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# INCENTIVE OPTIMISING MODEL FOR COMMUNITIES LIVING ADJACENT TO CATCHMENT FOREST RESERVES IN TANZANIA

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## ABSTRACT

Most Catchment Forest Reserves (CFRs) in Tanzania are managed in collaboration between government and communities through Joint Forest Management (JFM). In these forests, harvesting of timber and other valuable products are strictly prohibited. This led to minimal incentives for communities' participation in conservation. To readdress this anomaly, ecosystem goods and services are optimised to provide compensation for deferring timber benefits. This study aimed at developing an optimisation model based on sale of carbon and beekeeping activities. The study was conducted in Morogoro and Iringa regions in and around Kimboza and New Dabaga Ulongambi-(NDU) FRs respectively. The incentive model was developed using two decision variables (carbon and honey) and a set of constraints using linear programming. The model output revealed optimal returns ranging from USD 2025 to 6144 per forest per year in Kimboza and NDU FR respectively. Small returns in Kimboza were associated with small size of the forest reaching maximum at threshold between 615 and 1536 ha from a combination of carbon and honey. It is recommended to involve higher forest size (more than 600 ha) for community to maximise incentives particularly when carbon alone is considered. With lower forest size beekeeping activities become important.

Keywords: Catchment Forest Reserves-Communities-Incentives-Linear Programming-Carbon-REDD+NTFPs-Honey-Tanzania

## INTRODUCTION

Catchment Forest Reserves (CFRs) in Tanzania supply a vast number of goods and services (MNRT 2003). First, they supply direct use goods to local communities including firewood, honey, poles, animal fodder, fruits, vegetables, foods, weaving materials, nuts, game, and medicines. Second, CFRs provide environmental services including carbon sequestration, stabilisation of water flow, soil erosion control and biodiversity conservation, (Pattanayak 2004; Keles 2010). CFRs are reserved for water discharge, biodiversity and soil conservation. Most of them are managed in collaboration between government and forest adjacent communities through Joint Forest Management (JFM). However, there are concerns that in JFM, communities are given limited rights compared to the management responsibilities vested in them. In CFRs, harvesting of timber and other valuable wood products for domestic and commercial purposes is strictly prohibited. In this view, JFM considers communities as 'rightful beneficiaries' rather than 'logical source of authority and management' which in most cases the latter rests with the government (Wily

1998). This is disincentive to the communities.

According to Wily and Mbaya (2001), the lucrative incentive for communities to manage forest sustainably, is the sense that the forest belongs to them, either as recognized managers, or better still, as recognized owners. They need to see greater returns to their efforts in protecting and managing CFRs. Unless communities are given rewards and incentives for their efforts, the JFM process could be halted in its tracks before it has gathered momentum (Kajembe and Kessy 2000). One of the main problems with JFM currently is lack of incentives for local communities to participate in controlled, environmentally sound management of CFRs. JFM experiences from various countries have shown that weak incentives for communities are a primary cause of the high failure rate of Joint Management Agreements (JMAs) (Meshack and Raben 2005). The government of Tanzania has been setting up JMAs with communities to conserve forests with the following goals: attract community participation in the forest conservation activities, lower transaction costs, and increase benefits to local communities (Bromley and Ramadhani 2007). However, strength of JMAs is subject to the level of benefits derived from resource use and its contribution to local livelihoods. This in turn determines the level of motivation to fulfil obligations as laid out in JMAs. Currently, the perceived benefits as stipulated in the JMAs have not been realised countrywide (Kajembe and Kessy 2000). The net result is the collapse of agreements and a spread of disturbances (Meshack and Raben 2005). Experience has also shown that under the current legal framework, implementing JFM in CFRs is seriously constrained by the protection status of the forests, which severely restricts harvesting options (Meshack and Raben 2005).

Most ecosystem services have not been quantified, and hence there are no sufficient market prices to regulate their supply and demand, and thus provide weak financial incentives to promote their sustainable management. Such prices could be established to provide compensation to communities in exchange for deferring present livelihood benefits from CFRs (Nepstad *et al*. 2007; Jack *et al*. 2008). Existing REDD+ mechanism under two major global initiatives (United Nations Framework Convention on Climate Change-UNFCCC and Forest Carbon Partnership Facility of the World Bank need to view communities as the most relevant agents for managing forests to sequester carbon (Pagiola and Bosquet 2009) rather than focusing more on national governments (Chhatre and Agrawal 2009). While this may protect the direct and indirect benefits provided by the catchment forests through timber extraction, it means there are limited opportunities for the communities to earn cash income. It seems, communities have been asked to take care of forests for the greater national and international benefits without receiving adequate compensation. This is disincentive to them.

