0.18 (5)	2472.15 (4)
	Command with social & environment	2267.12 (5)	113.93 (2)	2381.05 (5)
	Cooperative	3440.88 (2)	84.12 (3)	3525.00 (2)
	Non-cooperative	4543.65 (1)	44.99 (4)	4588.64 (1)
Gondola-Manica	Command with social	5409.64 (3)	90.35 (1)	5499.99 (3)
	Command with environment	4035.49 (5)	24.86 (4)	4060.35 (5)
	Command with social & environment	4041.64 (4)	44.83 (3)	4086.47 (4)
	Cooperative	5506.10 (2)	61.54 (2)	5567.64 (2)
	Non-cooperative	6871.26 (1)	20.90 (5)	6892.16 (1)

[a] *Fugures in parentheses are the rankings of the management regime in terms of benefits derived by stakeholders*

(a) The commercial sector

For the three study sites, the highest discounted net benefits to the commercial sector would be consistently obtained under the non-cooperative management regime, i.e. under an open access situation. Since the non-cooperative regime is the most beneficial to the commercial/private sector, the sector would not welcome government intervention or cooperation with government or local communities unless the intangible benefits and the penalties for non-compliance exceed the additional benefits emanating from cooperation. The cooperative regime would be the second best option, followed by the command regime incorporating social concerns. Therefore if the aim is to promote private sector involvement in woodland management and use, then the open access (non-cooperative regime) situation or the status quo would be the most appropriate approach to the private sector.

(b) The household sector
The management regime that would lead to the highest discounted net benefits from woodland products to the household sector would be the command regime incorporating social concerns. The benefits accruing to the household sector under this regime would be more than 300% higher than those that would be obtained under the non-cooperative regime or open access situation for the three sites. In the case of Dondo and Nhamatanda, the regulated regime incorporating social and environmental benefits would be the second best option, followed by the cooperative regime. For the Gondola-Manica site, the cooperative regime would be the second best alternative followed by the regulated regime incorporating environmental benefits. The regulated option for environmental reasons would be least beneficial to the household sector in Dondo and Nhamatanda and it would be second least beneficial in Gondola-Manica. The non-cooperative arrangement would be least attractive for communities in Gondola-Manica. The conclusion is that if decision makers or rural planners put more weight on rural household welfare, then the command regimes (social and social + environmental concerns) appear to be the most appropriate management regimes for the woodlands, followed by the cooperative regime. The open access situation or status quo (non-cooperative regime) would appear to be very disadvantageous to local communities.

(c) The combined household and commercial sectors
For both the household and commercial sectors, if the objective is to maximize discounted net benefits from miombo wood products without considering their distribution between the two sectors, then the non-cooperative arrangement or status quo would be most attractive in all three sites, followed by the cooperative and then command with social concerns regimes. The command management incorporating social and environmental benefits would provide the least potential discounted net benefits from miombo wood products in Dondo and Nhamatanda, while the command arrangement incorporating environmental benefits would be the least attractive management option in Gondola-Manica.

However, since the bulk of the benefits flow into the commercial sector, the combined total benefits for the two sectors follow the trend of the commercial sector benefits (Table 2). Decision makers would be advised, to the extent possible, to make site-specific decisions on the management regimes. For example, it would appear that in Nhamatanda and Gondola-Manica, where few forests remain, giving households more weight than the commercial sector in forestry would be reasonable. This would then lead to the recommendation of the command regime incorporating social concerns as being more appropriate. In Dondo, where forest resources abound, private/ commercial sector initiatives alongside household welfare concerns could be promoted or given more weight than in Nhamatanda and Gondola-Manica. Under such a situation the cooperative regime or command regime with social concerns would appear to be more relevant. In both situations neither sector would realise the potential maximum benefits dictated by the best management option, the non-cooperative regime or the status quo; one sector loses while the other gains, depending on the weight we attach to either of the two sectors.

(d) Combined agricultural and woodland benefits
In terms of total household benefits (from miombo products and agriculture) the command regime incorporating social concerns would be the best for all the three sites (Table 3).

In the case of Gondola-Manica, there was a switch in ranking between the command arrangement incorporating environmental concerns and the non-cooperative arrangement with the latter occupying the last position and the former occupying the fourth position. The Dondo site, which is more endowed with forest resources, has the highest net benefits per capita while the Nhamatanda site, which has suffered most from deforestation, has the least net benefits per capita.

Table 3. Effect of management alternatives on household sector total benefits and annual total benefits per capita[a]

Study site	Management regime	Total benefits in US $ '000	Annual per capita net benefits US $
Dondo	Command with social	13100.20 (1)	60.07 (1)
	Command with environment	12024.80 (5)	55.13 (5)
	Command with social &environment	12621.50 (2)	57.87 (2)
	Cooperative	12604.20 (3)	57.79 (3)
	Non-cooperative	12273.60 (4)	56.28 (4)
Nhamatanda	Command with social	26193.50 (1)	38.94 (1)
	Command with environment	25739.70 (5)	38.26 (5)
	Command with social & environment	26004.80 (2)	38.66 (2)
	Cooperative	25975.30 (3)	38.61 (3)
	Non-cooperative	25879.30 (4)	38.47 (4)
Gondola-Manica	Command with social	28298.20 (1)	39.52 (1)
	Command with environment	28136.30 (5)	39.29 (5)
	Command with social & environment	28167.00 (3)	39.33 (3)
	Cooperative	28231.90 (2)	39.42 (2)
	Non-cooperative	28148.50 (4)	39.31 (4)

[a] *Fugures in parentheses are rankings of the management regime in terms of benefits derived by stakeholders.*

The average volume harvested annually and potential for labour employment that would lead to maximum discounted benefits under each management arrangement exhibit trends corresponding to those of benefits derived from these products.

These results seem to suggest that the two regulated (command) management arrangements that emphasise social and social plus environmental concerns (followed by the cooperative management regime) are potentially beneficial to local communities and the private sector. The failure by governments to guarantee a flow of such benefits (in the form of investment in economic and social infrastructure) to communities leaving in the proximities of forest resources has contributed to the poor performance of central or local government regulated management regimes. Therefore, decentralization of forest resource management to local levels with in built mechanisms for benefit sharing between the regulator (central or local government) and the communities has the potential to improve the welfare of the communities and the condition of woodlands. Some central or local government influence is still possible and desirable. This can be done through forestry extension agents who can raise and sustain in the local communities the awareness of the social and environmental values of the woodlands, thus facilitating their consideration in woodland management regimes that the communities might eventually evolve.

The other alternative is a partnership arrangement between the commercial sector and local communities (cooperative) in managing and harnessing forest resources in areas in the proximity to these communities. The current land law and forest and wildlife management policy provide a legal basis for putting such arrangements into practice.

4.1.2.2 Impact of different management regimes on forest resources

Incomplete property rights, poor agricultural practices and policy failure in internalising the externalities arising from the exploitation of forest resources have contributed to high rates of deforestation and land degradation. The weak institutional capacity to enforce existing legislation on use of forest resources has led to their utilization under open access. Table 4 presents a summary of the impact of different management regimes on the relative area of standing miombo and relative forest area converted to agriculture using the non-cooperative management regime (status quo) as a reference. At the steady state, the standing forest area at the end of the simulation period (relative to that of the non-cooperative management regime) would be highest under the command regime incorporating environmental concerns, followed by the command regime incorporating social and environment benefits, cooperative regime, command regime incorporating social benefits and lastly the non-cooperative regime. This trend is observed in all sites.

In all sites, the deforestation would be highest under open access (i.e. non-cooperative situation). At the end of simulation period only about 20% of the initial area will remain forested in the Dondo site (which is currently the most forested of the three sites), 26% in the Nhamatanda site and 25% in the Gondola-Manica site. As

Table 4. Relative area (in %) of standing miombo and that converted to agriculture[a]

Site	Management regimes	Relative area of standing miombo	Relative area converted to agriculture
Dondo	Command with social concern	141.19 (4)	385.06 (1)
	Command with environment	193.85 (1)	10.02 (5)
	Command with social & environment	175.03 (2)	221.06 (2)
	Cooperative	151.10 (3)	202.74 (3)
	Non-cooperative	100.00 (5)	100.00 (4)
Nhamatanda	Command with social	147.70 (4)	318.79 (1)
	Command with environment	175.90 (1)	0.28 (5)
	Command with social & environment	174.16 (2)	187.92 (2)
	Cooperative	148.87 (3)	159.42 (3)
	Non-cooperative	100.00 (5)	100.00 (4)
Gondola-Manica	Command with social	167.37 (4)	335.02 (1)
	Command with environment.	201.81 (1)	52.37 (5)
	Command with social & environment	195.32 (2)	82.95 (4)
	Cooperative	168.34 (3)	225.23 (2)
	Non-cooperative	100.00 (5)	100.00 (3)

[a] *The non-cooperative arrangement is used as a base for comparison and the figures in parenthesis are rankings of the management regimes*

expected, the regulated (command) system incorporating only environmental concerns would lead to least deforestation in all three sites, but it is the option least attractive to the household and commercial sectors in terms of incomes/benefits.

In terms of benefits for both commercial and household sectors, the command regimes incorporating social and environmental plus social concerns appeared favourable, and they would also appear to be a reasonable choice when consideration is given to the relative area of standing miombo in the long term. However, with the exception of the command regime with environmental concerns, the other two variants of the command regime (social and social + environment) would appear to be associated with relatively more area under woodlands converted to agriculture. But this is the price or trade-off for improving overall household benefits.

4.1.2.3 Implications of alternative management regimes

The alternatives analysed for managing miombo woodland resources reflect either on-going practices or practices in the early stages of being introduced. The experience of centrally regulated regimes has not been effective in redressing deforestation and land degradation. Although governments have the obligation to defend society-wide interests in natural resource conservation and use, experience shows that the policies adopted and instruments used for their implementation have been ineffective. The fact that social benefits implied by central government are not felt at grass-roots level gives an incentive for non-compliance, which in turn is facilitated by lack of institutional and financial capacity for enforcement.

The fact that the regulated (command) management regimes (central or local government) that take into account social needs or both social and environmental needs are potentially more beneficial to the household sector than when forests are exploited as in open access, suggests that if these benefits were to flow to the local communities, non-compliance could be minimized. This can be guaranteed under decentralized management with local community participation but with clear definition of the benefit sharing arrangement. The cooperative arrangement that already has a legal support for property rights protection needs to be promoted. Though this was ranked as second best, it would appear to be the best management regime for all sites because it has better potential than the command management regimes to allow for all the benefits to remain with the principal stakeholders the local communities and private sector.

4.2 Policy impact on stakeholders' benefits, wood products harvested and on the miombo woodlands under alternative management regimes

In this section we analyse the potential impact of sectoral and extrasectoral policies on the benefits of stakeholders' utilisation of woodland resources and the consequent impact on the resource. The extrasectoral policies considered here are those that influence agricultural performance, because of its central role in the livelihood and food security of rural communities, and because that agricultural activities are one of the main causes of deforestation. The sectoral policies considered here are those related to different types of fees charged for exploiting forest resources.

4.2.1 Increase in fees charged on forest products

An increase in various fees charged on forest products can be viewed as a means of raising public revenue and, at the same time, as a policy instrument to influence the exploitation of forest resources through its taxation effects on users benefits. The potential impact of a 30% increase in various fees charged on commercialised wood products on stakeholders' benefits, labour employment opportunities in forest activities and forest resources was analysed. Particular attention was paid to the interaction between the management regimes and the increase in fees. Table 5 presents a summary of the results on the benefits to the household and commercial sectors.

(a) Potential effects on the commercial sector

An increase in fees under ceteris paribus conditions is expected to reduce incomes to the commercial sector, but this could be to different magnitudes depending on the woodland management regime. A 30% increase in various fees charged on wood products would lead to a reduction in discounted net benefits to the commercial

Table 5. Potential effects of a 30% increase in fees on stockholders' benefits (US $'000)[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial -	3615.41(1)	2527.82(2)	2076.86(3)	1815.23(4)	1593.22(5)
	forest benefits	*(-37.1)*	*(-39.9)*	*(-42.0)*	*(-43.7)*	*(-44.6)*
	Household	125.94(4)	277.72(3)	558.76(1)	35.28(5)	361.05(2)
	forest benefits	*(43.8)*	*(21.5)*	*(36.2)*	*(64.5)*	*(32.4)*
	Household	1244.40(4)	12733.80(3)	13371.70(1)	12038.80(5)	1285.60(2)
	total benefits	*(1.4)*	*(1.0)*	*(2.1)*	*(0.1)*	*(1.9)*
	Household	57.04(4)	58.39(3)	61.31(1)	55.20(5)	58.95(2)
	benefits per capita[c]	*(1.4)*	*(1.0)*	*(2.1)*	*(0.1)*	*(1.9)*
Nhamatanda	Commercial-	2901.97(1)	2140.06(2)	1912.63(3)	1323.86(4)	1209.71(5)
	forest benefits	*(-36.1)*	*(-37.8)*	*(-37.7)*	*(-46.5)*	*(-46.6)*
	Household	55.23(4)	122.53(2)	200.06(1)	0.107(5)	114.62(3)
	forest benefits	*(22.8)*	*(45.7)*	*(10.8)*	*(-13.0)*	*(0.6)*
	Household	25935.70(4)	26050.30(2)	26170.80(1)	25739.70(5)	26048.00(3)
	total benefits	*(0.2)*	*(0.3)*	*(-0.1)*	*(0.0)*	*(0.2)*
	Household benefits	38.55(3)	38.72(2)	38.90(1)	38.26(4)	38.72(2)
	per capita[c]	*(0.2)*	*(0.3)*	*(-0.1)*	*(0.00)*	*(0.2)*
Gondola - Maniaca	Commercial -	4416.56(1)	3469.73(2)	3396.00(3)	2262.38(4)	2254.45(5)
	forest benefits	*(-35.7)*	*(-37.0)*	*(-37.2)*	*(-43.9)*	*(-44.2)*
	Household	28.35(5)	77.62(2)	102.66(1)	38.95(4)	54.66(3)
	forest benefits	*(35.7)*	*(18.0)*	*(13.6)*	*(56.3)*	*(21.9)*
	Household total	28183.10(4)	28284.40(2)	28368.00(1)	28149.10(5)	28192.10(3)
	benefits	*(0.1)*	*(0.2)*	*(0.3)*	*(0.1)*	*(0.1)*
	Household	39.36(4)	39.50(2)	39.61(1)	39.31(5)	39.37(3)
	benefits per capita[c]	*(0.1)*	*(0.2)*	*(0.3)*	*(0.1)*	*(0.1)*

[a] The figures in italics represent changes (in%) from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b]NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.
[c]US $ per year

sector of more than 35% under all management regimes. The largest reduction is observed under the command regime with environmental and social concerns, where the discounted net benefits relative to base scenario would be reduced by 45% in Dondo, 47% in Nhamatanda and 44% in Gondola-Manica. These results conform to a priori expectations since the social concern component is in favour of the household sector, meaning that in addition to the restriction on harvesting implied by taking up environmental concerns, the commercial sector is indirectly penalised by the social consideration that favours free access to the woodlands by the household sector for its needs. The discounted net benefits would appear to be least sensitive (smallest reduction relative to base results) to fees increase under the non-cooperative regime. However, the net benefits in relation to base results would be reduced by 37% in Dondo and 36% in both Nhamatanda and Gondola-Manica. This would imply that an open access situation would be conducive to increased harvesting and commercialisation to offset/contain the loss in volume of revenue due to an increase in royalty fees. Comparing the discounted net benefits under alternative management options the same ranking is maintained as in Table 2 (basic results) in the case of Dondo and Nhamatanda. The results therefore indicate that the commercial sector benefits would be very sensitive to modest changes in royalty charges and that the non-cooperative regime (an open access situation) followed by the cooperative regime would offer the best opportunities to cushion some of this impact through increased harvesting.

(b) Potential effects on household sector forest benefits

The imposition of royalty fees without an increase in the sales price of forest products is expected to reduce commercial harvesting of the woodlands, thus releasing labour that could possibly be engaged in agriculture and increase household benefits (Table 6). The results for the Dondo and Gondola-Manica sites show an increase in discounted total household benefits under all management arrangements (Table 5) as compared to basic results (Table 2). In Nhamatanda, all but the command regime with environmental concerns show an increase in total household benefits relative to the base results, with the highest values being attained under a cooperative regime. The same trend is maintained with respect to discounted net forest benefits that would increase appreciably, but from the insignificant changes in total household benefits this means that in value terms the forest benefits are relatively small. The observed increase in household discounted net forest benefits from miombo activities would be obtained as a by-product of land conversion to agriculture (agriculture becomes relatively more beneficial than miombo activities) through the sale of forest products harvested from the converted land. More labour would be available for household activities due to a decline in demand by the commercial sector as indicated in Table 6.

When the management regimes are compared after an increase in royalty fees, the same ranking as in the base scenario is maintained in terms of discounted forest benefits to the household sector in all sites. This would imply that a royalty fee increase policy would not influence the relative suitability of the five management regimes in the three sites when the development goal is to sustain or increase household benefits. The best forest management regime per site, as indicated by the base results, could therefore continue to be maintained under such circumstances.

(c) Potential impact on combined agricultural and woodland benefits to household sector
The overall potential impact of royalty fee increase on total household benefits from agriculture and forest activities appears to be small, less than 0.5% for both Nhamatanda and Gondola-Manica and between 1 and 2% for Dondo (Table 5). The substitution effects resulting from changes in relative net prices can explain this apparent lack of sensitivity. The benefits from crops on the expanded agricultural land coupled with benefits derived from miombo products harvested and sold from the converted land would be more than sufficient to compensate for the modest increase in royalty fees charged on any commercialised forest product. This result implies that the royalty fees charged are too low to affect the total household income. Again, the relative ranking of the management regimes in terms of discounted total household benefits has been maintained as in the basic results. In all sites the command regime incorporating social concerns continues to have the highest potential total household benefits.

d) Potential impact on labour employment and on woodland resources
An increase in fees has the potential to reduce labour employment by the commercial sector under all management regimes because commercial harvesting would become less profitable. However, the degree of responsiveness in the reduction of labour employment potential would be dependent on the forest management regime. As it can be seen in Table 6, the largest reduction in labour employment potential for commercial activities relative to basic results would be achieved under the command management regime that emphasizes social and environmental concerns in Dondo and Gondola-Manica and the command management regime that emphasizes environmental concerns in Nhamatanda. The least reduction would be achieved under the cooperative management regime in Dondo and the command management regime with social concerns in Nhamatanda and Gondola-Manica.

When the management regimes are compared, in terms of their ranking, with the base results, Dondo and Gondola-Manica maintain the same rankings. For the Nhamatanda site, a switch in ranking occurs between the command-social and command-social-environment management regimes.

Labour employment behaviour in the household sector when fees for woodland products are increased would appear to be opposite to that of the commercial sector, with the exception of the command-environment regime in the Nhamatanda site. As explained earlier, the potential for increased profitability of agriculture relative to forest activities would create a demand for more labour for land conversion to agriculture. This labour would be withdrawn from the less profitable commercial sector. As in the case of commercial labour employment, the degree of responsiveness to a fees increase would be dependent on the forest management regime and study sites. When the management regimes are ranked in terms of the level of labour employment potential by the household sector, Dondo and Gondola-Manica maintain the same rankings, in which the command management regime that provides for environmental concerns would appear to have the highest potential for labour employment (i.e. would release most labour), followed by the non-cooperative management regime. In the case of the Nhamatanda site, the cooperative management regime would have the highest potential, followed by the non-cooperative management regime.

