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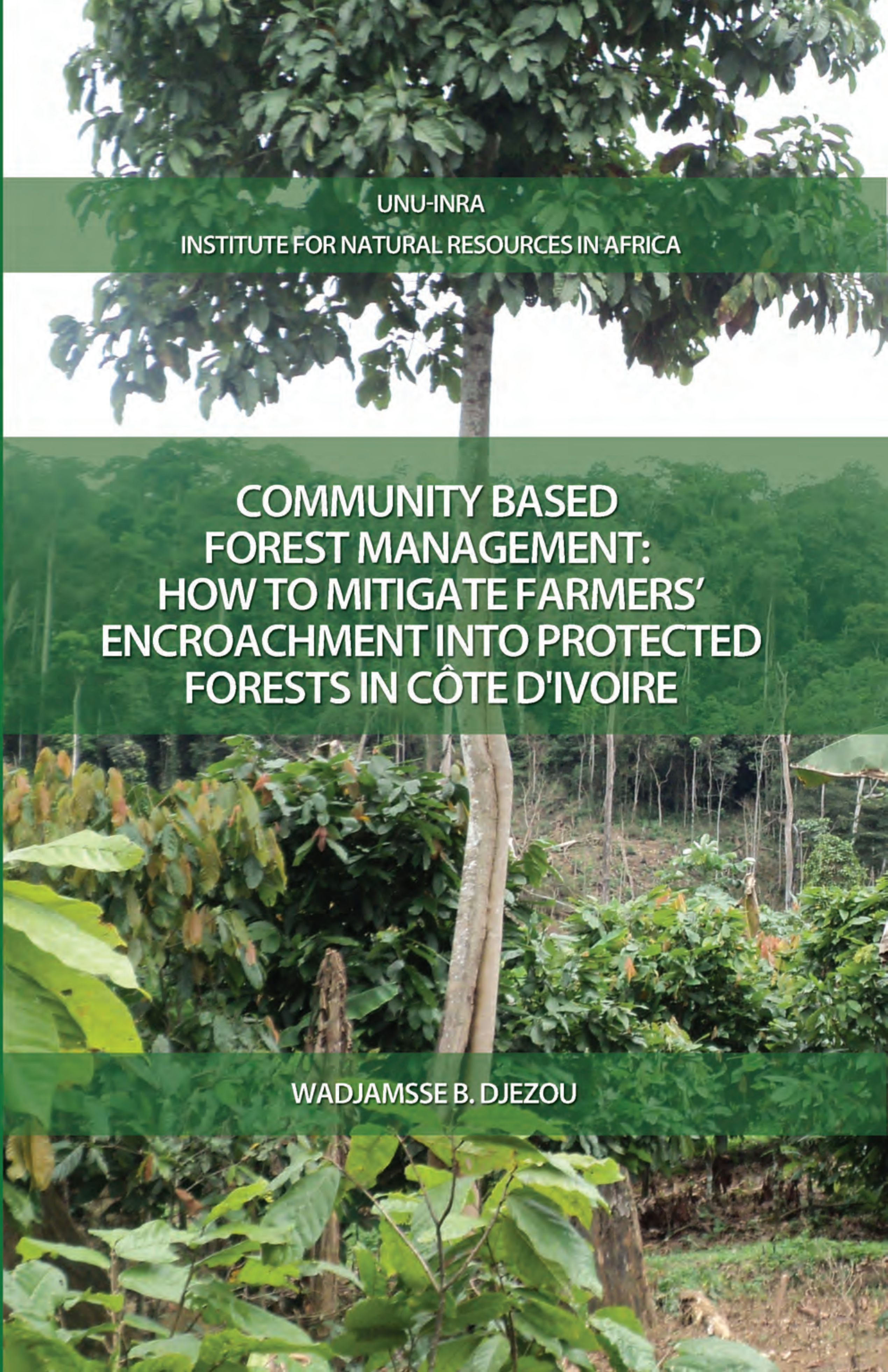

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COMMUNITY BASED FOREST MANAGEMENT: HOW TO MITIGATE FARMERS' ENCROACHMENT INTO PROTECTED FORESTS IN CÔTE D'IVOIRE

WADJAMSSE B. DJEZOU

UNITED NATIONS UNIVERSITY

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(UNU-INRA)