A number of reports (Pfliegner and Moshi 2005; MNRT 2006; Bromley and Ramadhani 2007; Kajembe *et al.* 2008) have attested to the reality that communities are not willing to continue investing their time in catchment conservation at the moment where the transaction cost seems to be higher than the benefits (Meshack *et al.* 2006; Lugandu 2010). According to Bond *et al.* (2009), one possible solution to this challenge is to create markets or market-like systems that internalise the costs and benefits of supplying environmental goods and services. Therefore, this study aims to address this challenge by developing an optimization model to optimise incentives in order to motivate forest adjacent communities through combination of carbon and honey.

## MATERIALS AND METHODS

### *Study Area Description*

The study was conducted in Morogoro and Iringa regions, Tanzania. These regions comprise the largest area of catchment forests and have a long history of JFM (MNRT 2006). Sampled FRs were Kimboza in Morogoro and New Dabaga Ulongambi (NDU) in Iringa. Kimboza is a lowland FR with an area of 405 ha situated at an altitude of 300 to 400 m. a.s.l. The forest is composed of lowland vegetation with patches of miombo, *Cedrella ordorata* and *Tectona grandis* tree species. The FR receives a mean annual rainfall of up to 1800 mm/year. Kimboza is important catchment forest draining water to Ruvu River which provides water to Morogoro municipality, the Coast Region and Dar es Salaam City. The NDU FR with 3 700 ha, is a montane forest with patches of bamboo. The forest lies at an elevation ranging between 1 760 and 2 060 m.a.s.l. (Lovett and Pocs 1993). NDU FR rceives mean annual rainfall ranging from 1 500 to 2 000 mm/year. Both forests are owned by Central Government and managed in partnership with communities. The information and data required for defining the objective function and constraints were extracted from the available comprehensive studies conducted in the study areas (Malimbwi *et al.* 2005; Lugandu 2010). In addition, some field surveys (e.g. disturbance transects) were conducted to compliment the data.

### *Decision Variables for the Model*

For sometime, NTFPs were overshadowed by timber products and have received increased policy and research attention only in the last two decades. According to Arnold and Ruiz-Perez (2001), this attention is based on three main reasons. First, NTFPs contribute significantly to the livelihood and welfare of households living adjacent to catchment forests. Secondly, their exploitation has less ecological distortion than that from timber harvesting. Lastly, NTFP production and development in a sustainable manner could reduce tropical deforestation. In the past three decades, there has been a growing awareness of the importance of honey as NTFPs for food and medicinal uses. This growing awareness is not only for the role they play in the subsistence economy, but also for their potential and real contribution to the economies of many developing countries (FAO 1995). It has been described that harvesting of NTFPs can provide an array of social and economic benefits to communities, and therefore makes it to be an important component of forest ecosystem management (Giliba *et al.* 2010). Among the list of NTFPs, honey is the most commercialized and therefore the most profitable product in the study sites due to development of the beekeeping sector in the country.

Due to increasing effects of climate change in recent years, the international community is in negotiations on rewarding forest conservation stakeholders for Reduced Emissions from Deforestation and Forest Degradation (REDD+) as a way to mitigate climate change. The role of forest ecosystems in global warming and climate change has created great interest in forestry research and development (Baskent and Keles 2009). Many countries with high emissions levels have started showing interests and willingness to pay developing countries that would be producing valuable carbon credits through preservation of natural forests. It was considered worth choosing carbon rather than biodiversity or water (for example) because large sums have already been spent on carbon management in Tanzania by the international community, particularly Norway. A REDD+ strategy has been developed and about nine piloting projects are being implemented in Tanzania.

It is because of these reasons and the fact that payment for water services in Tanzania is not yet well developed, carbon and NTFPs (specifically honey) were chosen to be decision variables in the optimization model.