An increase in fees has often been argued to have potential to promote forest or biodiversity conservation. The impact of increased fees on biodiversity conservation would be most pronounced under the two command management regimes that incorporate environmental concerns in all sites (Table 6), as seen from the proportion of woodland stock left standing at the end of the simulation. These management options would lead to the highest area of standing miombo woodlands in all sites at the end of the simulation period. However, in both Nhamatanda and Gondola-Manica the non-cooperative regime would also lead to the same conclusion, apparently from the reducing pressure now experienced on these resources. The forest royalty fee increase would be least effective in mitigating deforestation under the cooperative regime and the command with social concerns regime in all three sites. These results seem to suggest that the management options that will minimize conflicts between multiple objectives will be between these two extremes.

4.2.2. An increase in agricultural output prices by 25% and 75%

Policies leading to an increase in agricultural output prices are intended to stimulate improvement in agricultural production and consequently improve rural incomes and food security. The impact of price increases on agricultural production will be constrained by the resources and production technologies, at least in the short run.

Table 6. Potential effects of a 30% increase in fees on labour employment and woodland conservation[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest labour (Proportion)	0.481(1) *(-15.2)*	0.294(2) *(-13.3)*	0.201(3) *(-17.6)*	0.167(4) *(-31.1)*	0.129(5) *(-32.5)*
	Household forest labour (proportion)	0.110(4) *(25.9)*	0.132(3) *(16.8)*	0.320(1) *(17.7)*	0.005(5) *(54.3)*	0.134(2) *(25.2)*
	Standing miombo woodlands (% of initial area)	24.17(5) *(17.4)*	32.71(3) *(5.1)*	29.58(4) *(1.7)*	46.89(1) *(17.4)*	43.64(2) *(21.6)*
Nhamatanda	Commercial forest labour (Proportion)	0.440(1) *(-10.2)*	0.290(2) *(-9.4)*	0.233(3) *(-7.2)*	0.012(5) *(-93.5)*	0.107(4) *(-33.95)*
	Household forest labour (Proportion)	0.104(4) *(15.7)*	0.126(2) *(22.3)*	0.257(1) *(8.9)*	0.000(5) *(-0.35)*	0.108(3) *(4.9)*
	Standing miombo woodlands (% of initial area)	29.37(5) *(14.2)*	44.83(2) *(5.9)*	39.23(4) *(3.3)*	50.45(1) *(11.51)*	44.65(3) *(12.02)*
Gondola-Manica	Commercial forest labour (Proportion)	0.606(1) *(-13.9)*	0.403(2) *(-12.2)*	0.386(3) *(-12.1)*	0.188(4) *(-32.6)*	0.185(5) *(-33.2)*
	Household forest labour (Proportion)	0.095(4) *(14.7)*	0.113(2) *(11.9)*	0.185(1) *(10.8)*	0.018(5) *(26.8)*	0.103(3) *(11.7)*
	Standing miombo woodlands (% of initial area)	22.75(5) *(25.7)*	35.12(3) *(15.3)*	34.66(4) *(14.4)*	54.04(1) *(23.3)*	45.02(2) *(27.3)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

(a) Potential effects on stakeholders' benefits

The results on the potential effects of an increase in agricultural/crop output prices on stakeholders' benefits are presented in Tables 7 and 8. When agricultural prices increase, keeping other factors constant, forest activities will become less profitable relative to agriculture, causing a shift of more labour to agriculture. It is therefore expected that the benefits to the commercial sector will decline. In the case of the household sector, benefits from forest activities can actually increase as a result of the revenue obtained from the sale of wood products obtained in the process of land conversion to agriculture. However, our results show that the theoretical predictions are not always achieved, since these are constrained by initial land productivity and forest endowment (which are site specific) and forest management regime. The initial land productivity and forest endowment will influence the level of price changes at which a switch from forest activities to agriculture would occur.

Further, in this and other sections caution should be exercised in interpreting the magnitudes of percentage changes that might appear to be very high or very small, because these changes are related to the initial conditions. For example, an increase in benefits from US$1 to US$2 would represent a very big percentage change while in real monetary values the change would appear small, while a benefit change from US$100 to US$110 will represent a small percentage change but a higher monetary value change.

(i) Potential impact on commercial sector benefits

The commercial sector forest benefits would appear to be insensitive to increases in agricultural prices by 25% and 75%. At the 25% crop output price increase the changes in commercial forest benefits in relation to the base scenario would be less than 1% in all study sites and under all management regimes (Table 7). The highest change at the 75% crop output price increase would be achieved in Dondo under the command-environment management regime with a 4.28% decline in benefits relative to the those in the base results (Table 8).

The results also show a mixed effect (indeterminate) of price increase on benefits, depending on substitution effects resulting from changes in relative net prices, the goal of each management regime, and site specific initial conditions. For example, in Dondo, an increase in commercial forest benefits is predicted under the non-cooperative management regime and a decline is also predicted in all other regimes when there is a 25% crop output price increase. When the crop output price is increased to 75%, a decline is predicted under all management regimes. In the case of Nhamatanda, at the 25% crop output price increase commercial forest benefits are predicted to go up under the non-cooperative, cooperative and command-social regimes and would decline under the command-environment and command-social-environment regimes. At the 75% crop output price increase, the benefits under the cooperative regime would decline while the other management regimes would maintain the same pattern observed under 25% crop output price increase. Similar results are also observed for the Gondola-Manica site.

With 25 and 75% crop output price increases the ranking of the forest management regimes in terms of potential to improve commercial sector benefits appears to remain the same as in the base results in all study sites. The non-cooperative management regime continues to be the most profitable in all sites, while the command regime with environment and the command with social concerns would be least in all sites

Table 7. Potential effects of a 25% increase in crop output prices on stakeholder's benefits (US $ '000)[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest benefits	5758.77(1) *(0.1)*	4185.18(2) *(-0.5)*	3563.07(3) *(-0.4)*	3212.10(4) *(-0.5)*	2859.38(5) *(-0.6)*
	Household forest benefits	90.28(4) *(3.1)*	235.86(3) *(3.2)*	433.14(1) *(5.6)*	27.80(5) *(29.6)*	283.35(2) *(3.9)*
	Household total benefits	12823.0(4) *(4.5)*	13169.6(3) *(4.5)*	13701.7(1) *(4.6)*	12568.0(5) *(4.5)*	13191.8(2) *(4.5)*
	Household total benefits per capita[c]	58.79(4) *(4.5)*	60.38(3) *(4.5)*	62.82(1) *(4.6)*	57.62(5) *(4.5)*	60.49(2) *(4.5)*
Nhamatanda	Commercial forest benefits	4557.46(1) *(0.3)*	3443.53(2) *(0.1)*	3075.87(3) *(0.2)*	2459.45(4) *(-0.6)*	2265.78(5) *(-0.1)*
	Household forest benefits	39.58(4) *(-12.0)*	86.96(3) *(3.4)*	182.75(1) *(1.2)*	1.77(5) *(1173.4)*	123.57(2) *(8.5)*
	Household total benefits	34109.2(4) (4)*(31.8)*	34248.6(3) *(31.9)*	34523.4(1) *(31.8)*	33945.5(5) *(31.9)*	34291.0(2) *(31.9)*
	Household total benefits per capita[c]	50.70(4) *(31.8)*	50.91(3) *(31.9)*	51.32(1) *(31.8)*	50.46(5) *(31.9)*	50.98(2) *(31.9)*
Gondola – Maniaca	Commercial forest benefits	6875.17(1) *(0.1)*	5505.90(2) *(-0.0)*	5409.37(3) *(-0.0)*	4030.03(5) *(-0.1)*	4048.49(4) *(0.2)*
	Household forest benefits	12.23(5) *(-41.5)*	60.33(2) *(-2.0)*	87.14(1) *(-3.5)*	25.48(4) *(2.5)*	36.46(3) *(-18.7)*
	Household total benefits	35228.9(4) *(25.2)*	35341.6(2) *(25.2)*	35421.0(1) *(25.2)*	35224.8(5) *(25.2)*	35249.6(3) *(25.2)*
	Household total benefits per capita[c]	49.20(4) *(25.2)*	49.35(2) *(25.2)*	49.46(1) *(25.2)*	49.19(5) *(25.2)*	49.22(3) *(25.2)*

[a] The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b] NC = Non-cooperative, COOP=Cooperative, CM-S=Command Social, CM-E=Command Environment, CM-SE=Command social and environment.
[c] US $ per year

(ii) Potential impact on household sector benefits

Increasing agricultural output prices by 25 and 75% would increase household discounted net forest benefits under all forest management regimes in Dondo, while in Nhamatanda a decline would be realized under the non-cooperative management regime. There would be a decline in Gondola-Manica under all forest management regimes except under the command regime incorporating environmental/biodiversity concerns (Tables 7 and 8). However, the overall impact of a 25% crop output price increase on annual total benefits per capita in the household sector would be positive, ranging from slightly above 4% in Dondo, to 25% in Manica-Gondola and 32% in Nhamatanda, with small differences between forest management regimes (Table 7). On the other hand the potential effect of a 75% crop output price increase on total benefits per capita in the household would be large, ranging from 47% in Dondo to 75% in Gondola-Manica and 85% in Nhamatanda, with minor differences between forest management regimes within a study site (Table 8).

Table 8. Potential effects of a 75% increase in crop output prices on stakeholders' benefits

Study site	Variable	(US $ '000)[a]				
		Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial	5737.33 (1)	4134.24(2)	3551.57(3)	3089.05(4)	2797.29(5)
	forest benefits	*(-0.26)*	*(-1.73)*	*(-0.77)*	*(-4.28)*	*(-2.77)*
	Household forest	107.98(4)	295.45(3)	522.28(1)	79.06(5)	370.87(2)
	benefits	*(23.28)*	*(29.21)*	*(27.23)*	*(268.58)*	*(35.96)*
	Household total	17968.0(4)	18483.6(3)	19224.7(1)	17668.3(5)	18549.7(2)
	benefits	*(46.40)*	*(46.65)*	*(46.75)*	*(46.65)*	*(46.97)*
	Household total	82.38(4)	84.75(3)	88.15(1)	81.01(5)	85.05(2)
	benefits per capita[c]	*(46.40)*	*(46.65)*	*(46.75)*	*(46.65)*	*(46.97)*
Nhamatanda	Commercial forest	4560.64(1)	3440.52(2)	3087.43(3)	2432.82(4)	2258.62(5)
	benefits	*(0.37)*	*(-0.01)*	*(0.60)*	*(-1.65)*	*(-0.37)*
	Household forest	41.29(4)	96.81(3)	199.51(1)	7.71(5)	148.04(2)
	benefits	*(-8.22)*	*(15.01)*	*(10.51)*	*(5446.86)*	*(29.94)*
	Household total	47744.1(4)	47949.3(3)	48328.5(1)	47528.9(5)	48026.0(2)
	benefits	*(84.49)*	*(84.60)*	*(84.51)*	*(84.65)*	*(84.68)*
	Household total	70.97(4)	71.28(3)	71.84(1)	70.65(5)	71.39(2)
	benefits per capita[c]	*(84.49)*	*(84.60)*	*(84.51)*	*(84.65)*	*(84.68)*
Gondola—	Commercial	6880.9(1)	5515.16(2)	5414.7(3)	4022.45(5)	4047.54(4)
Maniaca	forest benefits	*(0.14)*	*(0.16)*	*(0.09)*	*(-0.32)*	*(0.15)*
	Household	5.02(5)	60.55(2)	86.95(1)	29.62(4)	40.49(3)
	forest benefits	*(-75.98)*	*(-1.61)*	*(-3.76)*	*(19.15)*	*(-9.68)*
	Household	49307.4(5)	49473.8(2)	49587.4(1)	49317.3(4)	49406.0(3)
	total benefits	*(75.17)*	*(75.23)*	*(75.23)*	*(75.28)*	*(75.40)*
	Household total	68.86(5)	69.09(2)	69.25(1)	68.87(4)	68.99(3)
	benefits per capita[c]	*(75.17)*	*(75.23)*	*(75.23)*	*(75.28)*	*(75.40)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command Social, CM-E=Command environment, CM-SE=Command social and environment.*
[c] *US $ per year*

As explained earlier the increase in household forest benefits resulting from crop output price increases would result from sale of forest products obtained when converting the forest to cropland (Tables 9 and 10). Such forest benefits would be higher at the 75% than at the 25% crop output price increase, probably because with a 75% crop output price increase more forest land would be converted to cropland (Table 10), a process that would be accompanied by more saleable forest products from the converted land.

The ranking of the forest management regimes in relation to household forest benefits has been maintained as in the base results in all sites. The same appears true in the case of total household benefits from agriculture and forest activities, with the exception of Gondola-Manica, where a switch occurs between non-cooperative and command-environment. The implication could be that the relative suitability of the forest management regimes to individual sites does not appear to be sensitive to or influenced by fairly significant rises in crop output price.

(b) Potential effects on forest or biodiversity conservation

Table 9 shows that a 25% crop output price increase would have an insignificant effect on the area of standing miombo at the end of the simulation period in all three sites when compared to base results. The results are mixed, with both decreases and increases in deforestation. For example, in Dondo, a small decline relative to the base results (less than 1%) is observed under non-cooperative, command with environmental/ biodiversity concern, and command with social concern management regimes. A potential increase in deforestation of less than 1% is indicated in Gondola-Manica under all management regimes.

When the management regimes are ranked in terms of the percentage of standing miombo at the end of the simulation period, the command regime with environmental concerns occupies the first position and the non-cooperative regime occupies the last

Table 9. Potential effects of a 25% increase in crop output prices on woodland conservation[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest labour Proportion)	0.570(1) *(0.5)*	0.335(2) *(-1.2)*	0.243(3) *(-0.4)*	0.227(4) *(-0.4)*	0.190(5) *(-0.5)*
	Household forest labour (Proportion)	0.089(4) *(1.3)*	0.112(2) *(-0.9)*	0.274(1) *(0.7)*	0.004(5) *(27.3)*	0.108(3) *(0.9)*
	Standing miombo (% of initial forest area)	20.46(5) *(-0.6)*	31.22(3) *(0.3)*	29.12(4) *(0.2)*	39.82(1) *(-0.2)*	35.93(2) *(-0.3)*
	Land converted to agriculture (ha)	29.09(4) *(2.3)*	58.80(3) *(2.0)*	113.25(1) *(3.4)*	3.70(5) *(29.8)*	64.70(2) *(2.9)*
Nhamatanda	Commercial forest labour (proportion)	0.492(1) *(0.4)*	0.321(2) *(0.3)*	0.253(3) *(0.8)*	0.186(4) *(-0.5)*	0.162(5) *(0.0)*
	Household forest labour (Proportion)	0.078(4) *(-12.5)*	0.099(3) *(-4.0)*	0.230(1) *(-2.5)*	0.000(5) *(1191.8)*	0.103(2) *(0.0)*
	Standing miombo (% of initial forest area)	25.98(5) *(1.0)*	38.35(3) *(0.2)*	38.05(4) *(0.2)*	45.17(1) *(-0.2)*	44.78(2) *(0.0)*
	Land converted to agriculture (ha)	18.09(4) *(0.3)*	31.33(3) *(8.9)*	63.38(1) *(10.2)*	0.29(5) *(545.9)*	38.25(2) *(12.8)*
Gondola-Manica	Commercial forest labour (Proportion)	0.700(1) (-0.6)	0.460(2) (0.2)	0.440(3) (0.2)	0.278(4) (-0.4)	0.277(5) (0.0)
	Household forest labour (Proportion)	0.070(4) *(-15.4)*	0.099(2) *(-2.4)*	0.164(1) *(-1.8)*	0.014(5) *(-1.4)*	0.088(3) *(-4.9)*
	Standing miombo (% of initial forest area)	18.25(5) *(0.8)*	30.52(3) *(0.2)*	30.33(4) *(0.1)*	36.59(1) *(0.2)*	35.43(2) *(0.2)*
	Land converted to agriculture (ha)	9.82(3) *(-0.9)*	24.80(2) *(11.1)*	37.01(1) *(11.5)*	5.78(5) *(11.4)*	8.87(4) *(7.9)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*

[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

position in all three sites. Nhamatanda and Gondola-Manica have maintained the same rankings as in the base run results.

Producer price increase appears to have the potential to promote forest conversion to agriculture under all management regimes in all three sites except under the non-cooperative regime in Gondola-Manica, where a small decline (less than 1%) is observed in relation to base results, implying that the crop output price increase would not necessarily be accompanied by an increase in deforestation. The response to price increase, in percentage terms, in forest conversion to agriculture is more pronounced under the command regime incorporating environmental benefits in the case of Dondo and Nhamatanda (29.8% and 545.9% respectively, relative to base results) and the non-cooperative regime in Gondola Manica (36% relative to base results). However, in absolute terms, the land area values involved would be very small despite the extremely high percentage changes associated with some management regimes in the tables, and this is also influenced by the initial conditions. Also, the physical area converted to cropland would be higher under the command management regime with social concerns while the command regime with environmental/biodiversity concerns hold potential for least forest area conversion. The model's prediction conforms to Barbier's (2000) observation that in low input agriculture, an increase in output prices will promote area expansion instead of intensification, at least in the short run. Although land conversion has been demonstrated to be responsive to modest price increase, its impact on deforestation would be insignificant largely because the areas involved are small, reflecting the low efficiency implicit in the hand tools used for forest conversion as well as, probably, inadequate adult male labour in the household. Normally men undertake the laborious task of clearing forests when opening new farms.

The impact of a 75% increase in producer price has maintained the same trend of deforestation observed under a 25% price increase (Table 10) in all sites and under all forest management regimes. The rate of deforestation under all forest management regimes has maintained its insensitivity to price changes, from the 25% to the 75% producer price increase. Much as forest conversion to agriculture shows a large percentage increase in comparison to the base results, in absolute terms the change in actual forest area converted to cropland would be small. Again, adult labour and technological constraints would indicate that the response of area converted to agriculture as a result of price increase has little impact on deforestation.

When the management regimes are ranked in terms of the area of standing forest at the end of the simulation period, the command-environment regime occupies the first position, while the non-cooperative regime (implicit of status quo) occupies the last position in all study sites. The results suggest that a compromise between conservation and profit will be found between these two extreme management regimes.

When the alternative forest management regimes are compared with the current practice (non-cooperative regime), they all appear to be better alternatives for forest resource conservation.

If the policy objective is also to improve the forest benefits of rural households, the command regime incorporating social concerns, the command regime incorporating both social and environmental concerns and the cooperative management regime constitute the best three forest management regimes for the study areas. It therefore appears that the government, as well as the local communities, have important roles to play in managing these resources, and that the advocacy on government devolution of management of these resources to local communities might not be appropriate to all natural forests.