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BY

WADJAMSSE B. DJEZOU

UNU-INRA Visiting Scholars Programme

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ABSTRACT

Protected forests are being encroached upon by farmers, negating the efforts by forest authorities to reach an ecological equilibrium. This situation is accelerating the pace of global warming and also threatening agricultural production, on which the economy of Côte d'Ivoire depends. To address this problem, the paper investigates the factors that lead to a sustainable management of protected forests by analysing the Joint Management Policy implemented by SODEFOR, using a bio-economic model. Dynamic optimisation techniques in continuous time were used to explore the policy responses that could stimulate forest conservation and poverty reduction. The study shows that the joint management approach improved the level of forest conservation compared to the state management approach implemented so far. To achieve these, some conditions needed to be fulfilled. Firstly, the results suggest that the share of income from the exploitation of secondary products going to the local community should at least be equal to that derived from timber exploitation, since it was found that the higher the share of revenue from secondary activity, the higher the level of anti-encroachment efforts. In particular, optimal anti-encroachment efforts are obtained when ß is close to unity while α is close to zero, as this provides incentives for forest conservation, for both the local community and SODEFOR. Secondly, the paper posits that the marginal revenue from logging activities should be relatively higher than is obtained from the exploitation of secondary products; however, an absolute increase in marginal revenue from secondary activities improves the level of conservation. Finally, the study demonstrates the necessity of external financing to secure the cooperation of local communities for forest conservation, to counterbalance the effect of the forest being regarded as a public good that benefits the international community.

Key words: *protected forest, encroachment, anti-encroachment efforts, sustainable management, external financial support, local community, poverty reduction.*

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ACRONYMS

AIFORT	Atelier International sur les Innovations dans l'Industrie des Forêts Tropicales et des Produits Forestiers
CIFOR	Centre for International Forestry Research
CIRAD	Agricultural Research for Development
CNEARC	Centre International d'Etudes Supérieures en Sciences Agronomie
ESAT	Etudes Supérieures d'Agronomie - Montpellier
FAO	Food and Agriculture Organisation
FMP	Forestry Management Plan
FOSA	Forestry Outlook Study for Africa (FAO.org)
INED	National Institute for Demographic Studies
JM	Joint Management
MINEFOR	Ministère des Eaux et Forêts
NGO	Non-Governmental Organisation
NPM	National Park of Marahoué
NTFP	Non-timber Forestery Products
PFC	Peasants-Forest Commission
SODEFOR	Société de Développement des Forêts de Côte d'Ivoire
UNU-INRA	United Nations University – Institute for Natural Resources in Africa

Non-timber forest products (NTFP) gathered by the community being offered for sale

1. INTRODUCTION

The world is confronted today with multiple threats: soil, water, and marine resource depletion, air pollution, the loss of the ozone layer, climate change, global warming and deforestation. The latter is partly the cause of the aforementioned threats since forests play a strategic role in the ecosystem, in particular in their capacity to protect watersheds, prevent topsoil erosion, help in the recycling of nutrients at the local level and provide advantages related to biodiversity and carbon sequestration at the international level. These environmental and natural resource management problems constitute major challenges for decision makers today. Indeed, tropical forests have decreased significantly under various pressures. According to Lanly (1982), from1976-1980 the annual rate of deterioration of humid tropical forests rose to about 6,113 million hectares. Some recent data indicates that world yearly deforestation which was about 8,868 million hectares between 1990 and 2000, is estimated at 7.317 million hectares per year between 2000 and 2005. Thus, the area of the world's forests decreased from 4.077 billion hectares in 1990 to 3.952 billion hectares in 2005 (FAO, 2007).

The forests of Côte d'Ivoire follow a similar deforestation trend (Aké Assi, 1984; Lord, 1996; Guessan, 2006). Indeed, shifting agriculture, over-exploitation of forests for timber and wood gathering for energy constitute the main activities that are leading to deforestation in Côte d'Ivoire (FAO, 2003). These actions have led to a deterioration of more than 83 percent of the country's forest area. Thus, from 15 million hectares at the beginning of the last century, there remained only 2.5 million hectares of forest in 1996 (SODEFOR, 1996) and even less in recent years. Today, unexploited forests are estimated at only a few thousand hectares, made up of the forest reserves and national parks on which Côte d'Ivoire has based the conservation of its flora and fauna.

Unfortunately, these protected areas are constantly being encroached upon for agricultural purposes. For example the National Park of Marahoué (NPM) recorded an estimated agricultural occupation of 13,746 ha in 1999 (MINEFOR, 2001). In general, the protected forests are in a relatively advanced state of deterioration. About 30 percent of these forest lands are used for agriculture and more than 72,000 families live inside these forests (AIFORT, 2008). As part of efforts to deal with the situation, the Ivorian government decided in 1992 to entrust SODEFOR (Société de Développement des Forêts de Côte d'Ivoire, a public company established in 1966), with the management of all Ivorian protected forests.

SODEFOR, with its expertise in industrial reforestation was required to find a solution to the expansion of agricultural activities into the protected forests. Towards this end, SODEFOR implemented a Joint Management Policy through a discussion forum called the "Peasants-Forest Commission". The policy aims at involving the local community in the management of protected forests.

Unfortunately, the expected results are not materialising, since the agricultural portion of the protected forest is still growing. Due to the drawbacks of the Joint Management Policy, the government decided in March 1997 to take strong deterrent measures.