## Choice of Mathematical Programming Technique

Linear programming is the most widely used mathematical programming method, and it has been the most broadly applied of all management science techniques in natural resource management and related disciplines (Martin and Sendak 1993; Holmes 1976). Some of its applications in forest management include planning of logging operations (Newnham 1975), product optimization in a log concentration yard (place for selling and marketing wood), planning of forest roads (Boughtonne 1967), appraisal of stumpage prices (Beuter 1965), analysis of internal transfer pricing policies for logs and reforestation planning (Buongiorno and Teeguarden 1973). The bibliography compiled by Martin and Sendak (1973) lists more than 416 publications related to the application of the management science in forestry and forest products, with more than 200 devoted to linear programming. Since the decision variables (carbon and honey) and the constraints were assumed to be linear, it was decided to use the simplex method of linear programming to optimise incentives.

Despite the considerable literature that exists on the optimization field, frequent application of the applied mathematical approach in the management of ecosystem goods and services in the developing world is minimal (Sadeghi *et al.* 2009). There are many efficient techniques for optimization of ecosystem goods and services out of which linear programming is a basic method (Jianbo *et al.* 2002; Gabriel *et al.* 2006). The impossibility of weighing relative importance to different objectives required for goal programming owing to inaccessibility of reliable data, and its simplicity make it more preferred for application (Chang *et al.* 1995; Amir and Fisher 1999; Benli and Kodal 2003).

## Choice of Analytical Software

The most popular software packages which are dedicated to solving linear programmes (LPs) and other types of mathematical programmes include LINDO, GAMS, LPWYE and XPRESS-MP. However, all these packages tend to be DOS based and are intended for a specialist market which requires tools dedicated to solving LPs (Dykstra 1984). In recent years however, several standard business packages have started to include LP solving option, and Microsoft Excel has now become robust. There are two reasons which attracted the use of MS Excel. Firstly, MS Excel is the most popular spreadsheet used both in business and in universities and as such is very accessible. It is a general purpose optimiser for small-scale linear programming problems included in Microsoft Excel and Microsoft Office for Windows and Macintosh. Secondly, the spreadsheet offers very convenient data entry and editing features which allow the user to gain a greater understanding of how to construct linear programmes. Models are created using the spreadsheet formula language and may employ many other spreadsheet features such as graphical formatting, outlining, charts and graphs, access to external databases, and an extensive library of mathematical, statistical, financial and engineering functions. Models are automatically translated in a manner similar to algebraic modelling languages, and solved by the spreadsheet optimiser software. Therefore, this study chose to use Microsoft Excel Solver to maximize net returns from a combination of carbon and honey for communities under JFM around NDU and Kimboza FRs.

The Mathematical Model

The general benefit maximization problem was formulated as shown in equation 1.

Max $Z = w_1X_1 + w_2X_2$ ........................(1)

Assuming the current price of certified Emission Reductions (CERs) is US$ 20 per tonne $CO_2$e and the price of honey is US$ 5 per Kg then the objective function in equation 1 becomes as shown in equation 2.

Max $Z = 20X_1+5X_2$..............................(2)

Subject to:

Labour (Hrs) :$10X_1+5X_2 \leq 3{,}072$ .......(3)

Capital (USD): $2X_1+X_2 \leq 7{,}400$………....(4)

Forest area (Ha): $5X_1+ X_2 \leq 3{,}700$.........(5)

Disturbance (m3/ha): $X_2 \leq 0.5$ ,……...(6)

$X_1 \geq 0$ Non-negativity constraint for $X_1$……………………………………..(7)

$X_2 \geq 0$ Non-negativity constraint for $X_2$……………………………………..(8)

Where:

Z= Value of the objective function (net returns per year)

$w_1$= Current price of carbon per tonne in the international market (US$ 20)

$w_2$= Average price of honey (US$ 5 per kg)

$X_1$= Amount of carbon credits to be produced (tonnes)

$X_2$= Amount of honey to be collected (Kg)

**Note**: The right hand side values shown in equations 3-6 are for NDU FR only.

Constraints of the Model

The objective function was subjected to a number of constraints (equations 3-8) including labour, capital, area of production (forest size) and human disturbances caused by illegal harvesting of wood.