Table 10. Potential effects of a 75% increase in crop output prices on labour employment and woodland conservation[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest labour (Proportion)	0.563(1)	0.332(2)	0.243(3)	0.218(4)	0.185(5)
		(-0.70)	*(-2.06)*	*(-0.41)*	*(-4.39)*	*(-3.14)*
	Household forest labour (Proportion)	0.084(4)	0.113(3)	0.271(1)	0.011(5)	0.119(2)
		(-3.43)	*(0.0)*	*(-0.39)*	*(258.73)*	*(11.22)*
	Standing miombo woodlands (% of initial forest area)	20.7(5)	30.8(3)	29.0(4)	39.1(1)	35.5(2)
		(0.50)	*(-1.03)*	*(-0.40)*	*(-2.16)*	*(-1.45)*
	Land converted to agriculture (ha)	32.7(4)	67.4(3)	128.3(1)	10.1(5)	78.68(2)
		(14.987)	*(16.89)*	*(17.13)*	*(254.03)*	*(25.15)*
Nhamatanda	Commercial forest labour (Proportion)	0.497	0.321(2)	0.255(3)	0.181(4)	0.162(5)
		(1)*(1.43)*	*(0.32)*	*(1.59)*	*(-3.21)*	*(0.0)*
	Household forest labour (Proportion)	0.070(4)	0.094(3)	0.224(1)	0.002(5)	0.107(2)
		(-22.12)	*(-8.45)*	*(-5.10)*	*(6787.2)*	*(3.88)*
	Standing miombo woodlands (% of initial forest area)	26.1(5)	38.5(3)	38.0(4)	45.0(1)	44.7(2)
		(1.37)	*(0.5)*	*(-0.08)*	*(-0.53)*	*(-0.13)*
	Land converted to agriculture (ha)	18.7(4)	34.01(3)	69.6(1)	1.2(5)	44.19(2)
		(3.60)	*(18.25)*	*(20.97)*	*(2461.25)*	*(30.35)*
Gondola-Manica	Commercial forest labour (Proportion)	0.706(1)	0.461(2)	0.441(3)	0.278(3)	0.277(5)
		(0.28)	*(0.43)*	*(0.46)*	*(-0.36)*	*(0.0)*
	Household forest labour (Proportion)	0.056(4)	0.095(2)	0.160(1)	0.015(5)	0.087(3)
		(-32.08)	*(-6.44)*	*(-4.19)*	*(7.25)*	*(-5.53)*
	Standing miombo woodlands (% of initial forest area)	18.3(5)	30.5(3)	30.3(4)	36.5(1)	35.4(2)
		(1.16)	*(0.12)*	*(0.07)*	*(0.02)*	*(0.26)*
	Land converted to agriculture (ha)	9.65(4)	28.02(2)	42.5(1)	7.2(5)	19.9(3)
		(-2.62)	*(25.53)*	*(28.04)*	*(39.11)*	*(142.1)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*
[b]*NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

4.2.3 Impact of an increase in crop yields by 25% and 75%

Modest crop yield increases of 25% through improved agronomic practices appear to have the potential to improve total household benefits per capita in all study sites and under all management regimes (Table 11).

This improvement in benefits would be accompanied by increased forest conversion to agriculture in all sites and under all management regimes (Table 12). An exception is observed in the case of the cooperative model in Nhamatanda, where a 5% decline in land conversion to agriculture is predicted. A reduction of about 2% is also observed in Gondola-Manica under the non-cooperative regime. The modest increase in crop yield (or reduction in post-harvest crop losses) would not be sufficient to cover household consumption and income needs, hence the continued increase in deforestation or forest conversion into cropland.

Table 11. Potential effects of a 25% increase in crop yields on stakeholders' benefits (US $ '000)

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial	5743.69(1)	4160.07(2)	3556.73(3)	3138.99(4)	2829.02(5)
	forest benefits	*(-0.1)*	*(-1.1)*	*(-0.6)*	*(-2.7)*	*(-1.7)*
	Household	103.13(4)	271.29(3)	483.37(1)	55.82(5)	333.26(2)
	forest benefits	*(17.7)*	*(18.7)*	*(17.8)*	*(59.3)*	*(22.2)*
	Household	15625.6(4)	16062.3	16706.8(1)	15337.9(5)	16104.0(2)
	total benefits	*(27.3)*	(3)*(27.4)*	*(27.5)*	*(27.6)*	*(27.6)*
	Household total	71.64(4)	73.65(3)	76.60(1)	70.33(5)	73.84(2)
	benefits per capita[c]	*(27.3)*	*(27.4)*	*(27.5)*	*(27.6)*	*(27.6)*
Nhamatanda	Commercial	4557.78(1)	3459.26(2)	3078.67(3)	2457.85(4)	2265.26(5)
	forest benefits	*(0.3)*	*(0.5)*	*(0.3)*	*(-0.6)*	*(-0.1)*
	Household	40.5(4)	68.97(3)	183.39(1)	2.23(5)	124.78(2)
	forest benefits	*(-10.0)*	*(-18.0)*	*(1.6)*	*(1504.3)*	*(9.5)*
	Household	34851.7(4)	34944.7(3)	35272.0(1)	34683.1(5)	35036.2(2)
	total benefits	*(34.7)*	*(34.5)*	*(34.6)*	*(34.8)*	*(34.7)*
	Household	51.81(4)	51.95(3)	52.43(1)	51.56(5)	52.08(2)
	total benefits	*(34.7)*	*(34.5)*	*(34.6)*	*(34.8)*	*(34.7)*
	per capita[c]					
Gondola-Maniaca	Commercial	6881.22(1)	5506.13(2)	5409.2(3)	4029.18(5)	4044.52(4)
	forest benefits	*(0.1)*	*(0.0)*	*(-0.0)*	*(-0.2)*	*(0.1)*
	Household	12.09(5)	62.31(2)	87.06(1)	25.35(4)	36.43(3)
	forest benefits	*(-42.1)*	*(1.3)*	*(-3.6)*	*(2.0)*	*(-18.7)*
	Household	35165.7(4)	35283.5(2)	35357.7(1)	35161.9(5)	35186.5(3)
	total benefits	*(24.9)*	*(25.0)*	*(25.0)*	*(25.0)*	*(24.9)*
	Household total	49.11(4)	49.27	49.38	49.10	49.14
	benefits	*(24.9)*	*(25.0)*	*(25.0)*	*(25.0)*	*(24.9)*
	per capita[c]					

[a] The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*
[c] *US $ per year*

On the other hand, a 75% yield increase would reduce forest conversion to agriculture in Gondola-Manica site under all management regimes (Table 14). In the case of Dondo, land conversion to agriculture would increase under all management regimes, although the increase is smaller than at the 25% price increase with the exception of the three command regimes, which show an increase in forest conversion to agriculture of 12.2%, 157%, 16.4% respectively in comparison to the basic scenario. The results indicate that for the Dondo and Gondola-Manica sites, a high yield increase in agriculture has the potential to reduce deforestation through land conversion to agriculture. In the case of Nhamatanda, land conversion to agriculture declines by 6.2% under the non-cooperative regime and increases under the remaining management regimes (Table 14).

Total household net benefits per capita per year would improve significantly in all sites and under all management regimes in comparison with the base results (Table 13). The improvement in net benefits would range from about 64% in Dondo to slightly above 100% in Nhamatanda. A big improvement in crop yields would appear to significantly

Table 12. Potential effects of a 25% increase in crop yields on employment and woodland conservation[a]

Study sites	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest labour	0.585(1)	0.335(2)	0.242(3)	0.221(4)	0.187(5)
	(Proportion)	*(-0.3)*	*(-1.2)*	*(-0.8)*	*(-3.1)*	*(-2.1)*
	Household forest	0.087(4)	0.114(3)	0.273(1)	0.008(5)	0.115(2)
	labour (proportion)	*(-0.3)*	*(0.9)*	*(0.4)*	*(58.4)*	*(7.5)*
	Standing miombo	20.6(5)	30.8(3)	29.0(4)	39.4(1)	35.6(2)
	woodlands (% of initial forest area)	*(0.2)*	*(1.0)*	*(-0.1)*	*(-1.3)*	*(-1.3)*
	Land converted	31.58(4)	64.26(3)	122.47(1)	7.22(5)	72.94(2)
	to agriculture (ha)	*(11.0)*	*(11.5)*	*(11.8)*	*(53.3)*	*(16.0)*
Nhamatanda	Commercial	0.495(1)	0.322(2)	0.253(3)	0.186(4)	0.162(5)
	forest labour	*(1.0)*	*(0.8)*	*(0.8)*	*(-0.5)*	*(0.0)*
	Household	0.079(4)	0.097(3)	0.230(1)	+0.000(5)	0.103(2)
	forest labour	*(-11.7)*	*(-5.9)*	*(-2.5)*	*(1573.2)*	*(0.0)*
	Standing miombo	25.9(5)	38.5(3)	38.0(4)	45.2(1)	44.8(2)
	woodlands	*(0.7)*	0.4(3)	*(+0.0)*	*(-0.2)*	*(+0.0)*
	Land converted	18.36(4)	27.40(3)	63.76(1)	0.36(5)	38.62(2)
	to agriculture	*(1.8)*	*(-4.7)*	*(10.9)*	*(699.5)*	*(13.9)*
Gondola-Manica	Commercial	0.704(1)	0.460(2)	0.439(3)	0.278(4)	0.277(5)
	forest labour	*(0.0)*	*(0.2)*	*(-0.0)*	*(-0.4)*	*(0.0)*
	Household	0.070	0.099	0.164	0.014	0.088
	forest labour	*(-15.0)*	*(-2.2)*	*(-1.8)*	*(-1.4)*	*(-4.9)*
	Standing miombo	18.2(5)	30.5(3)	30.3(4)	36.6(1)	35.5(2)
	woodlands	*(0.4)*	*(0.2)*	*(0.1)*	*(0.2)*	*(0.4)*
	Land converted	9.74(3)	25.46(2)	36.95(1)	5.75(5)	8.79(4)
	to agriculture	*(-1.7)*	*(14.1)*	*(11.3)*	*(10.8)*	*(6.9)*

[a] The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

increase household food self sufficiency and incomes to the extent that demand for new cropland (excised from the woodlands) would decline, resulting in a decreased rate of forest conversion to cropland.

At 25% and 75% crop yield improvements, the effect on commercial forest benefits would be insignificant (Table 11) largely because of insignificant labour mobility between commercial and household consumption activities. However, the results on household forest benefits would be significant and direction of change indeterminate (Table11).

In terms of the well-being of rural households, the command regime with environmental concern is the only option that would leave the households worse off in relation to the current management practice (open access), with the command regime with social concerns as the best. It would appear than crop yields would have to increase considerably before conversion of woodlands to cropland could be reversed. Only in Gondola-Manica and with crop yields of 75% could forest conversion be reversed (and under all the five management regimes); the other sites would probably need higher crop yields for woodland conversion to stop. These results suggest that policy

Table 13. Potential effects of a 75% increase in crop yields on stakeholders' benefits (US $ '000)[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest benefits	5764.82(1) *(0.2)*	4171.89(2) *(-8.3)*	3564.51(3) *(-0.4)*	3141.93(4) *(-2.6)*	2827.52(5) *(1.8)*
	Household forest benefits	90.47(4) *(3.3)*	264.81(3) *(15.8)*	467.48(1) *(13.9)*	55.37(5) *(158.1)*	326.48(2) *(19.7)*
	Household total benefits	20169.7(4) *(64.3)*	20707.0(3) *(64.3)*	21479.1(1) *(64.0)*	19840.6(5) *(65.0)*	20746.3(2) *(64.4)*
	Household total benefits per capita[c]	92.48(4) *(64.3)*	94.94(3) *(64.3)*	98.48(1) *(64.0)*	90.97(5) *(65.0)*	95.12(2) *(64.4)*
Nhamatanda	Commercial forest benefits	4573.5(1) *(0.7)*	3460.86(2) *(0.6)*	3093.9(3) *(0.8)*	2459.13(4) *(-0.6)*	2274.56(5) *(0.3)*
	Household forest benefits	31.53(4) *(-29.9)*	79.7(3) *(-5.2)*	165.03(1) *(-8.6)*	1.88(5) *(1252.5)*	118.31(2) *(3.8)*
	Household total benefits	52709.5(4) *(103.7)*	52917.8(3) *(103.7)*	53302.7(1) *(103.5)*	52497.9(5) *(104.0)*	52974.1(2) *(103.7)*
	Household total benefits per capita[c]	78.36(4) *(103.7)*	78.66(3) *(103.7)*	79.24(1) *(103.5)*	78.04(5) *(104.0)*	78.75(2) *(103.7)*
Gondola-Manica	Commercial forest benefits	6886.44(1) *(0.2)*	5522.18(2) *(0.3)*	5426.98(3) *(0.3)*	4054.58(5) *(0.5)*	4062.12(4) *(0.5)*
	Household forest benefits	0.01(5) *(-100.0)*	37.67(2) *(-38.8)*	55.37(1) *(-38.7)*	10.69(4) *(-57.0)*	16.67(3) *(-62.8)*
	Household total benefits	49168.7(3) *(74.7)*	49286.7(2) *(74.6)*	49372.5(1) *(74.5)*	49152.6(4) *(74.7)*	49146.1(5) *(74.5)*
	Household total benefits per capita[c]	68.66(3) *(74.7)*	68.83(2) *(74.6)*	68.95(1) *(74.5)*	68.64(4) *(74.7)*	68.63(5) *(74.5)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*
[c] *US $ per year*

intervention leading to only moderate crop productivity improvement might not lead to natural resource conservation, but at a high level of productivity increase, forest conservation could be promoted.

4.2.5 A simultaneous increase in agricultural producer prices and royalty fees

On one hand, an increase in producer prices promotes agricultural expansion, while on the other hand, an increase in royalty fees discourages exploitation of forest products. This interaction is felt by household sector, which performs both activities, while the commercial sector perceives the direct impact of royalty fees increase, and possibly an indirect impact of increases in crop output prices through labour supply reduction.

Table 14. Potential effects of a 75% increase in crop yields on labour employment and woodland conservation[a]

Study Site	Variable	Management Regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest labour (Proportion)	0.569(1) (0.4)	0.337(2) (0.6)	0.243(3) (-0.4)	0.222(4) (-2.6)	0.187(5) (-2.1)
	Household forest labour (Proportion)	0.080(4) *(-8.1)*	0.112(3) -0.9(2)	0.270(1) *(-0.7)*	0.008(5) *(156.5)*	0.113(2) *(5.6)*
	Standing miombo woodlands (Percent of initial forest area)	20.61(5) *(0.1)*	30.98(3) *(-0.5)*	29.17(4) *(0.3)*	39.34(1) *(-1.4)*	35.78(2) *(-0.8)*
	Land converted to agriculture (Ha)	29.99(4) *(5.5)*	54.21(3) *(11.3)*	122.90(1) *(12.2)*	7.26(5) *(154.7)*	73.16(2) *(16.4)*
Nhamatanda	Commercial forest labour (Proportion)	0.498(1) *(1.6)*	0.324(2) *(1.3)*	0.255(3) *(1.6)*	0.186(4) *(-0.5)*	0.163(5) *(0.6)*
	Household forest labour (Proportion)	0.066(4) *(-27.1)*	0.091(3) *(-11.5)*	0.221(1) *(-6.4)*	+0.000(5) *(1172.4)*	0.099(2) *(-4.0)*
	Standing miombo woodlands (Percent of initial forest area)	26.17(5) *(1.8)*	38.54(3) *(0.7)*	38.19(4) (0.5)	45.17(2) *(-0.2)*	44.79(1) *(0.2)*
	Land converted to agriculture (Ha)	16.92(4) *(-6.2)*	31.77(3) *(10.5)*	66.26(1) *(15.2)*	0.31(5) *(599.3)*	39.87(2) *(17.6)*
Gondola-Manica	Commercial forest labour (Proportion)	0.704(1) *(0.0)*	0.462(2) *(0.7)*	0.443(3) *(0.9)*	0.280(4) *(0.4)*	0.278(5) *(0.4)*
	Household forest labour (Proportion)	0.053(4) *(-36.1)*	0.090(2) *(-11.2)*	0.157(1) *(-6.0)*	0.006(5) *(-59.0)*	0.077(3) *(-16.8)*
	Standing miombo woodlands (Percent of initial forest area)	18.36(5) *(1.4)*	30.63(3) *(0.5)*	30.32(4) *(0.1)*	36.84(1) *(0.9)*	35.35(2) *(0.9)*
	Land converted to agriculture (Ha)	6.89(3) *(-30.5)*	20.2(2) *(-9.5)*	31.56(1) *(-4.9)*	2.44(4) *(-53.0)*	0.33(5) *(-95.9)*

[a] The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b] *NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

A 30% increase in royalty fees and a 25% increase in crop output prices were evaluated simultaneously. In the Dondo and Nhamatanda sites, the household discounted net benefits from wood products and total net benefits per capita per year would increase under all management regimes in relation to base results (Table 15). In the case of the commercial sector, the discounted net forest benefits would decline under all management options. Land conversion to agriculture resulting from improved terms of trade (emanating from the increase in agricultural prices with a re-enforcement effect coming from the royalty fees increase) would appear to be responsible for the

Table 15. Potential effects of a 30 % increase in fees and 25% increase in agricultural products prices on stakeholders' benefits (US $ '000)[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest benefits	3608.85(1) *(-37.3)*	2518.23(2) *(-40.1)*	2077.68(3) *(-41.9)*	1804.66(4) *(-44.1)*	1585.50(5) *(-44.9)*
	Household forest benefits	130.67(4) *(49.2)*	293.08(3) *(27.7)*	576.85(1) *(40.6)*	43.25(5) *(101.6)*	377.79(2) *(38.5)*
	Household total benefits	12998.9(4) *(5.9)*	13306.4(3) *(5.6)*	13970.7(1) *(6.6)*	12580.8(5) *(4.6)*	13442.0(2) *(6.5)*
	Household total benefits per capita[c]	59.60(4) *(5.9)*	61.01(3) *(5.6)*	64.06(1) *(6.6)*	57.68(5) *(4.6)*	61.63(2) *(38.5)*
Nhamatanda	Commercial forest benefits	2899.04(1) *(-46.2)*	2153.26(2) *(-37.4)*	1913.27(3) *(-37.7)*	1317.47(4) *(-46.7)*	1206.49(5) *(-46.8)*
	Household forest benefits	56.32(4) *(25.8)*	100.46(3) *(19.4)*	206.17(1) *(14.2)*	3.80(5) *(2633.8)*	127.51(2) *(11.9)*
	Household total benefits	34196.6(4) *(32.1)*	34282.5(3) *(32.0)*	34620.6(1) *(32.2)*	33947.6(5) *(31.9)*	34354.4(2) *(32.1)*
	Household total benefits per capita[c]	50.83(4) *(32.1)*	50.96(3) *(32.0)*	51.47(1) *(32.2)*	50.46(5) *(31.9)*	51.07(2) *(32.1)*
Gondola-Manica	Commercial forest benefits	4423.66(2) *(-35.6)*	5524.66(1) *(0.3)*	3398.43(3) *(-37.2)*	2259.71(4) *(-44.0)*	2259.18(5) *(-44.1)*
	Household forest benefits	18.39(5) *(-12.0)*	50.77(2) *(-17.5)*	100.78(1) *(11.5)*	42.38(3) *(70.5)*	41.70(4) *(-7.0)*
	Household total benefits	35269.50(2) *(25.3)*	28214.7(5) *(-0.1)*	35570.8(1) *(25.2)*	5240.7(4) *(25.3)*	35268.6(3) *(25.2)*
	Household total benefits per capita[c]	49.25(2) *(25.3)*	239.40(5) *(-0.1)*	49.59(1) *(25.5)*	49.21(4) *(25.3)*	49.25(3) *(25.2)*

[a] *The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.*
[b]*NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*
[c]*US $ per year*

increase. The increase in net benefits from wood products would come from the wood obtained in the process of land conversion to agriculture. In the Gondola-Manica site, an increase in total household benefits would materialize under the three management variants of command model, while a decline is predicted cooperative model.

With regard to the policy impact on the forest resource, it is observed that in all three sites, the percentage of standing woodland would increase in relation to the base results (Table 16). This improvement would basically be due to a significant decline in exploration by the commercial sector. The observed large percentage increase in land conversion to agriculture would, however, translate to a small land area largely due to constraints on availability of household male labour for forest clearing and the rudimentary technology for the job (mainly hand tools).