Its policy of deterrence consists of the forest authority (SODEFOR) systematically destroying all perennial crops as well as all food crops in the protected areas. Unfortunately, the encroachment still continues and threatens the ecological equilibrium of the country. Therefore, questions arising are whether the Joint Management Policy instruments are well formulated, whether all policy components, especially economic aspects are being taken into account and what the economic incentives of the Joint Management Policy are.

In other words, what are the economic factors that drive the optimal level of forest conservation and the mitigation of peasants' encroachment?

The objective of this paper is to analyse, on the basis of a bio-economic model, the Joint Management Policy that aims at a sustainable management of protected forests by mitigating peasants' encroachments into protected forests.

Our paper is structured as follows:

Section 2, gives an insight into forest management policy in Côte d'Ivoire and presents the Peasants-Forest Commission structure; Section 3 deals with the literature review; Section 4 lays out the methodology; Section 5 presents the results of the study and policy recommendations; Section 6 gives the conclusion; references are cited in section 7 and various equations are derived in the Appendix at Section 8.

A farm in a deforested area

2. FOREST POLICY IN CÔTE D'IVOIRE: AN OVERVIEW

In this section, we review the forest policy implemented so far by focusing on SODEFOR'S Joint Management Policy.

2.1 Management policy for forests in Côte d'Ivoire

Côte d'Ivoire's economic development began with favourable conditions for agriculture and timber exploitation, thanks to its extensive forests. Unfortunately, this forest cover is currently undergoing rapid degradation which is threatening the nation's ecological balance and economic development. The country's forest cover that accounted for almost 16 million ha in 1900 fell to less than 3 million ha in 1991 (FOSA, 2001) and is estimated to be less than 2 million ha today. In the face of the serious ecological, economic and cultural consequences of this development, the government undertook important political and institutional measures aimed at reversing the trend of forest degradation. This was mainly by promulgating the Forestry Management Plan (FMP) 1988-2015, which seeks to manage Côte d'Ivoire's forests in a sustainable way. The Plan focuses on the effective participation of local stakeholders in forest management in order to achieve efficient management of this natural resource (MINEFOR, 1988). This arrangement was reinforced by the Forestry Sector Reform in July 1994, which sought to improve forest management and intensify controls by creating the forestry police, strengthening monitoring capabilities and intensifying reforestation activities at village level. In spite of these measures, there still remain gaps and challenges in promoting sustainable management of the forests. These include:

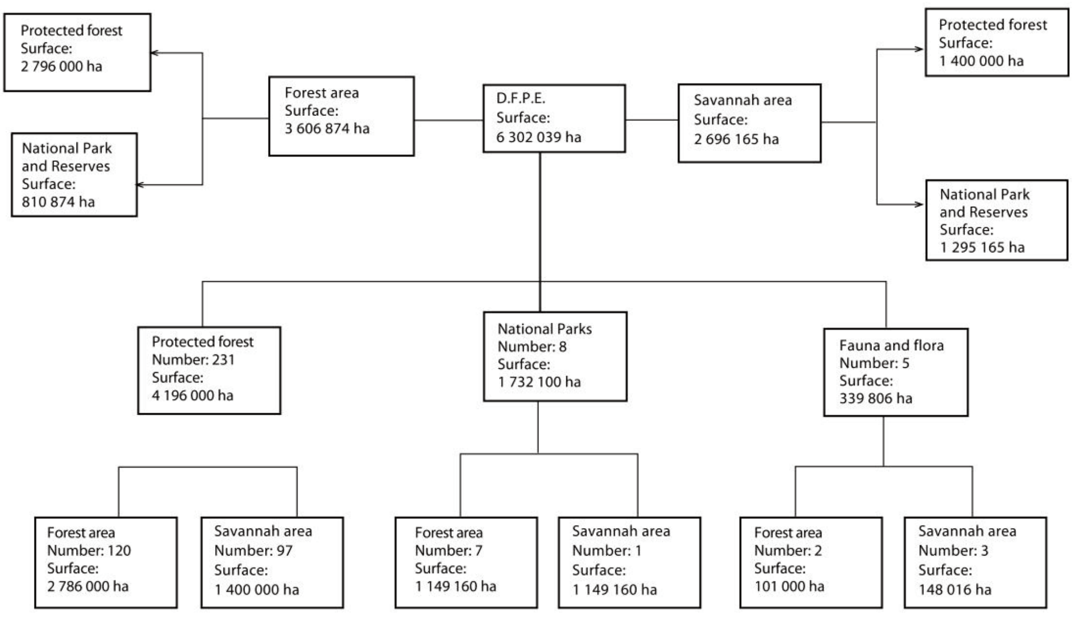
- high population pressure on forest resources for various social needs and agricultural purposes;
- weak adherence of the population to the principle of sustainable management of forest resources and the concept of reforestation;
- lack of financial resources for necessary investments.