### *Labour Availability*

In villages adjacent to CFRs, communities have other obligations to do apart from forestry (carbon management and honey production). On average, in both sites communities are involved in forestry activities for 8 hours per week. A group of about 8 Village Natural Resources Committee (VNRC) members in a single forest are working in 48 weeks (with assumptions that some of the weeks are lost due to public holidays and attending social emergencies) leading to a total of 3 072 hours required per year. These are number of hours used by communities to manage catchment forest reserves including time used for forest patrols, fire extinguishing and boundary maintenance. It has to be noted that, only time for actual management is considered, time for sitting in meetings and seminars is not included in the model. The 3 072 hours per year were applicable for both NDU and Kimboza forest reserves. It is assumed that 10 hours are required for each tonne of $CO_2$e produced (sold) and that the harvesting and processing of one kg of honey requires 5 hours.

### *Capital/Investment*

The low level economic conditions of the communities limit them to investing in large capitals. The JMAs have not yet guaranteed any reliable income and this is one of the evidences of such unreliable benefit to the communities as the cost-benefit sharing mechanism was not yet agreed. However, carbon credits production in the study areas builds up in the already established JFM. This makes it to have little investment as all the necessary start up and implementation activities have been carried out for the intended JFM objectives. The study by Zahabu (2008) estimated an average total annual management cost at USD 1 580 per village undertaking PFM. Furthermore, Zahabu (2008) estimated transaction costs related to measuring and monitoring of carbon (honey included) by communities to a forest bigger than 150 ha to be less than USD 2 per ha per year. Basing on this figure therefore, NDU FR (3 700 ha) needed a maximum of USD 7 400 while Kimboza FR (405 ha) needed not more than USD 810 for management of carbon sequestration. It is assumed that one tonne of $CO_2$e produced (sold) requires US$ 2, and that the harvesting of one kg of honey requires US$ 1. Harvesting of honey was the only cost considered because establishment cost had already been incurred during initiation of PFM.

### *Land availability (Forest size)*

The values (variables) to be optimised are assumed to be limited to the boundaries of the officially gazetted area of the relevant forest reserve. Therefore, land constraint for Kimboza was determined as 405 ha and that of NDU at 3 700 ha of land. These values reflected forest size limitations for the optimization model. It is assumed that the production (sale) of one tonne of $CO_2$e requires at least five ha of forest, and a kilogramme of honey requires at least one ha.

### *Forest Disturbance*

Forest disturbance may be referred to as a discrete force that causes significant change in structure and or composition of the forest (FBD 2005). Disturbance may be due to natural causes (wildfire, flood, wind or earthquake); mortality (insect and disease outbreaks) or human induced causes (wood harvesting). Among others, forest disturbances have negative impacts on the potential of a forest in carbon sequestration. Unlike natural and mortality, the human induced causes usually involve complete removal of forest biomass and thus causing carbon emissions and disturbing apiaries. According to this study, disturbance levels for new cuts were 2.7 $m^3$ $ha^{-1}$ and 0.5 $m^3$ $ha^{-1}$ for Kimboza and NDU FRs respectively. If the present level of disturbances was to be used as an upper limit, 1850 $m^3$ could be removed from NDU FR annually and 1094 $m^3$ from Kimboza FR. Only new disturbance levels were considered to reflect the current trends in these forests. It has been assumed that carbon sequestration does not lead to any disturbances while the production of one kg of honey may result in the removal of one $m^3$ of wood for beehives construction.

## RESULTS AND DISCUSSION

### The Model Output

The optimal solution for NDU FR has the value of USD 6144 per year (Table 1). In order to achieve this optimal solution, a combination of 307.2 tonnes of carbon and nothing of NTFP (0 Kg) were produced. The number of hours that were required (labour) for management of the forest was found to be binding. This could be true because NDU FR is a big forest (3 700 ha) surrounded by six villages. That means 3 072 hours of work (patrols, boundary maintenance, fire fighting and monitoring for carbon and beekeeping) is not sufficient for such a big FR. However, other constraints were in excess with positive slack values. That means, they were inadequate, and reducing their amount by the value shown as slack would not affect the optimum solution. Practically, this suggests that capital can be reduced by USD 1256 given the same conditions or assumptions. Forest area cannot be reduced because it is already gazetted and disturbances have already taken place. The optimal values obtained for both sites are comparable to findings of other studies. For example, Juma (2012) reported a potential of earning about USD 3 700 for Kwevumo FR and USD 3 900 for Derema PLFR in Eastern Arc sites, Tanga region. However, figures from the latter are relatively small, probably because the study used small prices of carbon (USD 5 per tonne in 2008 prices).