As compared to Table 9, more land would be converted to cropland (Table 16) due to the increased labour availability that would result from decreased commercial

Table 16. Potential effects of a 30 % increase in fees and 25% increase in agricultural products prices on labour employment and woodland conservation[a]

Study site	Variable	Management regime[b]				
		NC	COOP	CM-S	CM-E	CM-SE
Dondo	Commercial forest	0.479(1)	0.292(2)	0.202(3)	0.156(4)	0.129(4)
	labour (Proportion)	*(-15.5)*	*(-13.9)*	*(-17.2)*	*(-31.6)*	*(-32.5)*
	Household forest	0.110(4)	0.133(3)	0.321(1)	0.006(5)	0.137(2)
	labour (Proportion)	*(25.9)*	*(17.7)*	*(18.0)*	*(91.1)*	*(28.0)*
	Standing miombo	24.20(5)	32.66(3)	29.46(4)	46.78(1)	43.68(2)
	woodlands	*(17.5)*	*(4.9)*	*(1.3)*	*(17.2)*	*(21.2)*
	(Percent of initial forest area)					
	Land converted	49.26(4)	83.38(3)	163.09(1)	6.81(5)	103.88(2)
	to agriculture (Ha)	*(73.2)*	*(44.6)*	*(48.9)*	*(139.0)*	*(65.2)*
Nhamatanda	Commercial forest	0.440(1)	0.292(2)	0.233(3)	0.122(4)	0.107(5)
	labour (Proportion)	*(-10.2)*	*(-8.7)*	*(-7.2)*	*(-34.8)*	*(-33.9)*
	Household forest	0.098(4)	0.119(2)	0.252(1)	0.001(5)	0.111(3)
	labour (Proportion)	*(8.8)*	*(15.5)*	*(6.8)*	*(3012.8)*	*(7.8)*
	Standing miombo	29.61(5)	40.79(3)	39.39(4)	50.38(1)	50.15(2)
	woodlands	*(15.1)*	*(6.5)*	*(3.7)*	*(11.3(1)*	*(12.0)*
	(Percent of initial forest area)					
	Land converted	28.40(4)	42.78(3)	83.10(1)	0.70(5)	49.71(2)
	to agriculture (Ha)	*(57.4)*	*(48.8)*	*(44.5)*	*(1459.0)*	*(46.6)*
Gondola-Manica	Commercial forest labour (Proportion)	0.608(1)	0.461(2)	0.387(3)	0.188(4)	0.186(5)
		(-13.6)	*(0.4)*	*(-11.8)*	*(-32.6)*	*(-32.8)*
	Household forest labour (Proportion)	0.084(4)	0.095(3)	0.182(1)	0.018(5)	0.097(2)
		(1.2)	*(-6.0)*	*(9.0)*	*(33.3)*	*(5.0)*
	Standing miombo	22.82(5)	30.65(4)	34.67(3)	45.02(2)	45.13(1)
	woodlands	*(26.1)*	*(0.6)*	*(14.5)*	*(23.3)*	*(27.7)*
	(Percent of initial forest area)					
	Land converted	17.87(3)	20.39(2)	54.81(1)	10.6(5)	14.22(4)
	to agriculture (Ha)	*(80.3)*	*(-8.6)*	*(65.1)*	*(104.2)*	*(73.0)*

[a] The figures in italics represent changes in% from the corresponding base results, and the figures in roman parentheses are the ranking of the management regimes.
[b]*NC = Non-cooperative, COOP=Cooperative, CM-S=Command social, CM-E=Command environment, CM-SE=Command social and environment.*

activities. The combined policy strategy (forest fees/royalty and crop output price increases) also has potential to improve forest conservation, as illustrated by the greater area of standing miombo woodlands that is predicted to be there at the end of the simulation period (Table 16) as compared with a policy strategy that relies only on increasing forest fees (Table 9).

The simultaneous increase in crop yields and royalty fees demonstrated similar behaviour to that observed for the price-royalty fees combination. While the commercial sector's net benefits were predicted to decline, those of the household sector would increase. In relation to base results, the percentage of standing forest at the end of simulation period was predicted to improve in all sites and under all management options. As expected, labour employment for miombo activities by the commercial sector was observed to decline and only increase in the household sector.

5. SUMMARY AND IMPLICATION OF THE RESULTS

1. The results show that improvement in the well-being of woodland dependent households and resource conservation can be achieved with sound management practices. These results show that the command regime incorporating social concerns and the command regime incorporating social and environmental concerns have the potential to provide higher benefits to the household sector than the open access regime. The command management regime incorporating social concerns has the potential to raise discounted net benefits from wood products by over 300% in all three sites relative to the non-cooperative management regime. In the case of the command arrangement incorporating social and environmental concerns, this increase would range from slightly over 100% in Gondola-Manica to about 200% in Dondo. This means that command management regime incorporating social concerns and the command regime incorporating social and environmental concerns have the potential to improve the well-being of the rural communities and encourage forest conservation only if these benefits were actually felt at the community level.

   The results on the cooperative management regime show that both the local communities and the commercial sectors could gain under this arrangement. Although the commercial sector will have to forgo some direct benefits in favour of the household sector, the cost saving emanating from the reduction of conflicts between the two sectors might induce this cooperation. In the case of Mozambique, where the land law permits the communities to enter into partnership with private sector in managing and using natural forest resources the results show that such cooperation is potentially beneficial to local communities if properly implemented, and further, this could be the best option given that the benefits arising from the command model do not actually reach the other stakeholders.
2. Sectoral policies in the form of fees charged on various forest products manifest their impact on the forest resource mainly through commercial sector activities in the form of a reduction of harvesting activities, when there is no compensation in the form of an increase in sales price. In the case of the household sector, short-term compensation would be achieved through land clearing for agriculture. The reduced employment resulting from reduced private sector activities could have negative ramifications for rural development, if complementary policies are not put into place to create alternative employment opportunities. Promotion of small-scale rural agro processing industries through public investment in rural roads, electricity and water infrastructure and tax incentives are potential intervention measures to create rural employment alternatives.
3. The extrasectoral policies, particularly those directed at promotinge agricultural production, have both positive and negative effects on forest development. Our results show that modest price and productivity increases in agriculture

would not encourage significant woodland clearing for cropland. Reduction in land clearing for agriculture would be achieved only if improvement in agricultural production technology leads to a large increase in productivity. Further, the impact of these policies on the forest resources and the welfare of stakeholders would be influenced by the management regime in place.

4. The impact of management regime and/or policy intervention on the welfare of stakeholders and on the forest resource will depend on the amount of natural resource endowment and the initial economic conditions on the ground. While the general direction of policy or institutional change can be predicted, the actual impact will depend on the initial conditions, which are site specific. In addition, the results show that there is no management regime capable of satisfying all goals; that is, a trade-off between goals is necessary.

ENDNOTES

1. Nash based strategies, are the choices made such that each player's strategy is an optimal response to the opponents' strategies.
2. Concession is the right of use of land under specified conditions and period.

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ANNEX 1. SOME MIOMBOSIM COMPONENTS FOR MOZAMBIQUE

A. Household Sector

A non-separable household model is assumed since the communities operate in an environment with incomplete markets. A representative household is assumed to maximize utility derived from income (I) and leisure ($T=L^{max}-L$)

$$U(I,\ T)=(I-I^{min})+v(L^{max}-L) \qquad (1)$$

where:

I=gross income of the household
I^{min}=subsistence consumption
L^{max}=Maximum labour available from the household
L=labour used by household in activities undertaken
, are parameters of the utility function

The shadow wage (z) is obtained by total differentiation of the utility function and is presented in equation 2.

$$z = z(I,L) = -\frac{U_T}{U_I} = \frac{v\beta(I - I^{min})^{1-\alpha}}{\alpha(L^{max} - L)^{1-\beta}} \qquad (2)$$

The allocation of labour is made such that the marginal return to labour is the same across all activities and equal to the shadow wage. The production activities performed by the households are divided into three categories, namely: agriculture, harvesting of miombo wood and non-wood products and off-farm/off-miombo employment. For this model non-wood products have been excluded for lack of data. Wood products included are poles, firewood and charcoal (energy). The gross income and labour utilization are presented in the accounting equations 3 and 4 respectively

$$I_h=I_m+I_a+I_{of} \qquad (3)$$

$$L_h=L_m+(L_a+L_n)+L_{off} \qquad (4)$$

where:
h=household, a=agriculture, off=off-farm/off-miombo, n=new converted land. L_n =labour required for converting land to agriculture and L_a =labour required to cultivate land currently under agriculture.

i. <u>Income from agriculture and decision to convert miombo woodlands to agriculture</u>
In the model the income from agriculture is a sum of the income from the different agricultural enterprises practiced by a typical household as described in the descriptive results (Mlay *et al.* 2003). Optimal use of purchased inputs (where applicable) is determined from an additive production function presented in equation 5.

$$x=a+bl+cf^{d} \quad (5)$$

where: x =crop yield per hectare, l=labour requirement per hectare and f=purchased input per hectare and a, b,c, and d are parameters to be estimated.

Optimal input use is derived from first order conditions of gross margin maximization. On the basis of optimal quantities of purchased inputs and corresponding yields, net income from agriculture can be obtained on the basis of equation 6.

$$I_a=(P_a x-P_a f)H_a \quad (6)$$

Labour to be employed in agriculture is obtained by equation 7.

$$L_a=lH_a \quad (7)$$

where H_a is total land under agriculture, which is equal to the sum of the initial land under agriculture (H_i) and new land converted to agriculture (H_c).

The decision on whether to convert miombo woodlands to agriculture is made by comparing the net benefits from a hectare converted to agriculture (B_a-zl_c) with benefits from miombo wood products per hectare (B_m)

where:

$$B_a=P_a x-P_f f-zl \quad (8)$$

The conversion cost should be convex in land cleared to reflect increased labour as distance increases from the homestead. A convex labour function as presented in equation 9 is used.

$$l_c = gH_n^{\tau} \quad , \quad \tau > 1 \quad , g>0 \quad (9)$$

where H_n= new land converted to agriculture, l_c=labour requirement per hectare and and g area parameters

The total labour required to convert land to agriculture is given by equation 10.

$$L_n = \int_0^{H_n} gx^{\tau} dx = g\frac{1}{\tau+1}H_n^{\tau+1} \quad (10)$$

If B_a-zl_c>B_m for all positive values of H_n land will be converted to agriculture. If B_a-zl_c< B_m then no conversion will take place. Conversion of miombo woodlands to agriculture will continue until B_a-zl_c=B_m.

It should be noted that in the conversion process there are one-time benefits coming from the wood cleared (if it is used for poles, energy) which are accounted for in the model.

ii. Miombo activities

The households are assumed to harvest wood products for energy (firewood and wood for charcoal making) and building poles. The gross income from miombo activities would be given by equation 11.

$$I_m = P_{ave} H_m \tag{11}$$

where H_m is the volume of miombo wood harvested for poles and fuel (firewood and charcoal) and P_{ave} is a weighted price of the two products

The allocation of the total volume between energy (H_{fw}) and poles (H_{po}) is given by equations 12 and 13 respectively.

$$H_{fw} = \frac{P_{fw} H_m}{(P_{po} + P_{fw})} \tag{12}$$

$$H_p = \frac{p_{po} H_m}{(P_{po} + P_{fw})} \tag{13}$$

The volume of miombo products to be harvested by the household sector depends on the volume of standing miombo (N) and labour allocated for this activity (L_m). A Cobb-Douglass function as presented in equation 14 is used to depict the functional relationship.

$$H_m = q_h N^{\mu} L_m^{\psi} \quad 0 < \mu < 1,\ 0 < \psi < 1 \tag{14}$$

where q_h is the household efficiency parameter, μ and ψ are partial elasticities of production.

iii. Off farm/off-miombo activities

The income from off-farm/off-miombo activities depend on the wage rate (w) and labour allocated to these activities (L^{of}) as depicted by equation 15.

$$I^{of} = wL^{of} \tag{15}$$

B. Commercial Sector

The commercial sector component of the model is simpler than the household sector since it involves only one activity logging. The decision here is how much miombo to harvest each year in order to maximize total discounted benefits. The harvesting and net benefit functions for the commercial sector are presented in equations 16 and 17 respectively.

$$H_c = q_c N^{\mu} L_c^{\psi} \; ; \quad 0 < \mu < 1, \; 0 < \psi < 1 \qquad (16)$$

where q_c is the harvest efficiency parameter for the commercial sector. Since the harvesting process is semi mechanized, the private sector efficiency parameter is larger than that for the household sector.

$$B_c = p_c H_c - kL_c \qquad (17)$$

where k=is the wage rate exogenously determined, p_c price of a cubic meter of logs.

The labour used by the commercial sector is part of the labour available from the household sector.

C. Institutional Component

As was pointed out earlier, in Mozambique land belongs to the state and its use and the resources therein is regulated by the government to maximize society-wide benefits, which include direct economic benefits, social benefits (B_s) and environmental benefits (B_e). The problem the government or regulator faces is to determine the volume of miombo to be harvested by each sector in each year in order to maximize society-wide objectives.

Defining B_h as household private net benefits and B_c as commercial sector private net benefits, the social (s) and environmental (e) benefits (B) can be presented as follows:

$$B_s(\theta_c H_c, \theta_h H_h), \qquad (18)$$

$$\phi B_e(N - H_c - H_h) \text{ or } \phi B_c(H_c + H_h)$$

Where: (19)

$$\frac{\partial B_s}{\partial (N - H_c - H_s)} > 0 \text{ or } \frac{\partial B_s}{\partial (H_c + H_h)} < 0$$

Where:

a) $_h$ $_c$ are parameters reflecting the social preference of the society given to a participant in harvesting miombo wood products. The parameters take a value of 0 if there is no social preference and 1 if there is social preference. In the model $_h$ is assigned a value of zero and $_c$ is assigned a value of 1 indicating that the household sector is given social preference in harvesting miombo wood products.
b) ϕ is a parameter to capture society-wide concern about environment. It is assigned a value of 1 if the society cares about the environmental benefits and 0 otherwise.

D. Miombo woodland dynamics

The ecology of miombo is represented by a regeneration equation (equation 20), where a constant annual regeneration rate is assumed and miombo stock equation (equation 21). The two equations are presented below.

$$R_t = K_t \qquad (20)$$

$$N_t = sN_{t-1} + R_t - H_{c,t} - H_{h,t}; \qquad (21)$$

N_o is the initial stock of miombo woodlands, s is the survival rate.
For the implementation of the model, area under miombo and average volume per hectare of wood products were used.

21.

A system dynamics model for management of miombo woodlands in two communal areas of Zimbabwe

C. Sukume and E. Guveya

ABSTRACT

This paper reports results on the use of a systems dynamic model of woodland management (MIOMBOSIM) to two communities in communal areas of Zimbabwe – one abundant and the other less abundant in woodlands resources. The relatively well-endowed community borders the Mafungautsi Forest Reserve in Gokwe. The less endowed site was Mutangi in Chivi area. The objective of the modelling exercise was to simulate the effects over time of changes in agricultural and other economic policies on how local communities use woodlands under an open access regime and under institutional constraints imposing biodiversity concerns.

The simulations point to the following basic conclusions: a) rate of deforestation is higher in resource abundant areas; b) enforcing biodiversity requirements in a resource abundant area reduces deforestation at a lower cost in terms of loss in household benefits from woodland use compared to a resource poor area; c) increase in agricultural crop output price increases deforestation; d) decline in crop yields reduce deforestation; and e) increases in agricultural input prices and decrease in the income for basic needs produced indeterminate impacts on deforestation.

Key words: Woodlands, system dynamics, communal area, Zimbabwe.

1. INTRODUCTION

The total surface area of Zimbabwe is about 39 million hectares of which 41% is occupied by woodlands (Chipika and Kowero 2000). Close to a quarter of these woodlands consists of miombo woodlands, an African woodland dominated by *Brachystegia* species, either in pure stands or in association with *Julbernadia* and/or

Isoberlinia species (Chipika and Kowero 2000). The woodlands provide the bulk of the forest products required by the rural populace as well as serving the wood resource needs of many urbanites.

History and recent social changes have had a significant impact on the plight of miombo woodlands in Zimbabwe. Segregatory policies during pre-independence period led to the majority indigenous people being confined to agro-ecologically poor and crowded areas known presently as communal areas. The continually growing pressure for cultivation land and pastures has led to massive degradation of miombo in the communal areas. Deteriorating economic conditions especially during the 1990s, which led to massive retrenchments of workers, escalating cost of living and removal of government subsidies (Chipika and Kowero 2000) added to the burden of communal areas. The traditional role of communal areas being places of last refuge has meant that most retrenched workers come into these areas, worsening the impact on the woodland resources and the economic conditions of the households.

The above factors tend to encourage people to increase reliance on the woodlands for additional agricultural and pasture land. They could also provide an incentive to rural communities to increase harvesting of the woodlands for products for sale to supplement incomes. These and other activities have potential for deforestation and/or degradation of the woodlands. In Zimbabwe, we would expect factors affecting agriculture to have a particularly significant impact on woodland degradation. Unlike in countries such as Tanzania and Mozambique where a well-developed commercial market for charcoal exists, most woodland use in communal areas of Zimbabwe is in the form of wood for domestic use and clearing for agricultural production. Campbell *et al.* (1993), based on analysis of aerial photos, note that most deforestation is largely due to land clearing for cultivation.

The miombo in communal areas is used and managed under weak common property arrangements. In recent years, concerted effort has gone into attempts to strengthen management regimes for these woodlands (for example CAMPFIRE)[1] as a way of conserving and unlocking latent non-exploitative benefits from the woodlands. Designing institutions and strategies to protect these resources requires tools that can mimic the implications of alternative management regimes and policies.

The main problem in the woodland areas is one of reconciling the interests of key stakeholders. The local communities would want to continue relying on the woodlands for the many needs already mentioned. At the same time society in general is interested in sustained supply of goods and services of a public good character that can only be safeguarded if environmental protection measures guide management of the woodlands. All these demands have to be met in an environment of rapidly changing socio-economic policies that guide economic development in Zimbabwe.

In this paper, we develop and test a simulation model of miombo woodland management adapted from a generalised community miombo woodlands management model developed by Sumaila *et al.* (2001), on communities in Gokwe and Chivi. The model demonstrates the potential impacts of key sectoral and macroeconomic policies on local community benefits derived from the woodlands as well as potential environmental implications. This way the model serves as a potentially useful tool for rural development planning as specific hypotheses associated with the policies can be evaluated.

The paper is organised as follows. The next section provides a description of the two communities of Gokwe and Chivi that were the basis of the study. It is followed by an overview of the Sumaila *et al.* (2001) conceptual framework as well as modifications made to adapt the model to the prevailing situations at the project sites. Section 4 presents the data used to run the model while section 5 presents and discusses simulation results of impacts of different policy scenarios and management regimes. The last section gives a summary of major conclusions from the study.

2. DESCRIPTION OF STUDY SITES

The two districts, Chivi and Gokwe, within which the study sites are located, were purposely selected as they have differing agricultural potential, and settlement history. In Chivi, Mutangi, a dam catchment area was selected while in Gokwe, villages within a radius of about 30km from the Mafungautsi state forest were selected. Mutangi is 6 km on a gravel road from the main tar road running through Chivi business centre. The site is 80 km from Masvingo town and 19 km from Chivi business centre.

Chivi communal area, the major part of Chivi district, covers 3534 km^2. Its administrative centre is Chivi business centre, an old settlement established in the early part of the 20th century. Chivi was settled by its forefathers in the mid 19^{th} century. At the turn of the century the estimated population of Chivi district was only around 15 000 (Scoones *et al*. 1996). By 1930 the population had grown to an estimated 28 500, in part due to population movements in the reserves brought about by the implementation of the Land Apportionment Act of 1930 which set aside large tracts of land for the exclusive use of white settlers. Census figures in 1962, 1969 and 1982 showed district populations of 57 220, 80 580 and 103 656, respectively (CSO 1985). The 1992 census shows a total population for Chivi district of 157 428, with a growth rate of 1.98% and a population density of 44.5 people per square km. Campbell *et al*. (2001) calculated population densities at 58.2 people/km^2 for Mutangi.