Given the situation, the government decided in 1992 to allocate all protected forests to SODEFOR, which had been in existence since 1966. The forests of Côte d'Ivoire are divided into two management categories, namely: the permanent forest domain of the government and the rural forest domain that represents about 84 percent of the national territory (about 28 million ha) in which all activities of production such as agriculture and timber exploitation (80 percent of overall timber exploitation) are concentrated. The permanent forest domain under government control mainly consists of protected areas (national parks and natural reserves) and protected forests that currently cover an area of about 6 million ha. About 70 percent of this domain is in the forest and pre-forest areas while 30 percent is in the Savannah.

SODEFOR's objective is to sustainably manage 231 protected forests covering a total surface of 4,196,000 ha. Currently, 86 of them have development plans. Despite these arrangements, agriculture and timber exploitation have continued in the state managed permanent forest domain.

The structure of the permanent forest domain of the government is depicted at Figure 1 below. The government released about 975,000 ha of protected forest for agricultural purposes between 1960 and 1986, just to avoid encroachment (SODEFOR, 1992). However by 1993, more than 30 percent of the protected forest had been encroached upon and was cultivated by more than 500,000 farmers (Leonard, 1997). The average rates of encroachment over the periods of 1991-1996 and 1996-1999 were 26 and 27 percent respectively (FOSA, 2001).

The Western and South-Western Regions had the highest encroachment rates, with 24 percent and 44 percent respectively (SODEFOR, 1994). Therefore, as part of its integrated management policy, SODEFOR opted for the inclusion of social and agro-economic factors interfering with the sustainable management of forests.



Source: Aifort (2008)

Figure1: The structure of the permanent forest domain of the state (PFDS)

The policy led to the establishment of a participative commission called the "Peasants-Forest Commission (PFC)" as well as the implementation of a Joint Management Policy with the riparian population.

Unfortunately, this promising policy did not slow down the encroachment rate. A mid-term review of the policy revealed that the population had not really been involved, since decisions were taken unilaterally by SODEFOR and the Forestry Department.

The situation worsened when the government took repressive measures through the order of 7 March 1997 for a systematic destruction of all food and perennial crops that were not in production in order to expel peasants from the protected forests.

In such a situation, what can the future of the Joint Management Policy be, given an international context characterised by an interest in community forests? This paper attempts to explore ways of sustainably managing protected forests by revisiting the Joint Management Policy, focusing on the economic aspects to which local populations are sensitive (King, 1965).

2.2 Institutional arrangement of the Joint Management Policy: The Peasants-Forest Commission (PFC)

The Joint Management Policy designed by SODEFOR aims at addressing the problem of agriculture-forest interface in a consensual manner through a forum for discussion and decision making called the "Peasants-Forests Commission (PFC)". The Commission constitutes the main tool for the rehabilitation of protected forests, by including local populations in forest management while allowing the smooth resolution of their illegal settlements. This brings riparian peasant representatives, farmers who have settled in protected forests, local administrations, economic operators and SODEFOR together. It operates according to a charter and has internal rules that determine its constitution. The Commission has a local component (local PFC) and a national component (National PFC).

Locally, the Peasants-Forest Commission brings together riparian peasant representatives and the political authorities, i.e. the chair of the local PFC, elected officials and eventually the representatives of the political parties. At this stage, the Commission seeks to establish rules with the local population concerning the suspension of the administration's coercive measures, the cessation of forest clearing activities, the definition of repressive measures, the promotion of the general objectives of the intended management plan and the establishment of the basis for relating as partners.

At the national level, the Commission is composed of 18 members representing ministries, institutions and professionals of the forest sector and three members representing farmers (two for riparian communities and one for communities living inside the forest). The national component plays only a consultative role in giving its views on decisions taken at the local level, as the final decision depends on the Ministry of Agriculture.[1]

The process of rehabilitation of the forests is based on a general management methodology consisting of determining first of all, with local communities, the precise boundaries of the government's forest domain. Then the objectives are prioritised by focusing on social criteria in defining a series of management arrangements constituting the basis of the consolidation scheme. In other words, the objectives of forest production activities, reforestation and the constitution of biological reserves (formerly developed in individualised series) are pursued after having delineated agricultural series and sorted out their daily management. Indeed, this arrangement tries to stabilise agricultural production systems by promoting farming only within the forest domain of the state, since the principle of non-declassification of the forest has been accepted. To this end, it is planned to give facilities to farmers for organisation, structuring equipment, guaranteeing work tools, follow-up and development of innovation and training. In practice, such arrangements would be evidence of the principle of solidarity between forest rehabilitation and agricultural development.

[1] This Ministry was in charge of forests in 1992

However, many difficulties have affected the implementation of the Joint-Management Policy because the messages conveyed through the PFC have been misunderstood by stakeholders. As part of these difficulties, we note the problem of communication amongst the field staff and conflicts between the local populations and forest officers that have led to an increase in the number of clearings in the protected forest. In the same way, peasants-forest commissions are considered by various partners in rural areas to be a tool used by SODEFOR to make and adopt its own decisions.