**Table 1: Optimal solution for NDU FR**

| Return | Final Value | |
|---|---|---|
| Profit per ha | 6144 | |
| Decision Variable | Final Value | |
| Carbon Sequestered per ha | 307.2 | |
| NTFP producedper ha | 0 | |
| Constraints | Status | Slack |
| Labour | Binding | 0 |
| Capital | Not Binding | 1256 |
| Forest area | Not Binding | 2164 |
| Disturbance | Not Binding | 0.5 |
| Non negativity 1 | Not Binding | 307.2 |
| Non negativity 2 | Binding | 0 |

A study by Strassburg *et al.* (2009) which modelled the effects of reduced emissions from 20 most forested developing countries (Tanzania inclusive) concluded that USD 8 per $tCO_2$ was on the very low side of the UNFCCC estimates of mitigation options (they recommended the price to increase up to USD 100 per $tCO_2$).

Table 2 shows sensitivity analysis which is a measure of confidence in the results presented in Table 1. It shows that for optimal solution, one may increase labour up to 628 hours to the existing 3 072 hours per year to satisfy the objective function. It also shows that for every additional unit of labour there is and additional profit of USD 2, the value of shadow price (Table 2). For other constraints, there was a shadow price of zero showing that increasing the constraint value to any amount will never add any profit because they are already in excess.

**Table 2: Sensitivity analysis for NDU FR**

| Decision Variables | Final Value | Reduced Cost | Objective Coefficient | Allowable Increase | Allowable Decrease |
|---|---|---|---|---|---|
| Carbon sequestered per ha | 307.2 | 0 | 20 | 1E+30 | 10 |
| NTFP produced per ha | 0 | 0 | 5 | 5 | 1E+30 |
| Constraints | Final Value | Shadow Price | Constraint R.H. Side | Allowable Increase | Allowable Decrease |
| Labour | 3072 | 2 | 3072 | 628 | 3072 |
| Capital | 6144 | 0 | 7400 | 1E+30 | 1256 |
| Forest area | 1536 | 0 | 3700 | 1E+30 | 2164 |
| Disturbance | 0 | 0 | 0.5 | 1E+30 | 0.5 |
| Non negativity 1 | 307.2 | 0 | 0 | 307.2 | 1E+30 |
| Non negativity 2 | 0 | -5 | 0 | 614.4 | 0 |

For Kimboza FR, the optimal solution had a value of USD 2 025 per year (Table 3). According to the model, this optimum level is contributed mainly by the amount of honey produced from the FR. Forest area seemed to be small for production of significant carbon credits. This was true because the model suggests that labour and capital are in excess but forest area is binding with a slack value of zero (Table 3).

**Table 3: Optimal solution for Kimboza FR**

| Return | Final Value | |
|---|---|---|
| Profit | 2025 | |
| Decision Variable | Final Value | |
| Carbon sequestered per year | 0 | |
| NTFP produced per year | 405 | |
| Constraint | Status | Slack |
| Labour | Not Binding | 1047 |
| Capital | Not Binding | 3350 |
| Forest area | Binding | 0 |
| Disturbance | Not Binding | 2.7 |
| Non negativity 1 | Binding | 0 |
| Non negativity 2 | Not Binding | 405 |

According to Table 4, for Kimboza to qualify for carbon markets by its own (that is producing significant credits) it needs to be re-gazetted with additional area of 209.4 ha, something that is practically impossible. If that would be possible, the model simulates additional profit of USD 5 for every ha that could be added to Kimboza FR (the value of shadow price).

This finding is supported by Chhatre and Agrawal (2009) who also found that the area of the forest and the degree of rule-making autonomy are both positively associated with win–win outcomes for high carbon storage and livelihood benefits. They further argued that when local users perceive insecurity in their rights (because the central government owns the forest land), they extract high levels of livelihood benefits from them, and when their tenure rights are safe, they conserve the biomass and carbon in such forests. Therefore, to maximize profit based on carbon stock, forest size is one factor and forestland tenure is another.