Long-term mean annual rainfall at Chivi business centre is 545 mm (1913-2001). On average, 89% of this annual rainfall is received during the summer rainy season from November to March. However, rainfall amount, intensity and distribution are highly variable, and inter-annual variation is large (Campbell *et al*. 2002). The long-term mean has a standard deviation of 207 mm or coefficient of variation of 38 per cent. Droughts are recurrent in the region, and the most recent in 1991/92 was the worst on record, when only 83 mm of rain fell in the district. The rainfall average in Mutangi is 550 mm. Mutangi is a dam catchment utilised for irrigation, fishing, and water supply for domestic and livestock use by the local community. The soils are very poor and the area is very prone to droughts. Due to high population pressure, woodlands are being cleared for arable land, and to meet firewood and construction wood needs of the community.

The dominant vegetation in Mutangi is the woodland that forms an enclave of approximately 360 square kilometres surrounded by about five villages who share it (Campbell *et al*. 2002). The top three dominant tree species found in the area are *Colophospermum mopane*, *Terminalia sericea* and *Acacia tortilis*. Fruit trees also occur but are relatively scarce. Examples of the most commonly occurring fruit trees are *Diospyros mespiliformis*, *Azanza garckeana*, *Berchemia discolor* and *Ficus sycomorus*. Other forest products like honey, mushrooms, and medicinal plants also occur in the woodlands. There is very little wild game except for small animals like rabbits that can be found in some parts of the woodland. The woodland is mainly utilised as a grazing area for livestock, source of firewood, construction poles and occasionally as a source of fruits and other non-timber forest products (NTFPs).

The study area in Gokwe was one of communities surrounding the Mafungautsi state forest. Villages included in the survey are within a radius of 30 km from the western edges of the Mafungautsi state forest and about 50 km from Gokwe business centre. These communities have settled in the area for less than 70 years. The communities are still relatively sparsely settled and most areas are still covered by woodlands. Furthermore the communities have access to the Mafungautsi State Forest, a protected forest covering an area of 82 659 hectares (Vermeulen 1997). Villages located near the boundaries can access a total area of about 600 square kilometres of the forest.

Mafungautsi State Forest is entirely situated on the Mafungautsi plateau, one of the most northerly extensions of the Kalahari sands in Zimbabwe (Vermeulen 1997). The soils are dystrophic with poor water holding capacity. Mean annual rainfall for the area is around 819 mm. The forest is very dense with many tall and old trees. The dominant tree species is the *Terminalia sericea*, while important commercial timber species such as *Baikiea plurijuga* and *Pterocarpus angolensis* are also abundant. Many fruit trees can still be found within the forest. Wild game especially warthogs and antelopes still occur in large numbers in the forest. During the wet season, mushrooms sprout quite extensively in most parts of the forest. In addition, communities surrounding the forest are allowed to graze their livestock, collect dead wood and NTFPs like mushrooms, thatch and broom grass. However, the communities are not allowed to cut down trees, collect honey or hunt game.

3. CONCEPTUAL MODEL

To simulate potential impacts of different policies on woodlands use and condition, the study adopted a simulation model in Sumaila *et al.* (2001). The household is assumed to maximise utility (U (.)), which is a function of income(I) net of subsistence requirements(I^{min}) and leisure(L^{max} - L). That is

$$U(I,T) = (I - I^{\min})^{\alpha} + v(L^{\max} - L)^{\beta} \quad (1)$$

where:

- I =gross household income
- I^{min} =value of subsistence consumption
- L^{max} =maximum labour available to the household
- L =labour used by the household in all income generating activities; and

and are parameters of the utility function.

Based on the utility specification in equation (*1*), the shadow wage (z) is obtained by total differentiation of the utility function to yield (See Sumaila *et al.* 2001),

$$z = z(I,L) = -\frac{U_T}{U_I} = \frac{v\beta(I - I^{\min})^{1-\alpha}}{\alpha(L^{\max} - L)^{1-\beta}} \quad (2)$$

The household derives income from use of labour and other resources in three principal activities – agricultural related activities (I_a), woodland related activities (I_m) and off farm and off-woodland activities (I_{of}). The gross household income (I) is thus

$$I = I_m + I_a + I_{of} \qquad (3)$$

It is assumed in the model that a fixed proportion of labour available (L_{of}) is devoted to off-woodland/off-farm employment at a fixed wage rate (w):

$$I_{of} = wL_{of} \qquad (4)$$

At any given time, total labour usage (L) consists of labour use in woodland activities (L_m), labour use on existing agricultural land (L_a), labour use on newly converted agricultural land (L_n) and labour use in off-woodland/off-farm activities as represented by equation 5.

$$L = L_m + L_a + L_n + L_{of} \qquad (5)$$

Income from agricultural activities

Farm income per hectare is the product of yield (x) and area cropped (H_a) where yield or output, x, is a function of labour per hectare (l) and fertiliser per hectare (f):

$$x = a + bl + cf^d \qquad (6)$$

where a, b, c, d are parameters to be identified using field data.

If revenue per hectare or agricultural output price is P_a and cost of fertiliser per hectare is P_f, profit maximisation implies optimal fertiliser requirement of

$$f = \left(\frac{P_f}{cdP_a} \right)^{\frac{1}{b-1}} \qquad (7)$$

and income from agriculture is given by

$$I_a = (P_a x - P_f f) H_a \qquad (8)$$

The implied labour, L_a, requirements for the cultivation of H_a hectares (the sum of initial agricultural land H_i plus newly converted agricultural land H_n) is assumed to be

$$L_a = lH_a \qquad (9)$$

where l is labour required per hectare.

Whether or not the household expands area under agriculture and by how much will depend on the extra benefits it derives from agriculture compared to benefits from woodland activities taking into account the costs of wood clearance as well as the benefits from wood products from the clearance process.

Benefits per hectare of clearing and cultivating new land, B_a, consist of per unit land benefits from cultivating, less the costs of clearing (zl_c):

$$B_a = P_a x - P_f f - z l_c \tag{10}$$

where labour per hectare required to clear land, l_c, increases the more the household has to move to clear land. That is

$$l_c = gH_n^{\tau}, \tau > 1, g > 0 \tag{11}$$

where H_n is land cleared of woodlands and and g are parameters.

Given the specification of (11), total labour, L_n, required to clear land at any given time is

$$L_n = \int_0^{H_n} g x^{\tau} dx = g \frac{1}{\tau + 1} H_n^{\tau + 1} \tag{12}$$

If benefits from woodlands are greater than those from agriculture on converted land, no land will be converted to agriculture. However, if the reverse is true, forests will be converted to agriculture up to the point when marginal benefits from woodlands just equal marginal benefits from converted land less costs of land clearing.

Woodland activities

The products harvested from woodlands are mainly fuelwood (H_{fw}) and poles (H_{po}). Due to lack of information, non-timber forest products were not included in the calculation of net benefits from miombo woodlands. What proportion of the forest product harvested is used as poles and fuelwood was determined by the relative prices of each product. The proportion of area harvested for fuelwood, H_{fw}, was estimated as

$$\mathrm{H_{fw}} = \frac{\mathrm{P_{fw} H_m}}{\mathrm{P_{fw} + P_{po}}} \tag{13}$$

where:

H_m is the total area of woodland harvested for fuelwood and poles,
P_{fw} is the price of fuelwood/firewood (these terms are used interchangeably in this text),
P_{po} is the price of poles.
Similarly for poles, H_{po}, was estimated as

$$H_{po} = \frac{P_{po} H_m}{(P_{fw} + P_{po})}, \tag{14}$$

Meanwhile, the total harvest function for woodlands was formulated as a Cobb-Douglas function of existing stocks of woodlands and labour:

$$H_m = q_h N^{\mu} L_m^{\psi}, 0 < \mu < 1, 0 < \psi < 1 \tag{15}$$

where:
N is the volume of standing woodland (stock),
μ and ψ are parameters of the harvest function, each assumed to be 0.5 in the model, q_h is the harvest efficiency coefficient, that is, the proportion of the total woodland resources that can be cleared using all the capacity available to the households in a given period.

If P_{ave} is the weighted average price of poles and fuel wood, income from wood harvested can be presented as:

$$I_m = P_{ave} H_m \tag{16}$$

Woodland growth dynamics

Given the encroachment on forests implied by the relationships in previous sections, the state of the resource stock at any given time (N_t) is postulated to depend on the stock in the previous period, its natural survival rate(s) and the regeneration (R_t) (equivalent to the volume, K_t, created in a given year) as well as the amount, H_t, harvested in the year. This is captured by the following relationships:

$$R_t = K_t \tag{17}$$

$$N_t = sN_{t-1} + R_t - H_t \tag{18}$$

Objectives in management

The most fundamental modification to the conceptual model in Sumaila, *et al.* (2001) is that we have only one player or participant group here, and that is the household. There is no commercial or private sector in the two sites. So, the model is a sole owner/player/user model, which operates basically by an assumption that the interests of the members of the group are coordinated. However, environmental concerns are incorporated to reflect the desire to guide communities towards taking care of the woodlands as reflected in the growing emphasis worldwide on communities to manage such resources sustainably. When undertaking a participatory rural appraisal (PRA) of the two sites it was observed that there were local attempts to manage the woodlands, though they were taking off fairly slowly in Chivi. Further, woodland management approaches brought to the communities by outsiders were reported as weak, irrelevant and detached from existing social structures.

Figure 1 presents the steps taken by households on these two sites in making decisions on the allocation of woodland resources to either agricultural production or woodland use. It provides guidance on how to mathematically formulate the model.

For each site and at any time *t*, there is an area Nt of woodlands, a portion of which is initially under agriculture cultivation, denoted *Na,* and area *Nm,* which remains forested and available for future use as poles, *Hpo,* and fuelwood, *Hfw,* as well as for conversion to agricultural land, *Ha.*

The communities in these two sites are assumed to seek to maximise the present value, *B*, of net benefits derived through their allocation of labour to woodland, agricultural and off-farm/off-woodland activities over time. Following the logic of Figure 1 the objective in decision making by the household is summarised by the following function:

$$\max_{L}\sum_{t=1}^{T}\rho_{t-1}[B_t]=\rho_{t-1}[B_h(H_{h,t})+\theta B_e(N_t - H_{h,t})]$$

Subject to:

$$N_t = sN_{t-1}+K_t-H_{h,t} \qquad (19)$$

$$L = L_{m,t}+L_{a,t}+L_{n.t}+L_{of,t}$$

where:

B_h = benefits to households

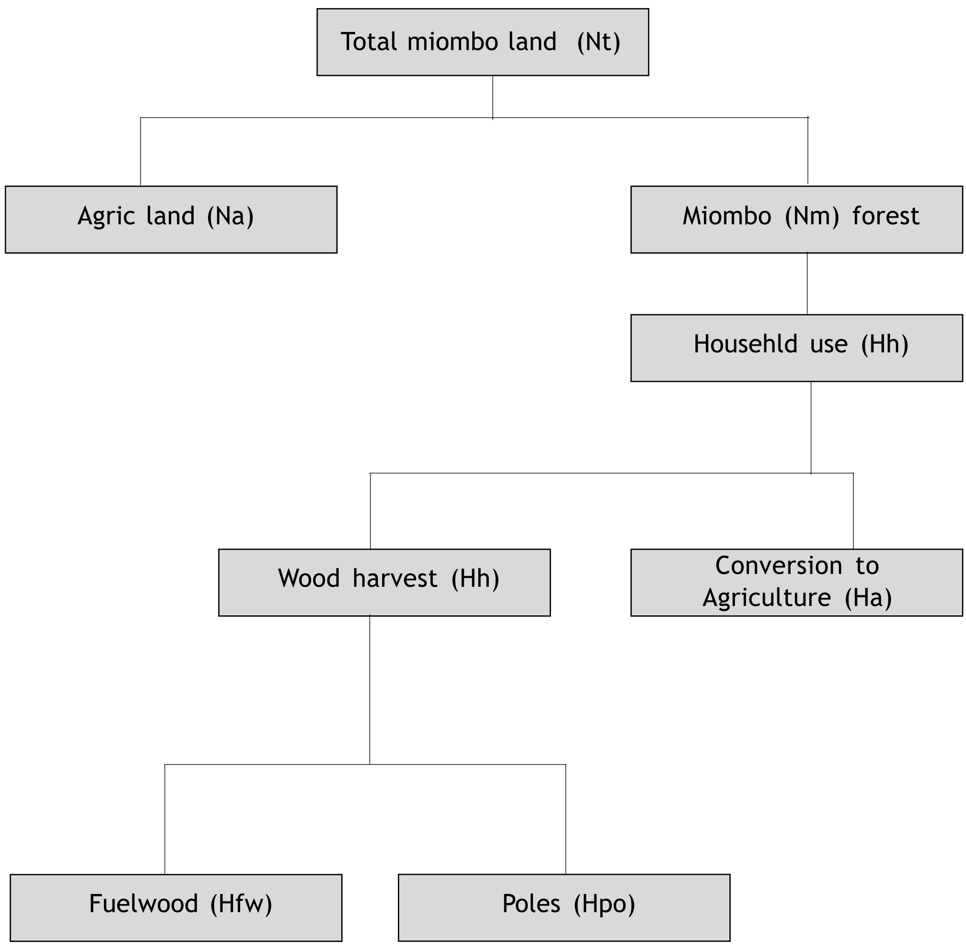
= discount factor

B_e = environmental benefits

θ = weight attached to woodland harvests to reflect concern for environment. θ =0 implies no environmental concern, and θ >0 implies the opposite.

and s is the survival rate of the woodlands.

Figure 1. Steps in decision making by the households in Gokwe and Chivi



In the above equations,

$$B_{h,t} = I_{m,t} + I_{a,t} - zL_{c,t} \qquad (20)$$

$$B_e = B_e(N_t - H_{h,t}) \qquad (21)$$

where $H_{h,t}$ is woodland susceptible to agricultural encroachment and harvesting for poles and firewood. B_e is such that

$$\frac{\partial B_e}{\partial(N - H_h)} > 0, \frac{\partial B_e}{\partial H_h} < 0$$

4. MODEL OPERATIONALISATION

To solve the above decision making model, the study uses the numerical algorithms (MIOMBOSIM) in Sumaila *et al.* (2001), which is implemented using the simulation package Powersim. Data used is based on surveys conducted in 1999 by Siziba and Mutamba (2002). The field data in this report was used to estimate the MIOMBOSIM parameters for the two sites as presented in Table 1.

In Table 1, the discount factor assumed is based on a social interest rate of 12 percent, the rate used by government for planning purposes in Zimbabwe. Based on PRA and questionnaire data about 55% of the population was active and the household

Table 1. Model data

Item	Site	
	Gokwe	Chivi
Environmental parameter ( )	1	1
Discount factor ( )	0.893	0.893
Harvest efficiency parameter (q_h)	0.133	0.0641
Off-woodland labour (proportion) (L_{of})	0.1	0.15
Average agric price/m^3 equiv (US$) ($P_{ave}$)	5.71	7.31
Wood demand/ household/per year (m3)	62	40
Fertilizer cost (US$/kg) ($P_f$)	0.14	0.10
Forest area (ha) (N_t)	42,120	5,670
Existing agric land at start of analysis (N_a)	18,323	1,042
Maximum annual labour available to household users (L) (normalized)	1	1
Number of households in the community	4,558	453
Off woodland wage for all households (US$) (w)	2,007,526	199,519
Price per m^3 of woodland firewood by the household (US$) ($P_{fw}$)	1.84	2.76
Price per m^3 of woodland poles (US$) ($P_{po}$)	1.84	2.76
Revenue from a hectare of agricultural produce (US$) ($P_a$)	285	365
Cost of seed (US$)	0.15	0.21
Subsistence income for the community (US$)	1,429,329	160,370
Woodland survival rate (s)	0.95	0.95
Total person days in community per year	4,562,558	453,453
Parameter to labour cost function of households (v)	0.5	0.5
Standing volume of wood per hectare (K_t)	50	50
Initial volume of woodland for the site (normalized)	1	1
Parameters in household cost function	0.9	0.1

size averaged 7 people in both sites. Further, it is assumed there are 260 working days in a year. The total person days per community per year is calculated as the product of the active population and the number of working days per year. Subsistence income for the community is the product of per household income and the total number of households in the community. The per-household income used is the optimal income from Linear Programming models of representative households in the two communities under study. Off-woodland wage for all households was estimated as the product of minimum commercial farm worker wage ($0.44 per day), the total active population in the community and the total working days in a year (260 days).

Wood demand per household per year was estimated as the product of average wood collected per day and the average number of days in a year the household collects wood, based on survey estimates. Siziba and Mutamba (2002) estimated that for Chivi the average household collected 0.35 m^3 per day for 116 days in a year while in Gokwe average household collected 0.43 m^3 per day for 142 days in a year. Revenue from a hectare of agricultural production was estimated as the weighted average of revenues from all crops grown by the community with proportion of area put to the different crops being used as weights. This was converted to average agricultural price per cubic metre of wood by dividing the revenue per hectare by the standing volume of wood per hectare (assumed to be 50 m^3).

5. IMPACTS OF POLICIES ON WOODLAND USE: SIMULATION RESULTS

The model allows us to answer a number of questions about the likely effects of changes in the socio-economic environment in which the Gokwe and Chivi communities under study reside. Specifically, we scrutinise the likely impacts on levels of woodland use, labour utilised in woodland related activities, household incomes, community benefits from woodlands, among others, under the following scenarios:

- Continuation of current community practices;
- Continuation of current community practices but with institutional arrangements instituted to safeguard biodiversity concerns;
- All agricultural commodity prices increased;
- Agricultural productivity reduced;
- Agricultural input prices reduced;
- Money required to satisfy subsistence income reduced and
- Wage rates in the non-woodland use sector reduced.

The justification for selecting each of these scenarios is given in the following sections.

5.1 Base case runs

Table 2 presents the base case results from the simulation runs of the model based on data for Gokwe and Chivi study areas. For both sites, the results reveal the trade-offs in the use of woodland resources for current economic gains versus conservation of the resources for biodiversity concerns. If the objective is to maximize households economic benefits without any special consideration given to environmental concerns, a net present values of US$ 2.52 million and US$ 81,000 are realised in Gokwe and Chivi, respectively. Present values are reduced to US$ 2.45 million and US$ 62,000 for

Gokwe and Chivi, respectively; when the objective is to maximize household economic benefits while protecting/conserving the environment. This represents a revenue loss of about 2.4% and 24% for Gokwe and Chivi, respectively. Gokwe borders a Government forest reserve with abundant firewood that is freely collected for household use and minimal sales at low prices. Chivi is a wood scarce area with high population pressure on land and woodland resources, thus raising the price of firewood much higher as compared to that obtaining in Gokwe (see Table 1). Therefore, financially households in Chivi could lose proportionally more than those in Gokwe if environmental conservation measures are rigorously enforced on the woodlands.