Overall, the joint-management tools designed by SODEFOR have not been used efficiently by both SODEFOR's agents and farmers. Indeed, these instruments have mostly been designed without the participation of the local populations. In addition, these tools have not been truly tested and sufficiently disseminated. There is also under-representation of local populations on the Commission (1/6) which constitutes major evidence of its failure. Finally, there are major financial problems, since no budget has been set up for the implementation of the policy. Basically, this approach has real advantages for addressing the problem of illegal settlements without leading to open conflict between the growers and the administration. However, its effectiveness and sustainability are related to economic factors that have not sufficiently been taken into account so far. In this paper, we are trying to fill this gap by exploring factors such as economic incentives. The rehabilitation of the state managed forest domain must include the active involvement of the local populations in order to achieve social justice and, especially, a fair redistribution of generated income.

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Peasant farmers in a deforested area

3. LITERATURE REVIEW

In the literature, several different approaches help to reach biodiversity conservation objectives (Wilhussen & al., 2002, Schwartzman & al., Terborgh, 1999, Oates, 1999). In this context, there are, on the one hand, the partisans of a full protection of natural forests that are rich in biodiversity and on the other hand, the partisans of an approach reconciling conservation of the forests with the well-being of the local populations. The first paradigm consists of the creation of exclusive protected natural zones where local populations are considered a threat to biodiversity conservation. To the defenders of this approach, named "fortress conservation", some uninhabited natural protected areas would be the best solution for sustainably protecting natural areas. However, with the advent of the sustainable development concept, this paradigm of conservation has been considerably modified. In reality, the traditional "top-down" approach of area protection that aims at excluding all human presence is unsustainable (Brown, 2003) for multiple reasons, among them are the impossibility of enclosing protected areas, poorly equipped reserve control staff, and the frustrations generated by the exclusion of the local populations who continue their encroachment, etc.

Therefore, at the end of the 1980s, there was a new conservation approach, based on a capacity building strategy for local populations as a fundamental means of reaching conservation objectives. This is called "new conservation" or a "people-oriented approach". For this paradigm, the dependency of rural populations on forest resources is part of the significant reasons for the deterioration of natural resources. The poor farmers are the ones whose incomes are derived from agriculture, thus they depend more on the forest (Pascal et al., 2002). Therefore, all conservation projects should aim, in the first instance, to improve the conditions of life of local populations. This approach has been accepted and adopted by institutions in charge of conservation, countries and non-governmental organisations (NGOs).

A first approach of this indirect method of conservation is to develop eco-tourism in the designated forest zone, which has been supported by the financial institutions, especially the World Bank (Nicholls, 2004). However, indirect conservation has been severely criticised. The criticisms were about the low profits that local populations get from this method. The profits derived are lower than those obtained from unsustainable activities.

Most local communities involved in eco-tourism projects get a low share of the profits earned from that activity and rely alternatively on activities that are predatory (extremely aggressive) (Oates,1999, Nicholls, 2004). Worse still, according to Ferraro and Simpson (2003) the indirect approach of conservation failed because of erroneous affirmations about their desires relating to forest conservation by local populations, the ambiguous effects of conservation incentives and the difficulties of implementation linked to the achievement of the spatial and temporal aspects of conservation objectives. In order to contribute to the debate, this study does not only aim at researching incentives as factors for forest conservation but also determines their optimal level through a rigorous modelling of the case of Côte d'Ivoire.

From this perspective, Ferraro et al. (2002, 2003) proposed a new concept of conservation, that is "you should pay for what you want to get". In other words, if financial institutions want to achieve the objectives of conservation, they should pay for the conservation and not for the activities related to the conservation (Ferraro & Kiss, 2002).

Indeed, the profits deriving from forest services and the existence of future option values benefit the international community more than the local community (Balmford & Whitten, 2003). Therefore, the recourse to direct mechanisms in the form of aid to local populations for "conservation performance" would constitute a win-win solution, because it would help conservation objectives as well as development (Gueneau et al., 2004).

Using an econometric model, Ferraro & Simpson (2003) show that in the case of Madagascar for example, for the same budget allocated to conservation, the direct payments option would have permitted the protection of 80 percent of tropical forests as against 12 to 22 percent with indirect measures. Besides, the incomes of the local populations would have doubled, thanks to the direct measures. For these authors, biodiversity would simply be in danger in less developed countries because the profits that local populations get from its destruction are more than what they get from its preservation. Protected areas result in a loss of income and an opportunity cost that is not efficiently compensated. For example, according to some evaluations, two national parks in Madagascar contribute to the reduction of about 10 percent in the incomes of the adjacent populations (Nicholls, 2004).