**Table 4: Sensitivity Analysis for Kimboza FR**

| | Final | Reduced | Objective | Allowable | Allowable |
|---|---|---|---|---|---|
| Decision Variable | Value | Cost | Coefficient | Increase | Decrease |
| Carbon sequestered per ha | 0 | 0 | 20 | 5 | 1E+30 |
| NTFP produced per ha | 405 | 0 | 5 | 1E+30 | 1 |
| | Final | Shadow | Constraint | Allowable | Allowable |
| Constraint | Value | Price | R.H. Side | Increase | Decrease |
| Labour | 2025 | 0 | 3072 | 1E+30 | 1047 |
| Capital | 405 | 0 | 810 | 1E+30 | 405 |
| Forest area | 405 | 5 | 405 | 209.4 | 405 |
| Non negativity 1 | 0 | -5 | 0 | 81 | 0 |
| Non negativity 2 | 405 | 0 | 0 | 405 | 1E+30 |

It has to be noted that the prices for carbon and honey may change at any given time. It was estimated for example that carbon prices may rise up to USD 100 by 2030 (Strassburg *et al.* 2009). Any increase of these prices will also increase the profit. In next two years, the price of one tonne of carbon would reach USD 30 and a kilogramme of honey would be sold at USD 10 (Keles 2010). Using the production costs as shown in the model, carbon and honey prices increase would generate up to USD 9215 and USD 4050 per year for NDUFR and Kimboza FR respectively.

### *Implications of forest Size*

Forest area is an important determinant for the product mix between carbon credits and honey. According to this model, forest area below 615 ha will have its optimal solution contributed by honey alone (Fig. 1). Also, any forest area above 1 536 ha will have optimal solution contributed by carbon. Therefore, the model estimates that smaller forests would not be suitable/effective for carbon sequestration or they have insignificant contribution in sequestering carbon and hence insignificant payments to managers. Increasing forest area above 1 536 ha has no impact in the amount of honey produced if other factors are held constant. This implies that communities around Kimboza FR should not expect to generate significant carbon credits from their forest but rather they may concentrate on beekeeping and maximize its potential. Figure 1 is an illustration of the sensitivity of the model parameters to forest area.

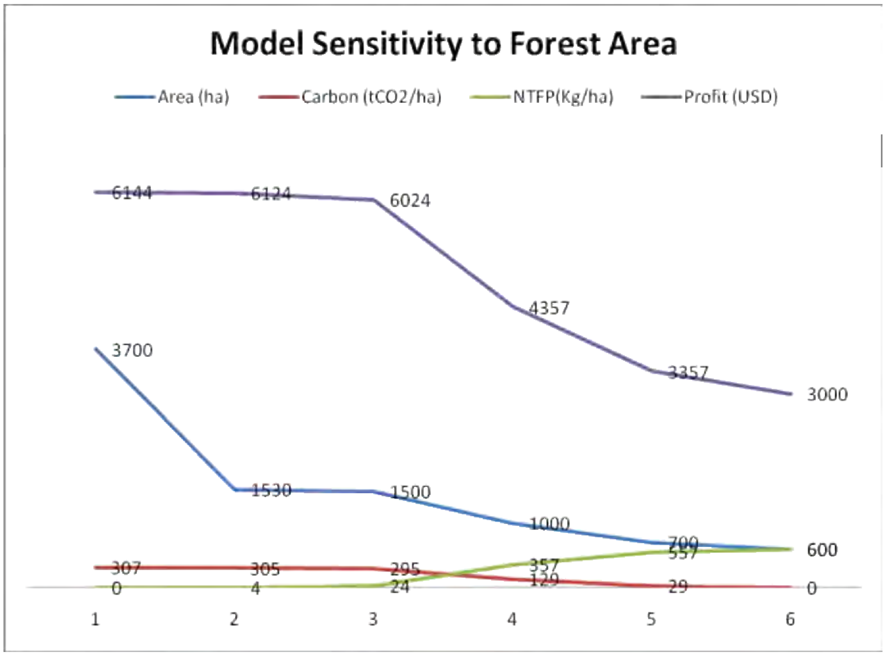

**Figure 1: Model Sensitivity to Forest Area**

The model further suggests that communities around NDU FR can generate up to USD 6 144 per year in their 3 700 ha forest even without a mix with beekeeping. According to Figure 1, there are always possibilities of mixture of both carbon and beekeeping to attain a certain profit. This happens only when forest area is between 615 ha and 1 536 ha. However, in any mix of these variables, the profit is always slightly below the maximum (USD 6 144 per year). For example, if the forest area were 1 250 ha while other factors are constant, about 212 $tCO_2$ and 191 kg of honey would be produced, leading to the profit of USD 5 191 per year. However, too much reduction of the area reduces the profit significantly but with increase in amount of NTFP combination (Figure 1).