Table 2. Baseline Results of Simulations in Gokwe and Chivi

	Gokwe			Chivi		
	No-Env*	Env*	% Change	No-Env	Env	% Change
Benefits from woodlands ($'000)	2,515	2,453	-2.4	81	62	-24
Sustainable amount of woodlands	0.25	0.27	8.5	0.51	0.54	6
Labour used in woodland activities (%)	17	16	-7	5	3.2	-37
Woodland area converted to agric. land (ha/yr)	642	609	-5	19	13	-34
Average area of standing woodland (ha)	17,058	17523	2.7	3,978	4,090	2.8
Community use of woodland products (m^3/yr)	43,015	40,808	-5	1,337	888	-34
Household disposable income ($/yr)	901	896	-1	552	540	-2

*No-Env and Env indicate simulated values under respectively the 'without' and the 'with' environmental concern scenarios, and '% change' is percent difference between the two.

A measure of resource preservation is how much of the initial woodlands in the long term can be sustainably maintained based on current consumption patterns. The results again show a marked trade-off between the 'with and the 'without' environmental concerns scenarios. For Gokwe, current woodland products consumption patterns imply a long run sustained stock of a quarter of current woodland resources under the 'without' environmental concern scenario. With the environmental concern, the long-run sustainable proportion of the resources increases to about 27% of initial. For Chivi, continuing with the current consumption pattern and without environmental concerns holds potential for sustaining, in the long run, about 51% of initial woodland stock, while the proportion could increase slightly to 54% were environmental or biodiversity conservation measures adhered to. The difference between the two sites can partly be explained by the more than 50% higher per household woodland products consumption observed in the sample of households in Gokwe (see Table 1). The difference in sustained stock levels tends to indicate that households and community do adjust their consumption in response to scarcity. Gokwe households currently consume more resources because they have an abundant supply while Chivi households used to a relatively poor resource base have adjusted their consumption downwards. The model as currently structured, however, does not allow for adjustment in demand in response to increasing scarcity.

The high woodland products consumption in Gokwe translates into a high proportion (17% and 16%) of labour used on woodland activities compared to Chivi (5% and 3.2%), both in the 'without' and 'with' environmental concern cases. Results also show that a significant proportion of woodland use in Gokwe is from agriculture encroaching into forest areas. The model predicts that 642 hectares of land on average could be converted into agricultural land each year in Gokwe as compared to only 19 hectares in Chivi, if there is free access to the woodlands or encroachment on them cannot be contained. When considerations for environmental or biodiversity conservation are taken into account Gokwe's encroachment could be reduced by 5% as compared to 34% in Chivi.

The 'without' and the 'with' environmental concern results in Table 2 indicate that for the Gokwe community, an 8.5% increase in the proportion of sustained forest resources can be realized for the loss of only 2.4 % of net benefits from the forest. However, gains in environmental benefits come at a higher cost to the Chivi community. A 6% gain in proportion of initial forest sustainably remaining comes at a cost of close to 24% loss in household economic benefits. The losses are magnified if we use the average area of standing woodlands over time as a measure of sustainability of resources. In this case the gain in resource conservation due to the incorporation of environmental concerns are 2.7 and 2.8 percent for Gokwe and Chivi, respectively.

Finally, Table 2 reports average household disposable income in the 'with' and 'without' environmental concern scenarios for the two communities. The results reflect the relative wealth of Gokwe community compared to Chivi due to the better agro-ecological endowments in the former. Using per household disposable income as a welfare measure dampens the effect of incorporating environmental concerns in woodland use decision-making. Here households' income losses at 1 and 2 % for Gokwe and Chivi, respectively, are smaller than the ecological gains in terms of both average standing woodlands and long-run sustained forest as proportion of initial forest. This means that in relative terms more is gained ecologically when environmental concerns are incorporated in the objective function than what is lost in terms of disposable income. In other words, the households lose relatively less disposable income compared to the relative gain in environmental benefits. This outcome is achieved most probably because the household cost function is endogenously determined, hence, costs (mainly labour costs) decrease enough in the 'without' scenario to bridge the gap that would have emerged as a result of the reduction in woodland harvested.

5.2 Effects of an increase in output prices

To assess the impact of general increase in output prices that could be brought about by for instance, improvement in road infrastructure, setting up of marketing infrastructure closer to the community, devaluation of an overvalued exchange rate or removal of explicit government taxes on outputs, we simulated the Gokwe and Chivi models with prices of outputs set at 25 % more than current prices. Table 3 reports the simulated outcomes as well as percent changes from the base model results obtained for the two study sites.

A priori, we would expect a general increase in output prices to increase agricultural profitability encouraging expansion of agriculture and causing deforestation. Indeed a substantial body of research shows that general increases in agricultural prices lead to deforestation. Using data from 19 Tanzanian regions Angelsen *et al.* (1999) observed a significant increase in cropped area with increases in agricultural prices. A study by Deininger and Minten (1996) using satellite imagery information from Mexico found a significant positive relationship between deforestation and agricultural price increases. Similar results were found in two separate studies on deforestation in Thailand by Cropper *et al.* (1997) and Panayotou and Sungsuwan (1994). In Zimbabwe, a study by Chipika and Kowero (2000) found a weak positive relationship between agricultural land expansion and crop price increases.

Simulation results from the two sites in this study presented in Table 3 generally agree with the above-cited findings. For Gokwe, a 25 % increase in agricultural prices has the potential to induce about 22% increase in economic benefits from woodland use under both the 'without' and 'with' environmental concern objective functions. These increases in community benefits from the woodlands translate to close to 35 % increase in per household disposable income under the two scenarios. The bulk of these benefits would come from an expansion in agricultural land. A projected 7% and 8% more land could be converted to agriculture under the 'without' and 'with' environmental concern scenario.

In terms of impact on woodland resource stock, the results from the Gokwe site imply a modest 2% reduction in the long-term sustainable standing woodlands under both the 'without' and 'with' environmental concern scenario. Thus, the cost in environmental damage would appear to be relatively small and making the inclusion of environmental concerns in managing and using the woodlands to marginally impair long term sustainability of the woodlands. Only 3.5% and 4% more household labour is diverted to the exploitation of woodland resources under the 'without' and 'with' environmental concern scenario, respectively.

Simulations of effects of general agricultural price increases for the Chivi community gave results similar to those for Gokwe with the exception being a more pronounced conservation effect compared to the Gokwe site results. The price increase is estimated to induce 26 and 28% increases in economic benefits under the 'without' and 'with' environmental concern scenarios, respectively. Under both scenarios, households are projected to gain about 40% increase in disposable income, most probably due to higher output prices obtaining in Chivi as compared to Gokwe (see Table 1). Based on the 'without' environmental concern objective function, 6% more land is converted to agriculture compared to 11% under the 'with' environmental concern scenario. Thus, taking into account biodiversity concerns into account results in 5% less converted agricultural land for no loss in individual disposal incomes. This is reflected in woodland product consumption that drops by less than 1% under the 'without' compared to 5% drop under the 'with' biodiversity concerns scenario. Consequently, only 1% (half that of Gokwe) and 6% (slightly higher than that of Gokwe) more household labour is devoted to exploiting woodlands under the 'without' and 'with' environmental concern scenarios.

In conclusion, agricultural price increases hold potential for improving livelihoods in Chivi communities more than in Gokwe. This happens through modest increases in disposable incomes, slightly higher levels of woodland products harvesting and consumption, encroachment on protected woodlands for agriculture, slight increase in labour employment in woodland activities and overall benefits from sale of woodland products. All this comes at a negligible cost in terms of loss in woodland sustainability in the long run.

Table 3. Impacts of a 25 % increase in output prices

	Gokwe				Chivi			
	No-Env	% change	Env	% change	No-Env	% change	Env	% change
Benefits from woodlands ($'000)	3,068	22	2,999	22	102	26	79	28
Sustainable proportion of woodlands	0.25	-1	0.26	-2	0.51	0.2	0.54	-0.2
Labour used in woodland activities (%)	18	3.5	17	4	5	1	3	6
Woodland area converted to agric. land (ha/yr)	687	7	657	8	20	6	14	11
Average area of standing woodland (ha)	16,730	-2	17,188	-2	3,959	-0.5	4,065	-0.6
Woodland products used by community (m^3/yr)	43,560	1	41,716	2	1,338	0.1	928	5
Household disposable income ($/yr)	1,210	34	1,205	35	771.24	40	757	40

5.3 Effect of a loss in agricultural productivity

In general, we would expect changes in agricultural productivity to have an indeterminate direction of impact on woodland use. On one hand, an increase in productivity which does not have an appreciable impact on commodity prices and labour demand will lead to an increase in agricultural profitability and hence promote conversion of woodland to agriculture. On the other hand, yield improvements may trigger declines in prices affecting agricultural profitability reducing pressure on woodlands (Kaimowitz and Angelsen 1998). This indeterminacy of the impact of productivity on deforestation is borne out in empirical research. Studies by Deininger and Minten (1996) and Panayoutou and Sungsuwan (1994) showed that increase in agricultural yield was associated with a reduction in deforestation while studies by Angelsen *et al.* (1999) and Katila (1995) report an increase in deforestation with productivity improvement. Yet studies by Barbier and Burgess (1996) and Chakraborty (1994) showed no significant effect of yield changes on deforestation.

To assess the impact of general decline in agricultural productivity, we simulated the Gokwe and Chivi models with yields reduced by 25 %. Results in Table 4 generally support the results of studies elsewhere referred in the previous paragraph. For Gokwe, the decrease in yields are projected to induce, respectively, 22 and 23% reduction in economic benefits from miombo use under the 'without' and 'with' environmental concern objective functions. There is also a 34 % decrease in per household disposable income under both scenarios. These are largely stemming from 10% and 11% less land converted to agriculture under the 'without' and 'with' environmental concern objective functions, respectively.

The Gokwe simulations also indicate that a 25% productivity decline has potential to boost the average area of standing miombo by 2.7 and 3.4 % under the 'without' and 'with' environmental concern scenario, respectively. The reduction on encroachment on woodlands translates to 2% and 6% less woodland use related employment under the 'without' and 'with' environmental concern scenarios, respectively.

The simulations for Chivi, a more resource poor community showed similar but more pronounced of impacts of yield decrease on woodland resource utilisation. A 25% yield decline is projected to induce 26 and 30% decrease in economic benefits from woodland use under the 'without' and 'with' environmental concern scenarios, respectively. At household level, this results in a decrease of 40% in disposable income.

There is scope for a significant reduction in pressure on the woodlands, in relation to demand for agricultural land, in Chivi as compared to Gokwe on both 'with' and 'without' scenarios. However, the trade-off for this appears to be partly reflected in 4% and 11% less woodland related employment potential under both scenarios. Because consumption is much lower under baseline conditions in Chivi compared to Gokwe (see Table 1) the effect of the agricultural yield decline on the woodlands is significantly less. About 1 % more area of woodlands under both the 'without' and 'with' environmental concern scenarios are maintained.

These results show that in both sites agricultural yield reduction could constrain deforestation. This result ought to be qualified much as logic would support that pressure on the woodlands could be alleviated if households had better incomes. However, the model does not endogenously allow for the possibility of supply induced changes in prices due to productivity changes, thus not permitting the possibility of land extensification compensating for reduced yield.

Table 4. Simulation of effects of 25% decrease in agricultural yields

	Gokwe				Chivi			
	No-Env	% change	Env	% change	No-Env	% change	Env	% change
Benefits from woodlands ($'000)	1,956	-22	1,894	-23	60	-26	43	-30
Sustainable proportion of woodlands (%)	0.25	2	0.28	4	1	0.00	0.53	-1
Labour used in woodland activities (%)	17	-2	15	-6	5	-4	3	-11
Woodland area converted to agric. land (ha/yr)	578	-10	540	-11	17	-11	11	-17
Average area of standing woodlands (ha)	17,521	2.7	18,120	3.4	4,005	0.7	4,126	0.9
Woodland products use by community (m^3/yr)	42,238	-2	39,452	-3	1,308	-2	806	-9
Household disposable income ($/yr)	593	-34	588	-34	333	-40	322	-40

5.4 Effect of an increase in input prices

Increasing the prices of inputs is likely to lead to two opposing effects (Kaimowitz and Angelsen (1998). On one hand, an increase in input prices could decrease agricultural profitability thereby decreasing the incentive for conversion of woodland to agriculture. On the other hand, subsistence farmers following a safety-first food production strategy may substitute cash inputs with land if input prices are increased and this could increase deforestation. The net effect of this price change is therefore likely to be indeterminate. In a number of CGE modelling efforts that looked at impact of lowering agricultural subsidies – which is the same as increasing input prices – this indeterminacy seems to be supported. A study by Mwanawina and Sankayan (1996) in Zambia estimated that an increase in input prices tends to increase the level of encroachment on woodlands while a similar study in Tanzania showed no effect due to input price increases. A study by Coxhead and Shively (1995) in the Philippines estimated a reduction in deforestation due to input price increases.

Other dimensions that may affect how responsive a community's woodlands use is to input price increases are the initial levels of cash inputs use and the cropping patterns. Communities in the study areas that use a lot of cash inputs and are involved in cash crops such as cotton that demand more cash inputs (fertilisers, seed agrochemicals) would tend to exhibit more inelastic response to changes in prices as compared to communities that traditionally use little bought inputs. Thus we would expect the response to be more muted in Gokwe where cotton growing is a major enterprise as compared to Chivi which is relatively more subsistence oriented.

To assess the impact of general increase in cash input prices we simulated the Gokwe and Chivi models with cash input prices increased by 25 %. Table 5 reports the changes from the base model results obtained for the two study sites. The minute changes projected in woodland use as well as inconsistent directions of impacts would tend to support the indeterminacy hypothesis. For Gokwe the 25% increase in input prices is projected to induce only 1 and 1.3% reduction in economic benefits from woodland products under the 'without' and 'with' environmental concern scenarios, respectively. Even though the projected impact is reduction on encroachment on agricultural land, the effects are almost insignificant. Close to 0.2% less land is converted to agriculture under the 'without' and 1% more in the 'with' environmental concern scenarios, respectively. Corresponding drops on woodland related employment are only 2% and 1% under the 'without' and 'with' environmental concern objective functions, respectively. The net projected impact on woodlands indicates contradictory and very insignificant effects. Though there is a projected 0.1% decrease in area of woodlands under the 'without' environmental concern scenario, the results for the 'with' environmental concern scenarios indicate a 0.4% increase in average area of woodland resources.

Results show that responses tend to be slightly larger in Chivi supporting the hypothesis that more commercialised communities are more input price inelastic. Still the results show very small changes in woodland use from the 25% input price increase in Chivi tending to support the indeterminacy hypothesis. The price increase is projected to induce only 3 and 2.5% decreases in economic benefits from woodland products under respectively the 'without' and 'with' environmental concern scenarios accompanied by loss in woodland related employment that amounts to close to 3% and 1% under the 'without' and 'with' environmental concern, respectively, as well as reductions in per household disposable income that amounts to less than 2 % in both scenarios. Land converted to agriculture could be reduced by about 0.6% and 0.2% under the 'without' and 'with' environmental concern scenarios, respectively. Average woodland area improves by about 0.2 and 0.1 % under the 'without' and 'with' environmental concern scenarios, respectively. All these results support our earlier assertion that responses in Gokwe would most likely be more muted as compared to Chivi.

Table 5. Simulation of effects of 25% increase in agricultural input prices

	Gokwe				Chivi			
Outcome	No-Env	% change	Env	% change	No-Env	% change	Env	% change
Benefits from woodlands ($'000)	2,492	-1	2421	-1.3	79	-3	60	-2.5
Sustainable proportion of woodland	0.25	-0.4	0.27	1	0.51	0.4	0.54	0.00
Labour used on woodland activities (%)	17	-2	16	-1	5	-3	3	-1
Woodland converted to agric land (ha/yr)	641	-0.2	604	-1	19	-3	13	-0.2
Average area of standing woodland (ha)	17,043	-0.1	17,596	0.4	3,988	0.2	4,093	0.1
Woodland products used by community (m^3/yr)	43,099	0.2	40,615	-0.5	1,306	-2	888	0.1
Household disposable income ($/yr)	887	-1.6	881	-1.7	543	-1.8	531	-1.6

5.5 Effect of a decrease in subsistence income

The reduction in income necessary to meet community basic needs which can come about through lowering of consumption goods due to economic growth or improvements in social infrastructure – better roads, clinics near homesteads, more retail out lets, *etc* – lowering transactions costs, will likely have two conflicting impacts on the woodlands use. It lowers the need for agriculture to generate enough income to meet subsistence need and therefore reducing use of woodlands. On the other hand, reduction in labour demand on existing agricultural land may make more labour available for woodland related activities thus increasing pressure on the forests.

To assess the impact of such a change in the community's economy we simulated the Gokwe and Chivi models with the subsistence parameter arbitrarily set at 25 % less than current. Table 6 reports the changes from base model results obtained for the two study sites. For Gokwe the decrease in subsistence requirements generally induced very mild impacts on woodland use. Table 6 shows that Gokwe experienced a tenth of a percent increase in economic benefits under the 'without' and third of a percent reduction in economic benefits under the 'with' environmental concern scenarios, respectively. All other indicators of woodland condition and community well being with the exception of household disposable income showed responses of less than 1 percent. The only significant impact was on disposable income which increased by about 9% under both the 'without and 'with' environmental concern scenarios.

Similar results were observed in the case of Chivi with the exception that the impact on income in Chivi was substantially higher than in Gokwe showing an improvement in per household disposable incomes of about 16% under both scenarios.

The net results tend to support the indeterminacy hypothesis under both decision-making scenarios and in both sites.

Table 6. Simulation of effects of 25% decrease in subsistence income

	Gokwe				Chivi			
	No-Env	% change	Env	% change	No-Env	% change	Env	% change
Benefits from woodlands ($'000)	2,517	0.1	2,446	-0.3	80	-1	62	0.3
Sustainable proportion of woodland (%)	0.25	-0.4	0.27	0.8	0.51	0.2	0.54	0.00
Labour used in woodland activities (%)	17	0.00	16	-0.6	5	-1	3	0.3
Woodland converted to agric land(ha/yr)	644	0.3	607	-0.4	19	-1	13	0.3
Average area of standing woodland (ha)	17,033	-0.2	17,581	0.3	3,982	0.1	4,089	-0.01
Woodland products use by community (m^3/yr)	43,129	0.3	40,647	-0.4	1,325	-1	890	0.3
Household disposable income ($/yr)	980	9	974	9	641	16	628	16.4

5.6 Effect of a decrease in off-woodland/off-farm wage

The reduction in off-woodland wages, which can come about through poor growth in the rest of the economy, will likely increase the pressure on woodlands in order to sustain the community (Kaimowitz and Angelsen 1998). To assess the impact of such a change in the community's economy we simulated the Gokwe and Chivi models with the off-woodland wage parameter arbitrarily set at 25 % less than current. Table 7 reports the changes from base model results obtained for the two study sites.

The decrease in off-woodland wages generally induced very mild and mixed impacts on woodland use in both Gokwe and Chivi. Table 7 shows that impacts on all indicators of woodland use were 1 % or less in Gokwe under the two decision scenarios. Largest impacts of 1.2% and 1.3 % were experienced for decreases in disposable income. Similar results were observed in the case of Chivi. However, in Chivi the negative impact on disposable income at 3% under the two scenarios were more pronounced than in Gokwe.

An explanation of the mixed direction of impacts of reduction in off-woodland wages is that our model does not allow reallocation of labour between woodland/

agricultural use and off-woodland activities. Labour allocated to off-woodland activities is fixed for the community. Thus, declines in off-woodland incomes will not lead to a shift in labour into agriculture or woodland using activities. In addition, the mild impacts we observe may be partly due to the fact this source of income constitutes only a small part of the total income of the household.