For some authors, the conservation of tropical forests is integrated in an economic system where the supply and the demand of biodiversity are privatised (Lescuyer, 2004). Therefore, biodiversity is considered a "commodity" that one can buy and sell (Nicholls, op.cit.). This is a trade approach of conservation or "market-based conservation" where contracts between states, private firms, NGOs and local communities are based on market instruments.

However, the joint management approach as a solution to the sustainable management of protected areas has been imposed in a dogmatic manner, without reference to research works. Therefore, an improvement in the indirect approach of conservation, based on research that aims at understanding the complexity of local communities, finding efficient conditions for a participatory process, determining the factors of responsibility of local populations and valuing the impact of the sustainable development actions, is indispensable.

Globally, it is agreed that the remittance of direct supports should be well designed with strategies for indirect instruments like dialogue, education and other factors that are necessary to orient the practices of the local populations towards sustainable development, Nicholls (op cit.). It is in this context that our study attempts to find out the factors for an efficient and a sustainable management of the protected forests of Côte d'Ivoire based on an appropriate modelling of the phenomenon.

4. METHODOLOGY

4.1 Joint Management Policy formalisation

We formulated a bio-economic model with two agents (local community and SODEFOR) and two activities (agriculture and forest conservation) to analyse the Joint Management Policy using dynamic optimisation techniques in continuous time. SODEFOR has a fixed amount of forest (protected forest) for protection and reforestation. The local community lives adjacent to the protected forest and has user rights over the remaining land for agricultural purposes. The two agents acted in a defined area but conflicts arose when farmers encroached upon the protected forests in search of fertile land for agricultural purposes.

We considered two cases in the context of profit sharing:

- the market solution where each agent (local community and SODEFOR) maximised its own profits.

- the social solution where social planners undertook unified resource management.

From these two solutions, we derived socially optimal economic measures.

4.1.1 Local community

In a joint-management context where the local community is involved in the management of the protected forest, it receives a discounted profit π^{cl}. For this involvement, it receives remuneration (α and β) as part of the different types of income for SODEFOR. SODEFOR sells forest exploitation permits to forest harvesters and gets in return an income $R(q_{1t})$ where q_{1t} represents the standing volume of wood contained in a given area and sold in the year *t*. We suppose that $R'_{q_{1t}}(q_{1t}) > 0$ and $R''_{q_{1t}q_{1t}}(q_{1t}) < 0$. It also receives another income $R(x_{1t})$ from the exploitation of secondary products[2] such as charcoal, rafters, planks, beams, etc. We suppose that this income grows with the stock of the protected forest x_{1t} with a positive first derivative and a negative second derivative i.e. $R'_{x_{1t}}(x_{1t}) > 0$ and $R''_{x_{1t}x_{1t}}(x_{1t}) < 0$.

The local community gets an income $R(q_{2t})$ from its agricultural activities on its own lands that are outside protected forests with x_{2t} the area under agricultural exploitation at time *t*. This functions such that $R'_{q_{2t}}(q_{2t}) > 0$ and $R''_{q_{2t}q_{2t}}(q_{2t}) < 0$. It also gets a benefit $B(x_{1t})$ from the existence of the protected forest in terms of medicinal plants, non-woody forest products etc. We suppose that this income grows with the stock of protected forest x_{1t} with a positive first derivative and a negative second derivative i.e. $R'_{q_{2t}}(q_{2t}) > 0$ and $R''_{q_{2t}q_{2t}}(q_{2t}) < 0$. In return, the local community must provide a monitoring effort θ of the protected forest at the cost $C(\theta)$ with first and second positive derivatives, i.e. $C'_{\theta}(\theta) > 0$ and $C''_{\theta\theta}(\theta) > 0$.

[2] We evaluate at 60% the percentage of wood residues from timber harvesting (AIFORT, 2008)

The maximisation of this profit takes into account the dynamics of the forest resource. $g_2(x_{2_t})$ is the natural growth of the unprotected forest with the positive first derivative and negative second derivative i.e. $g_2^{'}(x_{2t}) > 0$ and $g_2^{''}(x_{2t}) < 0$. $g_1(x_{1t})$ is the natural growth of the protected forest with a positive first derivative and the negative second derivative i.e. $g_1^{'}(x_{1t}) > 0$ and $g_1^{'}(x_{1t}) > 0$. Finally $I(x_{1_t}, \theta)$ is the function of farmer encroachment that grows with the stock of protected forest and decreases with the level of effort θ. The properties of this encroachment function are as follows: $I(0,\theta) = 0, I_{x1_t}^{'}(x_{1_t},\theta) > 0, I_{\theta}^{'}(x_{1_t},\theta) < 0, I_{x1_t x1_t}^{''}(x_{1_t},\theta) > 0, I_{x1_t\theta}^{''}(x_{1_t},\theta) < 0, I_{\theta x1_t}^{''}(x_{1_t},\theta) < 0,$ and $I_{\theta\theta}^{''}(x_{1_t},\theta) > 0$

4.1.2 SODEFOR

The discounted income of SODEFOR π^{SOD} consists of the sum of the remaining parts after extraction of those of the local community and is equal to $(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})$ since $0 < \alpha < 1$ and $0 < \beta < 1$ We will solve this problem by considering two cases: the market and social planner cases.