### *Possible solution to fragmented forest areas*

Small forests would not qualify for carbon payments under REDD+ policy especially in forests managed by communities. To solve such a problem, several nearby FRs may be aggregated in terms of forest management, assessment and therefore in payments. Meshark *et al.* (2006) contend that pooling projects together could significantly lower transaction costs which are normally higher in community projects because of their smaller size. Project pooling could also be carried out by national governments, like in Costa Rica, or by international non profit organizations like the Face Foundation (Smith 2003). This initiative is also not new in Tanzania as it is being practiced by Tanzania Forest Conservation Group (TFCG) in management of small community based forests for carbon offsetting under the project “Making REDD+ work for communities and forest conservation.” Every village does measure its forest and manages it according to agreed standards. Monitoring is done to check the agreed standards and later assessment is done for several forests under one network where they are considered as one forest ecosystem and therefore paid as one forest. Later, the funds would be distributed to villages based on the forest size. This is in line with what Thomas *et al.* (2010) asserted that the formation of community networks is essential for the success of the project to meet minimum transaction costs, even for small-scale projects developed or implemented by low-income communities. In Brazil for example, these networks are implemented through agricultural cooperatives. In many regions they represent one of the few opportunities to add value to rural production as well as the insertion of small and medium producers in concentrated markets. In the study sites, this initiative can easily be implemented due to the existing institutional structures such as Tanzania network for forest adjacent communities (MJUMITA) or rather through the Tanzania network of farmer groups (MVIWATA). Therefore, Kimboza FR need to be aggregated to other nearby forest reserves including Ruvu FR in order to benefit from carbon payments.

### *Model Limitations and Simplifications*

Several important issues were not addressed in this modeling but could be incorporated into future research to make the model more comprehensive. Cathment forest ecosystems provide a number of products and services with values beneficial to people (Keles, 2010). Water and biodiversity values are equally important and are the best co-benefits in catchment conservation in the study sites. However, this study considered only two important forest values, honey and carbon because of constraints of data availability and time. Our estimates also carry uncertainties of the studies used as sources of information. Important to understand is the fact that catchment dynamics is a prerequisite if one wants to develop good catchment forests management practices that include all non-timber forest goods and services. The optimization model developed is not spatially explicit, excluding effects of activities in nearby areas. Since it is dynamic, it is subject to evaluation of both the biological and the economic risks involved. The model does not include the rate of carbon sequestration of these forests because biomass change could not be established which necessitated undertaking two forest inventories. The carbon price in the international market is a big determination of profitability. The prices and coefficients of the constraints used are also conservative. The models have also been simplified due to limited techniques in modeling including availability of sophisticated software.

## CONCLUSION

Weak incentives for conservation of catchment have given rise to an increasing concern by researchers and communities of how to give value to ecosystem goods and services especially in areas with high biodiversity values. As the results of this study showed, conservation of CFRs for carbon and beekeeping is worth undertaking especially when the managed forests have relatively big areas of above 600 ha. The assumptions of this study are in line with most principal agent models which predicted that increasing incentives has a higher performance, and therefore leads to sustainable management of CFRs. The optimal solutions given by the model in this study suggests a reasonable amount in addition to what is currently available to communities from sale of carbon and beekeeping activities, leaving other potential benefits of water and biodiversity that were not a concern of the current study. It can be concluded that a range of USD 2 025 to 6 144 per year is worth acting as incentive to motivate communities who are jointly managing CFRs with government in the hope that the latter will be willing to let carbon finances flow down to communities. The study therefore recommends scaling up of JFM in bigger forests (with more than 600 ha) for community to maximise incentives particularly when carbon payments are considered.

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