Table 7. Simulation of effects of a 25% decrease in off-woodland wages

	Gokwe				Chivi			
	No-Env	% change	Env	% change	No-Env	% change	Env	% change
Benefits from woodlands ($'000)	2,520	0.2	2,441	-0.5	80.75	-0.4	60	-3.4
Sustainable proportion of woodland (%)	0.25	-0.4	0.27	1	0.505	0.00	0.54	0.2
Labour used in woodland activities (%)	17	0.00	16	-0.6	5	-1	3	-3
Woodland converted to agric land (ha/yr)	644	0.3	605	-0.7	19	-1	12	-3
Average area of standing woodland (ha)	17,023	-0.2	17,627	0.6	3,980	0.05	4,098	0.21
Woodland products use by community (m^3/yr)	43,111	0.2	40,525	-0.7	1328	-1	866	-3
Household disposable income ($/yr)	890	-1.2	884	-1.3	536	-3	523	-3.2

6. MAIN FINDINGS AND CONCLUSIONS

This paper presents and demonstrates a useful framework for analysing the impacts of policies on woodland condition and use. The findings point to the following basic conclusions:

- There is a tendency to extract more wood resources in Gokwe compared to Chivi, which, given the difference in access on the two sites, supports the notion that easy access to woodlands promotes deforestation.
- Introducing biodiversity concerns in a resource abundant area such as Gokwe could reduce deforestation at a lower cost in terms of loss in benefits from the woodlands as compared to a resource poor area such as Chivi.
- Increase in agricultural product prices has the potential to increase deforestation on both project sites. The magnitude of woodland loss, however, tends to be more in the forest resource abundant Gokwe compared to a resource poor Chivi.
- Decrease in yields could lead to reduced deforestation in both resource abundant and scarce areas. However, this result may be misleading since the model does not allow for a price response to changes in supply.
- Increase in agricultural input prices could lead to a decrease in woodland area on

both sites in the long run. However, the change in steady-state proportion of remaining woodland would appear to be indeterminate tending to support the hypothesis that there are two opposing impacts caused by input price increases – decrease in deforestation due to decline in profitability, and increase in deforestation due to substitution of land for cash inputs.

- A decrease in income required to meet subsistence needs could lead to mixed impacts on deforestation under both community profit maximisation and maximisation subject to environmental concern constraints. Though a reduction in the requirement for agriculture to meet basic needs may lead to less encroachment on forests, the labour released from existing agricultural land may promote non-agricultural forms of woodland use that exert pressure on the environment.
- Though we would expect that declines in growth in the rest of the rural economy to reduce non-agricultural wages and enhance reliance on agriculture thereby leading to deforestation, simulations in this study show mixed results. This is largely due to the structure of the model, which does not allow for a shift in labour away from off-woodland activities to agriculture.

These conclusions demonstrate the strong effect on woodland use and condition of agricultural policies and institutional arrangements protecting forests. As Zimbabwe proceeds with its second - and much expanded - phase of the land reform and redistribution exercise, it is important that issues of protection of the woodlands are not ignored. Of particular concern is the lack of consideration for development of local level institutions governing the use of forest resources in the current land redistribution exercise. The model presented here provides a tool for potential use in crafting new policies and institutions governing woodland resource use in the newly settled areas.

However, despite its robustness the model used in the current study can be improved in a number of ways. There is need to allow for price response to changing supply and demand conditions for both inputs and outputs from woodlands and agriculture. Differences in woodland product consumption between resource abundant and resource poor areas indicate the need to allow for a demand response to scarcity in the model. Finally, the model can benefit from explicit incorporation of population dynamics.

ENDNOTES

1. CAMPFIRE stands for Communal Areas Management Programme for Indigenous Resources.

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22.
Management of miombo woodlands in Malawi: An application of system dynamics modelling

R. Kachule, H. Tchale and C. Mataya

ABSTRACT
The effect of different policy changes in the forestry and agriculture sectors of Malawi were assessed using a systems dynamic model with the acronym MIOMBOSIM on three different sites, namely, Chimaliro, Dzalanyama and Mdeka. The model was applied to establish the effect of five management regimes on the welfare of the local communities and sustainability of forest resources. Five management scenarios were evaluated, namely, 'command management regime' which assumes that central, local or village government controls management of the resources; 'cooperative management regime' whereby local communities manage the resource with active cooperation among themselves; and 'non cooperative management regime' whereby stakeholders have free access to the resources without taking the interests of each other into account. The latter mimics an open access scenario. Further, the command management regime assumes that the government takes into account 'social', 'environmental', 'social and environmental' concerns of all stakeholders; thus giving us three potential management scenarios.

Results indicated that highest total monetary benefits from the woodlands to all stakeholders would be realized under the command model with social concerns in all the sites. This is contrary to expectations because current policy by the central government is to devolve management of the woodland resources to the local communities and the private sector, a move that implicitly advocates the cooperative management approach. The potential for environmental protection or biodiversity conservation in all sites would appear to lie with the command regime that emphasises environmental concerns. Increases in the price of fuelwood to 75% might not significantly influence deforestation in the three sites under all management regimes,

most probably due to the fact that labour for harvesting and transporting the product on the head or with bicycles to distant markets could be a limiting factor for households to take advantage of the high prices. Increases in fertilizer prices by 75% could result in modest increases in total household benefits in both Dzalanyama and Chimaliro, because households would harvest and sell more fuelwood to more than offset any cuts in crop production that would result from using less fertilizer. However, in Mdeka total household benefits would decline as this site is almost depleted of woodland resources that households could fall on to offset decreases in agricultural production due to low fertilizer use.

Key words: System dynamics, forest resources, households, Malawi.

1. INTRODUCTION

Malawi is a small landlocked country surrounded by Mozambique to the south, east and west, Tanzania to the north and east and Zambia to the west. It has a land area of 118,480 km^2. About 9.8 million of its inhabitants occupy a land area of 9.4 million ha. Of the total land area, agricultural land accounts for 61% while forests occupy about 38%. About 20% of the total land area is under protected forests consisting of natural forests (71%), natural grassland (15%), plantation forest area (6%), potentially agricultural land (7%) and other protected areas (1percent) (Government of Malawi 1998).

The country's forests are dominated by miombo woodlands, mainly species of *Brachystegia*, *Julbernadia* and *Isoberlinia*. Miombo woodlands account for approximately 70% of the total forest area and 97% of all forest species (Government of Malawi 1996). The distribution of the forest resources is skewed; with 50% of them in the Northern Region and the rest of the forest resources are distributed equally between the densely populated southern and central regions. Administratively, the country is divided into three regions (northern, central and southern regions) with a total of 27 districts.

The population of the country is estimated at 9.8 million with the Southern region accounting for 47%, Central region 41% and Northern region 12%. Population growth rate is estimated at 1.9% and 50% of the population is below the age of 15 years. Poverty is widespread in the country and is characterized by hunger, malnutrition, and low per capita incomes with the most vulnerable groups being women, children and the elderly. Literacy rate is estimated at 56.6% and 27.2% for men and women, respectively. Life expectancy at birth is estimated at 38.9% for women and 38.6% for men. HIV sero-prevalence rates range from 3.3% in rural areas to 30.4% in major urban centers (United Nations and Government of Malawi 1993).

The country's economy is based on agriculture which contributes about 40% of the Gross Domestic Product (GDP), accounts for about 90% of the export earnings, offers employment to almost 80% of the population and supplies over 90% of the food consumed in the country while manufacturing accounts for only 13% of GDP (Malawi Government 2001). Productivity in agriculture has remained low and about 60% of the people live below the poverty line. Unless the rate of economic growth exceeds that of population, poverty will continue to increase and exert pressure on shrinking cropland and natural resources. The result could be an ecological imbalance that has potential to adversely affect the agricultural sector, the backbone of livelihoods of rural households and the national economy.

In an effort to contain the deteriorating economic situation, Malawi has since 1981 implemented economic reforms, commonly referred to as Structural Adjustment Programmes (SAPs), in collaboration with the International Monetary Fund and the World Bank. The SAPs aimed at:

- Stabilizing the economy;
- Accelerating agricultural growth;
- Diversifying the export base;
- Increasing efficiency of export substituting enterprises and parastatals;
- Improving the mobilization and management of public resources including sustainable utilisation of natural resources to anchor the economic activities (World Bank 1994).

In line with other on-going initiatives to improve the well being of Malawians, these reforms have potential to influence the behaviour of individuals and industry in ways that could impact on the sustainability of the country's forest resources.

This study was initiated with the purpose of developing a model that would demonstrate the potential effects of selected economic reform (SAPs) and sectoral policies on the welfare of rural communities and the status of forest resources they depend on. The model was constructed to demonstrate these effects under five potential natural forest management scenarios, namely: management by government (central, local or village government), referred to as 'command regime'; management by local communities with active cooperation among themselves, referred to as 'cooperative regime'; and a situation whereby stakeholders have free access to the resources and do not take the interests of each other into account, referred to as 'non-cooperative regime'. The latter mimics an open access situation. The command management regime assumes that the regulator who controls the woodland resources (i.e. the government) would take into account social and environmental concerns of all stakeholders. This means that the regulator could give more weight to environmental concerns when managing the woodland resources, and this would give us an 'environmental scenario' as would be the case of protecting biodiversity in fragile ecosystems or managing water catchment areas. Alternatively the regulator could give more weight in managing the woodlands to the social concerns of the local communities that depend on these resources, like allowing them free access to collect firewood or perform rituals in sacred forests. This would give us a 'social concern scenario'. Further, the regulator could take into account in managing the woodlands both the social and environmental concerns, thus giving us a fifth management regime, the 'social and environmental concerns scenario'.

Policy experiments were carried out to highlight the potential effects of different policies on rural employment, household incomes, and encroachment on natural forests, and sustainability of the forest resources.

This paper is arranged as follows: section 2 describes the study sites; section 3 describes the methodology employed, section 4 presents results on baseline scenarios, section 5 presents policy experiments/sensitivity analyses, and section 6 summarises the major findings.

2. DESCRIPTION OF STUDY SITES

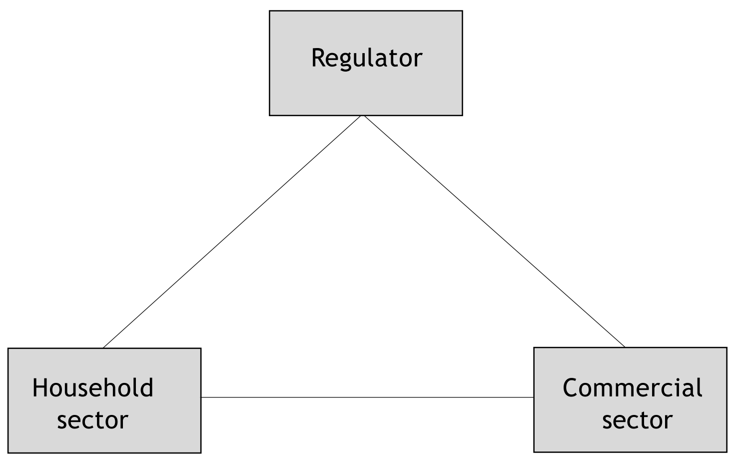
The research was conducted in three different sites bordering forest reserves namely, Chimaliro and Dzalanyama in the central region of the country and Mdeka in the Southern Region of the country. Tchale *et al.* (in this book) gives detailed description of each site, with more details on Dzalanyama found in Ngalande (1995) and that of Chimaliro in Lowore *et al.* (1995). Proximity of the area to urban centers was one of the criteria used in selecting the study sites, since this defined a gradient of accessibility to markets and other infrastructure, with those areas far from urban centers being the most deprived of these facilities. Dzalanyama and the Mdeka sites are close to the cities of Lilongwe and Blantyre, respectively, while the Chimaliro site was selected because of its remoteness.

3. METHODOLOGY

3.1 The conceptual model

The systems dynamic model follows the generic model developed by Sumaila *et al.* (2001). Two user groups of miombo woodland resources identified in the study sites belonged to the 'household sector' and the 'commercial sector'. It was necessary to disaggregate them this way so as to differentiate 'household consumption' activities as constituting a 'household sector' from those that target 'commercialisation' of forest products that is done by a few households and mainly in collaboration with middlemen, as constituting a 'commercial sector'. Otherwise in these rural areas we are principally dealing with households only. A third woodland stakeholder is a 'regulator' who influences decision-making and therefore activities of the two user groups. The regulator in this case can be the central or local government, or the village authority/ government (Figure 1).

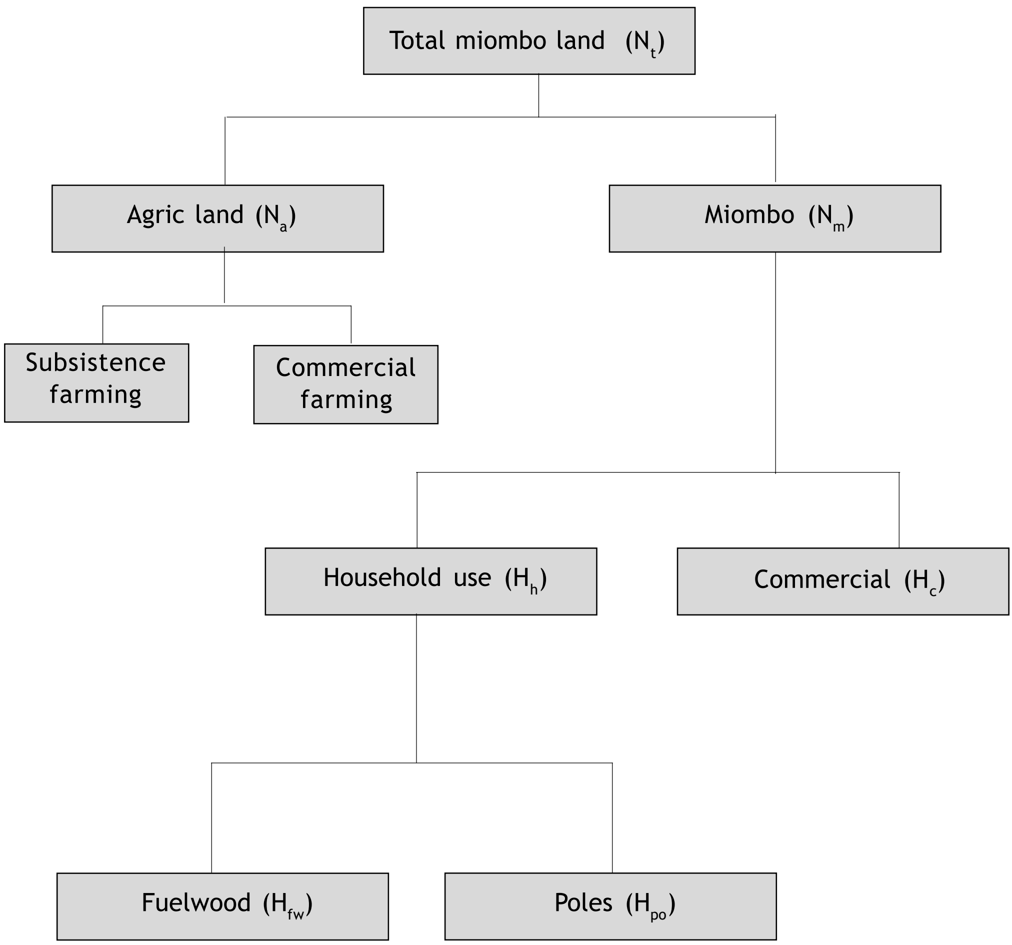
Figure 1. Main agents in the model



The logic or reasoning guiding the use of the woodland resources is illustrated in Figure 2. In any site there is an area of miombo woodland that local communities have access to, and this area is denoted as N_t. It is part of this area that has been cleared for the existing agricultural land, N_a, which is found in the site and which supports crops, livestock, habitation and other land-based household necessities. Households in the study areas have to make decisions on how to improve food availability/security and incomes.

For example, both goals and objectives could be partly achieved by encroaching on a woodland area N_m that they harvest for poles and fuelwood for both household consumption (H_h) or for sale (H_c).

Figure 2. Decision making process of the household



As mentioned earlier there is no clear demarcation between the household and the commercial sector in the sense that it is the same household members that indulge in some commercial activities based on forest products. What actually happens is that households extract firewood and poles principally for domestic use. However, because of limited alternative sources of income, the households extract more than their domestic requirements and sell the excess for cash income. This also includes charcoal in some cases. It is the selling activities of the households that basically constitute the activities of the commercial sector in this model. Commercialisation of forest products is increasingly becoming a feature of rural households and is confined to the informal sector of the economy. It is therefore important to monitor its development and contribution to household livelihoods.

Secondly households could improve food security and incomes by expanding cropland area N_a through encroachment on the woodland area N_t for subsistence and commercial farming as well as livestock husbandry.

The households implement these activities within a defined policy environment that influences decisions on crop and livestock production as well as harvesting and selling of woodland products. The policy environments and their potential impacts on the welfare of the households and sustainability of the woodland resources are explored in detail in Section 5.

3.2 The MIOMBOSIM for Malawi

3.2.1 The command model

In the command model, the regulator/government influences the behaviour of the household as to its consumption ('household sector' activities) and sales choices ('commercial sector' activities) by, for example, regulating access to and prices of woodland resources. The assumption is that the government would want the households to maximize total net benefits B_t through the choice of the amount of labour to be used in the 'commercial sector' (L_c) and the 'household sector' (L_h) activities in each year and in the time horizon, T, of the model. This is the situation that has been common in central government policies, but it was observed to be scantly demonstrated or completely absent on the ground in the study sites. The objective function is therefore presented as follows:

$$\max_{L_h, L_c} \sum_{t=1}^{T} [B_t]\, \rho_{t-1} \qquad (1)$$

subject to the relevant ecological and household labour constraints.

and

$$B_t = B_{c,t} + B_{h,t} + \theta B_{e,t} + B_{s,t} \qquad (2)$$

where:

B_t = Total benefits accruing to household and commercial sectors

B_c = Net private benefits accruing to the commercial sector from the use of woodland resources (i.e. benefits from sales of woodland products plus value of harvested woodland products for household use. This applies to households that reported selling woodland products)

B_h = Net private benefits accruing to the household sector from the use of woodland resources (i.e. value of harvested woodland products consumed by the household. This applies to households that did not report sale of woodland products)

B_e = Environmental benefits

B_s = Benefits accruing to the whole society

θ = weight put on the harvests by the two sectors to reflect their concern for environmental protection, with a value of one indicating strict environmental or biodiversity protection and a value of zero meaning that there is no protection for environment or biodiversity, as would be the case in an open access situation. We also put weights on the harvests of the 'commercial' (H_c) and 'household' (H_h) sectors in order to incorporate social concerns.

Also,

$$\rho_{t-1} = \frac{1}{(1+r)^{t-1}},\ \rho_0 = 1,\ t = 1,\ldots,T.$$

where   is the discount factor and r is the discount rate.

The regulator therefore influences choices that reflect environmental, social or a combination of social and environmental concerns.

3.2.2 The cooperative model

Under the cooperative regime, it is assumed that there are efforts towards participatory management of the natural resources by all households either on their own or in a joint venture with the government. It is the type of management that governments are encouraging by devolving management of natural forests to local communities. We were therefore interested to find out the potential for it and its implication in all the study sites. In a cooperative management case we put weights   and (1-) to respectively the 'commercial' and 'household' sector benefits as a measure of their preferences so as to maximize their combined benefits from exploiting the woodland resource (Sumaila *et al*. 2001). The objective function for the cooperative model is presented as:

$$\max_{l_h, l_c} \sum_{t=1}^{T} \left[\alpha \rho_{h,t-1} B_{h,t} + (1-\alpha)\rho_{c,t-1} B_{c,t}\right] \qquad (3)$$

subject to the relevant ecological and household labour constraints.

where

B_c = Benefits accruing to the 'commercial sector'

B_h = Benefits accruing to the 'household sector'

 and 1-   = weight put by the commercial and household sectors as a measure of their preference in maximizing benefits from the woodland resources.