Indeed, the forest resource is a public good which produces external effects that are not always taken into account by market mechanisms. This will help in controlling different aspects of forest resource management.

4.2 Market based optimisation problems

According to this approach, we solve the optimisation programme of each economic agent (the local community and SODEFOR) independently.

4.2.1 Local community's optimisation programme

For the local community, it is a question of maximising on an infinite time horizon, the flux of net revenue derived from its forest preservation and agricultural activities, taking into account the dynamics of the resource. Therefore, the optimisation programme of the local community is as follows:

$$\underset{(q_{2t},\theta)}{Max}\,\pi^{cl} = \int_0^{\infty}[\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)]e^{-\delta t}dt \quad (1)$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \quad (2)$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \quad (3)$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

4.2.2 SODEFOR's optimisation programme

For this structure it is a question of maximising on an infinite time horizon, the incomes deriving from its main and secondary activities while taking into account the dynamics of the resource, especially the encroachment phenomenon.

$$\underset{(q_{1t})}{Max}\,\pi^{SOD} = \int_0^\infty [(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \tag{4}$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \tag{2}$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

4.3 The social planner's optimisation problem

As can be noted from the optimisation problems, the Forestry Department and local community are ignoring the public good effect of the forest while at the same time the former does not fully take into account the negative external impact which the forest imposes on the latter. Ignoring externalities will necessarily mean that the socially optimal solution would differ from the two market solutions. We now assume that a social planner who knows the society's valuation of the costs and benefits of the different land uses and with powers to dictate what the forestry department and the local community should each do would carry out unified resource management. The social planner maximises the present value of forest and agricultural profits while taking into account the nuisance costs and the public good effect of the forest, $B(x_{1t})$ by choosing x_{1t}, x_{2t} and θ subject to the dynamics of the stock of forest and agricultural land. $B(x_{1t})$ captures the value of the forest to the general public in the form of its contribution to biodiversity, option value and existence value. We would expect that $B(0)=0, B'_{x_{1t}}(x_{1t})>0$ and $B''_{x_{1t}x_{1t}}(x_{1t})<0$ for a stock of forest that is regarded as a public good.

Contrary to market logic, the social planner takes into account the externalities due to the public property characteristic of the forest and the nuisance generated by the presence of the protected forests which limit the expansion of agricultural activities by the local community. It is a question for the social planner to maximise over time the social profits of the different actors (that is, the local community and SODEFOR) by taking into account the public good effect (existence and option value) of the forest, i.e $B(x_{1t})$:

$$\underset{(q_{1t},q_{2t},\theta)}{Max}\,\pi^{Social} = \int_0^\infty [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) + (1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \tag{5}$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \tag{2}$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \tag{3}$$

Where $e^{-\delta t}$ is a discount factor and δ a discount rate.

5. RESULTS

The resolution of the optimisation programmes above has been done in the Appendix [see equations (1) - (20)]. The results and their interpretations in this section distinguish market based solutions from the social planner's solution.

5.1 Market based solutions

In a market-based resource use regime the two agents, SODEFOR and the local community ignore the externalities that they jointly derive from forest conservation. The results derived from the maximisation problems of these agents are presented; these are subsequently followed by analyses of the agriculture-forest conflict and welfare implications of resource-use regimes where the local community does not reap any benefit from the forest and gets a fixed share of profits from secondary activities and logging (sale of forest concession permits). The problems are presented in the context of a resource-use regime where profit sharing exists. The resolution is done in the Appendix.

5.1.1 Joint management case where $\beta \neq 0, \alpha \neq 0$

The necessary conditions for the forest authority (SODEFOR) and local community maximisation problems are reduced to equations (6) - (13) in the Appendix. We note that the local community has its own valuation of the forest that differs from the valuation by the forest authority. Condition (6a) shows that the local community will apply anti-encroachment efforts up to a level at which the marginal cost of such effort is equal to its marginal benefit. The marginal benefit consists of the value of the forest saved from encroachment as a result of anti-encroachment efforts and this is evaluated at the current shadow price of the forest resource.

With the positiveness of $(\delta - (g^{'}_{1,x1t}(x_{1t}) - I^{'}_{x1t}(x_{1t},\theta)))$ from equation (13c), the shadow value of the forest from the point of view of the local community is strictly positive. From equation (8a) we note that the larger the β the higher the value associated with the forest resource by the local community. β can be seen as the degree of integration (involvement) of the local community in the joint management project. It is clear from equations (6) and (8c) or (8b) that the level of anti-encroachment effort and the share of revenue β accruing to the local community are positively related. Thus, β is nothing else than the level of incentive provided to the local community to exert anti-encroachment efforts towards forest preservation. From equation (8c) the local community's shadow value of the forest is positively related to β and negatively related to α.