3.2.3 The non-cooperative model

In the non-cooperative model, each household aims at maximizing its own private benefits without taking into account interests of the other stakeholders. The management problem facing 'household sector' under the non-cooperation is defined as:

$$\max_{L_h} \sum_{t=1}^{T} \left[\rho_{h,t-1} B_{h,t}\right] \qquad (4)$$

subject to the relevant stock and the labour constraints.

Similarly, the non-cooperative management by the 'commercial sector' can be stated as follows.

$$\max_{Lc} \sum_{t=1}^{T} \left[\rho_{c,t-1} B_{c,t}\right] \qquad (5)$$

subject to the relevant stock and the labour constraints, and
where

B_c = Benefits accruing to the 'commercial sector'
B_h = Benefits accruing to the 'household sector'

Based on the conceptual framework of the MIOMBOSIM model and the description of the study sites, it would appear that the cooperative model best describes the situation observed on the ground during data collection in Dzalanyama and Chimaliro sites while the non-cooperative model would appear to depict the prevailing situation in the Mdeka site. However for purposes of this study, policy experiments were made on the different management scenarios (command, cooperative and non-cooperative) on all the three study sites to find out what would be the outcome if each management style were applied.

All the models were solved using a software package called Powersim.

4. BASELINE DATA AND SCENARIOS

Baseline data that was used to run the models for all the three sites are presented in Table 1. This data set gave the base case scenarios, i.e., the "status quo" in all the three sites. The base case scenarios formed the basis on which policy experiments were conducted. The data was obtained from field surveys while some were computed from secondary sources.

4.1 Results of base case scenario

The base runs were made under the five different woodland management regimes, viz. command regime with social, environmental and both social and environmental concerns; cooperative management regime, and the non-cooperative management regime. These runs were made to determine, among others, the total monetary woodland benefits accruing to both the household and the commercial sectors, average woodland resources remaining at the end of the simulation period (Ave_WLR), and the employment and environmental/biodiversity conservation implications associated with the generation of these benefits, among others.

Table 1. Baseline data for the model

	Dzalanyama	Chimaliro	Mdeka
Proportion of household labour employed on existing agricultural activities (%)	0.39	0.45	0.30
Existing agricultural land, N_a, (ha)	8,000	16,300	2,800
Social concern parameter,	0.5	0.5	0.5
Cost of employing households in harvesting woodland resources (US$/m^3)	7.60	6.34	5.10
Cost of inputs including labour used by commercial sector in harvesting woodland resources (US$/ha)	75	30	90
Discount factor	[0.89;0.87]	[0.89;0.87]	[0.91;0.90]
Efficiency parameters[1]	[0.023;0.07]	[0.023;0.07]	[0.023;0.07]
Fertilizer cost (US$/kg)	10.25	10.25	10.25
Forest area, N_t, (ha)	17,110	16,000	5,000
Proportion of household labour employed for collecting firewood	0.12	0.12	0.15
Proportion of household labour employed for management and control of forest resources	.001	.001	.000
Maximum labour available normalized to 1	1	1	1
Off-miombo wage (US$/man day)	0.41	0.41	0.41
Price paid by of commercial sector for a cubic metre of firewood (US$)	5.7	5.7	5.3
Price paid by of household sector for cubic metre of firewood (US$)	3.2	2.0	4.0
Revenue per ha. of agric. land, N_a, (US$)	434.17	180.12	148.30
Seed cost (US$/kg)	3.46	5.64	2.45
Subsistence income for all households in the community (US$000)	380.25	519.02	257.95
Survival rate of the miombo woodland	0.95	0.95	0.80
Environmental concern parameter	[0;1]	[0;1]	[0;1]
Total man days in community (000' man days/year)	25317.56	18654.70	28246.76
Parameter to labour cost function	0.5	0.5	0.5
Parameters to household cost function [2]	(0.9,0.1)	(0.9,0.1)	(0.9,0.1)
Volume of firewood harvested per household/year (m^3)	10	12	10
Volume of standing miombo (m^3/ha)	80	85	60
Initial woodland resources (WLR_0) normalized to 1	1	1	1

[1]An efficiency parameter represents the efficiency with which either the household or the commercial sector is harvesting the woodland resources.
[2] The household is assumed to maximise utility (U (.)), a function of income (I) net of subsistence requirements (I^{min}) and leisure (L^{max} - L). That is:

where: $$U(I,T) = (I - I^{\min})^{\alpha} + v(L^{\max} - L)^{\beta} \quad (6)$$

I = gross household income
I^{min} = subsistence consumption
L^{max} = maximum labour available to the household
L = labour used by the household in all income generating activities; and and are parameters of the utility function.

4.2 Monetary woodland benefits

The base case scenario (Tables 2a-c) indicates that highest total benefits (for 'household sector' and 'commercial sector') would be derived under the command regime with social concerns in all the three sites.

Since some values are very small, they have been reported beyond two decimal points to facilitate comparisons because when the absolute values are aggregated for all households in all the sites, the outcome, especially in monetary terms, would probably be easily ignored in decision making.

Table 2a. Base run scenario for Chimaliro

Variable	Command management regime			Cooperative management	Non-cooperative management
	Social	Environ-mental	Social plus environmental		
Benefits to commercial sector ($000')	179	148	136	199	145
Benefits to household sector ($000')	331	109	251	246	107
Total benefits ($000')	510	257	386	446	252
Ave_WLR	0.526	0.607	0.597	0.591	0.521
Proportion of labour in commercial sector	0.0872	0.065	0.0598	0.0994	0.0642
Proportion of labour in household sector	0.232	0.0249	0.127	0.125	0.0242
Quantity harvested by household sector (000m^3)	3061	2635	2431	3632	2658
Quantity harvested by commercial sector (000m^3)	20717	3469	13836	13591	3457

Table 2b. Base run scenario for Dzalanyama

Variable	Command management regime			Cooperative management	Non-cooperative management
	Social	Environ-mental	Social plus environmental		
Benefits to commercial sector ($000')	174	145	128	191	103
Benefits to household sector ($000')	539	298	461	434	250
Total benefits ($000')	713	443	589	645	354
Ave_WLR	0.517	0.601	0.578	0.571	0.425
Proportion of labour in commercial sector	0.0857	0.0642	0.0564	0.0953	0.0564
Proportion of labour in household sector	0.237	0.0549	0.149	0.144	0.0454
Quantity harvested by household sector (000m^3)	21353	6785	6784	15671	15209
Quantity harvested by commercial sector (000m^3)	3000	2606	2290	340	2317

Table 2c. Base run scenario for Mdeka

Variable	Command management regime			Cooperative management	Non-cooperative management
	Social	Environ-mental	Social plus environmental		
Benefits to commercial sector ($000')	1.58	0.149	0.141	0.406	0.317
Benefits to household sector ($000')	38	0.0845	14.59	14.58	1.19
Total benefits ($000')	39	0.234	14.73	14.99	1.50
Ave_WLR	0.196	0.208	0.205	0.205	0.185
Proportion of labour in commercial sector	0.0162	0.00871	0.00826	0.0133	0.000186
Proportion of labour in household sector	0.0412	0.000247	0.00868	0.00854	0.000373
Quantity harvested by household sector (000m^3)	654	1.94	211.43	212.43	29.08
Quantity harvested by commercial sector (000m^3)	29	8.15	8.02	17.25	5.44

The results also show that households in the 'household sector' would derive more benefits under the same management regime in all the three sites. However, these benefits would be realized at the expense of much lower standing miombo at the end of the simulation period. In other words, these outcomes would be associated with the highest loss of biodiversity in practically all sites.

On the other hand, the commercial sector could derive more benefits under the cooperative management regime in the Chimaliro and Dzalanyama sites.

This would imply that households that engage in selling of woodland products would have more potential to trade in these products in these two sites as opposed to the woodland scarce Mdeka site. However, the central government through its Forest Department tends to discourage commercially oriented activities from the indigenous woodlands while at the same time encouraging communities' participation in management of the woodlands. In return to these efforts, households are allowed to freely harvest some of the woodland resources such as dead wood for firewood, grass, thatch and poles for house construction.

The non-cooperative regime, which mimics an open access situation, would produce the lowest total benefits in Chimaliro and Dzalanyama, while for Mdeka it would be the command model with environmental concerns. The latter management regime is implicit of strict biodiversity conservation with minimal or no harvesting of the woodlands, and therefore logically leading to minimal monetary benefits.

4.3 Labour employment potential

There appears to be a potential for households to increase their employment in woodland activities for their own consumption rather than for sale for all management regimes. However, this potential is very low for Mdeka households, ranging from zero to about 4%, while for Dzalanyama and Chimaliro, sites that are more endowed with woodland resources, the potential ranges from about 2 to 23%. The command regime with social concerns appears to offer the best opportunities for labour employment in household activities in the woodlands while, as expected, the command regime with environmental concerns offers the least potential. The same trend was observed for monetary benefits to the households in all sites. This observation would appear to confirm that it is the households that tend to use much of the woodland resources for own consumption and probably for unreported commercialization. The commercial sector appears to be not well developed as demonstrated by its relatively low monetary benefits in all sites as well as its low potential for labour employment opportunities ranging from 6 to 10% in Dzalanyama and Chimaliro to zero to 2% in Mdeka. Probably the prevailing prices for fuelwood are not high enough to allow for significant dislocation of labour from crop production to harvesting and sale of fuelwood. Further, the woodlands do not appear to have potential for a significant alleviation of rural unemployment.

4.4 Environmental/biodiversity conservation implications

With respect to environmental benefits, i.e., proportion of woodland resources (Ave_WLR) remaining at the end of the simulation period, the command regime with environmental concern had the highest values of remaining woodland resources in all the three sites, being about 60% for Chimaliro and Dzalanyama and about 20% for Mdeka. This makes sense because Chimaliro and Dzalanyama have more woodland resources than Mdeka.

With respect to volumes of harvested wood, the commercial sector would appear to have the potential for harvesting more from the Chimaliro site as compared to the household sector. This could be attributed to the tobacco industry in the Chimaliro area whereby estate owners buy a lot of wood for use in tobacco production. In the case of Dzalanyama, the household sector would harvest more woodland resources as compared to the commercial sector, most probably due to unreported commercialization done by the household sector and perhaps as a response to woodland conservation measures implicit in the co-management efforts introduced by the Forest Department in the area; measures that would curb open commercialization of fuelwood while allowing for its harvesting for household consumption.

The woodlands are mainly encroached upon for agriculture. The three sites have an average household size of five people and a land-holding size of 1.44, 1.25 and 0.55 hectares for Dzalanyama, Chimaliro and Mdeka, respectively. The results indicate that at the end of the simulation period about 40 to 60% of the initial land under woodlands would remain in Dzalanyama and Chimaliro under all management regimes, while the proportion for Mdeka would be much lower, averaging 20% for all management regimes. Mdeka experiences more land pressure as already seen from the small average land holding size for households of similar size to the other two sites. Further, Mdeka has much less woodland cover.

It would appear that the command with social concerns and the non-cooperative management regimes have the potential to deplete the woodlands more rapidly than the other regimes. The command regime with environmental concerns appears to have the best potential for protecting biodiversity.

5. POLICY EXPERIMENTS/SENSITIVITY ANALYSIS

Some sensitivity analyses or policy experiments were run based on the results from the base scenarios. They were made based on some assumed policy changes with potential effects on the behaviour and decisions of the household and commercial sectors as they relate to the miombo woodlands. The policy simulations were based on potential increases in the prices of fuelwood and agricultural inputs, given the strong linkages between the agriculture and forestry sectors.

Results of the sensitivity analyses would help to guide policy makers on the choice of woodland management regime to adopt in order to maintain a sustainable stand of indigenous forest resources as well as to improve the welfare of the local communities that depend on these woodlands.

5.1 Potential effects of increasing the price of fuelwood

Rural and urban dwellers in Malawi depend heavily on fuelwood. However, fuelwood sources are dwindling, very fast in the south and rather slowly in the north of the country. Land clearance for agriculture and related activities in Malawi is estimated at about 48,000 hectares annually (Minde *et al.* 1997). The pressure on forests and woodlands fluctuates widely among in the three administrative regions. In the southern region that supports 50% of the population, there is little forest cover left outside forest reserves. Annual deforestation in this region has been estimated at 2,000 hectares. The highest pressure on the forests and woodlands is in the central region, which supports about 39% of the population. In this region annual deforestation has been estimated at about 32,000 hectares. In the northern region that supports about 11% of the population the pressure is less and there are more forests and woodlands. The estimated annual deforestation in this region is about 14,000 hectares (*ibid.*).

As demand for fuelwood increases its price is bound to increase. We explored the potential effect of fuelwood price increase on household consumption, commercialisation and sustainability of the woodlands.

In the more woodland rich Dzalanyama and Chimaliro areas, a modest increase in the price of firewood by 25% would produce a very insignificant effect on the woodland remaining at the end of the simulation period. This woodland area would decline by between 1 and 2% for all management regimes and would remain unchanged in the non-cooperative management regime in Dzalanyama. Further, this firewood price increase would also have a modest but indeterminate effect on commercialised fuelwood, ranging from 3 to 8% in Dzalanyama, but the changes could become more pronounced in Chimaliro, ranging from 1% (with command management regime that emphasises social concerns) to 275% under the non-cooperative management regime.

With a price increase of 50% the proportion of woodland that would remain at the end of the simulation period would not decline significantly, remaining under 2% in both Chimaliro and Dzalanyama for all management regimes. However, if prices were to increase by 75%, the decline could jump to between 1% and 3% with the exception of command with social and environmental concerns in Dzalanyama that would have a decline of 13%.

However, in the woodland scarce Mdeka, the picture would be more or less the same, with the area of woodland remaining at the end of the simulation period declining by less than 1% when firewood prices increase by 25, 50 and 75%.

These price increases might not significantly influence deforestation in all study sites under all management regimes. Labour for harvesting and transporting the product on the head or with bicycles to distant markets could be a limiting factor for households to take advantage of the high prices. Further, firewood prices are fairly low, and increasing them modestly might not trigger a significant relocation of labour from crop production to firewood harvesting and selling.

5.2 Potential effects of increasing the price of fertilizer

The major inputs to crop production are fertilizers. These are mostly imported and their prices continue to rise. The hypothesis in this section is that increases in fertilizer prices could constrain agriculture production therefore encouraging the local communities to increase their reliance on the woodlands, a development that would increase deforestation.

The results indicate that there would be modest changes to total household benefits from woodland resources arising from increasing fertilizer prices by between 25% and 50%. When fertilizer prices are increased by 25% household total benefits could increase by between zero and 11% in Dzalanyama and 4 to 11% in Chimaliro, but decline by between 1 and 45% in Mdeka. In Dzalanyama households would harvest more wood for sale, with the non-cooperative management regime providing more flexibility in this, followed by the cooperative management regime. Both these regimes would respectively allow for a 135% and 124% increase in commercialized fuelwood. This could increase to 106% and 500% if fertilizer prices were to increase by 50%. The increases in commercialized fuelwood would more than offset decline in net revenues from crop production due to fertilizer price increases, resulting into the noted modest increases to total household benefits. The same trends are noted for Chimaliro, with the non-cooperative regime encouraging increased harvest of fuelwood by 68% and this could rise to about 184% if fertilizer prices were increased by 50%.

Mdeka is a woodland scarce area and would therefore not have the capacity to cushion a decline in total household incomes through increased fuelwood sales when fertilizer prices increase, hence the noted decreases in total household benefits to between 2 and 3% at 25 and 50% fertilizer price increases for respectively the command management regime with social and command management regime with environmental concerns. The decrease is much more pronounced to 27% and 45% for respectively the cooperative and command with social and environmental concerns regimes.

The magnitudes of the resultant changes in fuelwood harvests in the three study sites appear to be very big in some cases, but the actual volumes of fuelwood to be harvested from the woodlands would be fairly small. Since the commercialized volumes of fuelwood are a small fraction of the fuelwood for household consumption the observed potential increases in commercialized fuelwood would appear to have insignificant effects on the woodland that would remain at the end of the simulation period. In other words, the sustainable woodland resources at the end of the simulation period would remain relatively unaffected by these fertilizer price increases.

6. MAIN OBSERVATIONS AND CONCLUSION

a) The results demonstrate that the command management regime that emphasizes managing the woodlands with emphasis on social concerns would be more relevant to all the three study sites if derivation of highest total benefits to both household and commercial sectors is the criterion. The households would also derive highest benefits under this management regime in all the three sites, while the commercial sector would do better under the cooperative management regime in Chimaliro and Dzalanyama. These results would appear to contradict the logic of the present drive by central government to devolve ownership and management of the woodlands to the local communities, a move that implicitly advocates for the adoption of the cooperative management regime by the households in managing these resources. Further, the results demonstrate the relevance of continuing with government management of the woodland resources in all sites so long as the government gives priority access to the local communities (i.e. employing the command management regime with social concerns).

b) The potential for environmental protection or biodiversity conservation in all sites would appear to lie with the command management regime that emphasises environmental concerns.

c) In terms of potential for creating employment in these rural areas (or alleviating unemployment) the command management regime that emphasises social concerns would appear to be the best in all sites for household related activities. However, the cooperative management regime appears to have more labour employment potential for commercialised forestry activities. In general the potential for the forestry sector to alleviate or reduce rural unemployment in the three sites would appear to be relatively small.

d) Increases in price of fuelwood to at most 75% might not significantly influence deforestation in the three sites under all management regimes, most probably due to the fact that labour for harvesting and transporting the product on the head or with bicycles to distant markets could be a limiting factor for households to take advantage of the high prices. Further, fuelwood prices are fairly low, and modest increases in prices might not trigger a significant relocation of labour from crop production to fuelwood harvesting and selling. Another possible reason for this result is that we are dealing largely with subsistence communities and once they attain their subsistence level of income the pressure on the woodlands declines.

e) Increases in fertilizer prices by at most 75% could result in modest increases in total household benefits in both Dzalanyama and Mdeka, because households would harvest more woodland products to more than offset any cuts in crop marketable surplus that would result from using less fertilizer. However, in Mdeka total household benefits would decline as this site is almost depleted of woodland resources that households could fall on to offset revenue declines in agricultural production.

f) Much as emphasis has been on the agriculture and forest sectors, the systems dynamic model can also incorporate other sectors, like those of mining and construction to assess their impact on forest resources and welfare of rural communities.

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Policies and Governance Structures in Woodlands of Southern Africa

Southern Africa is essentially a woodland region. The woodlands are home to some of the largest herds of wildlife in the world, support a vast livestock industry, play a pivotal role in the hydrological functioning of the region, support the livelihoods of millions of people through agriculture, forest products and other services. However, there is scanty scientific information to guide their development and management. Given the numerous end uses and many stakeholders, it is not possible to rely exclusively on conventional forestry approaches and tools to manage the woodlands.

This book highlights different facets of local community governance of woodlands. The outcomes for people and forest are often dependent on local institutional arrangements (rules, regulations, organisational dynamics). The book explores the role of local institutional arrangements in woodland management, in community-based approaches and in conflict resolution.

It documents approaches and tools to reconcile the demands of the three key stakeholders on the woodlands (the local communities, government and private sector) in the framework of the three prominent rural development goals of food security, increased rural incomes and biodiversity or forest conservation. It also highlights tradeoffs between the goals and between five potential woodland management options by: (i) local communities, as a result of devolution of authority and management from central government, (ii) government but with a strict biodiversity conservation focus, (iii) government with access given to local communities for basic needs, (iv) government with a combined conservation focus and limited local community access for basic needs, and (v) perpetuating the present situation of open access.

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