In addition, the forest authority obviously has a positive existence value for forest resources as shown in equation (12). But, this value decreases with α.

Thus, the higher the share of revenue from secondary activity is, the higher the level of anti-encroachment effort. The optimal (highest) anti-encroachment effort is obtained when β is close to unity while α is close to zero. This will give incentives to both the local community and SODEFOR for forest conservation.

According to equation (13c), the marginal natural growth of forests net of encroachment is slower than the discount rate, to the extent that the secondary activity is relatively more valuable than the main one. These two variables are growing almost at the same rate when the converse is applied i.e when the main activity is more valuable than the second one.

This shows that the rate of time preference is mitigated and grows at the same rate with the marginal natural growth of forest net of encroachment to the extent that SODEFOR's main activity is relatively more valuable than the second one. This is desirable for environmental purposes especially for forest conservation. The more relatively valuable the main activity is, the more forest conservation there is. At a given value of $R'_{x1t}(x_{1t})$ and $R'_{q1t}(q_{1t})$ conservation of the forest will be better if β is close to unity while α is close to 0. Globally, the joint management of forest resources is sustainable if $R'_{q1t}(q_{1t}) \geq R'_{x1t}(x_{1t})$ and $\beta \geq \alpha$. From these considerations it is clear that forest resource exploitation will be sustainable if, and only if, the social discount rate does not exceed the marginal natural growth of forests, net of encroachment.

Equation (13) shows that the forest authority will continue to expand the stock of forest up to the point where the marginal cost of that expansion is equal to its marginal benefit. The benefit of expansion comprises additional secondary revenue, the increase in the value of the forest resource (capital gain) and the stock effect (a higher stock of wildlife yields increased growth) that comes with an increase in the stock of forest. The opportunity cost of forest conservation is the additional encroachment that would have been avoided and the foregone interest receipts on proceeds from the sale of forest products (timber) that would have been realised if the forest had not been conserved. This opportunity cost is evaluated as the shadow price of the forest resource. Equation (13) solves the optimal stock of forest to be conserved x_{1t}^{*JM}[3] given the value of θ^{*JM} derived from the local community's optimisation programme. From equation (8c) we get μ_{1t}, given β and α. Then from equation (6) we get θ^{*JM}.

The optimal stock of non-protected forest land x_{2t}^{*JM} is obtained from equation (9a). According to equation (9), the local community will expand its agricultural area until the marginal cost is equal to the marginal benefit. The marginal benefit of non-protected forest land conservation consists of the stock effect (a higher stock of non-protected forest land yielding increased growth) that comes with an increase in the stock of agricultural land and the increase in the value of agriculture (capital gain). The opportunity cost of conservation of non-protected land is the foregone interest receipts on proceeds from the sale of agricultural products that would have been realised if non-protected forest land had not been conserved (or if non-protected forest land is converted to agriculture). This opportunity cost is evaluated at the shadow price of non-protected forest land.

The local community has a positive valuation of non-protected forest land as shown in equation (7). Equation (9a) shows that non-protected forest land must grow at the discount rate δ which is the opportunity cost of conservation of non-protected forest land. From equations (10) and (11) we can get q_{1t}^{*JM} and q_{2t}^{*JM} knowing x_{1t}^{*JM} , x_{2t}^{*JM} and θ^{*JM} assuming steady state.

[3]JM stands for joint management

The welfare of the local community is indicated by its profit from agriculture and forest conservation $\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)$ and that for SODEFOR by the profit from forest conservation ($(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})$). Thus, the optimal stock of forest is supposed to be greater in this case than in the case where there is no joint-management arrangement. The local community does more forest conservation since they reap some benefits from forest conservation activities.

5.1.2 Discussion about *α* and *β*

If $\alpha = \beta$, then the forest authority's incentives for forest conservation remain the same as under the pre-joint-management regime (see equation (13c) but the local community's incentives for forest conservation become stronger (see equations (8c) and (6) and the welfare expression) in this joint management regime.

If $\alpha < \beta$ then we would expect a greater increase in the optimal stock of forest under the Joint Management Policy. Both agents have more conservation incentives with profits from secondary activity (see welfare expression).

Overall, the optimal stock of forest (more conservation) would increase under the joint-management regime than before. The local community does more forest conservation (monitoring) activity than agricultural activity.

5.1.3 No joint management case where *α*=*β*=0

Considering the pre-joint-management situation where $\alpha=\beta=0$, condition (8b) will only be satisfied with an optimal anti-encroachment effort of zero. Thus, the local community applies no anti-encroachment effort in that regime i.e. $\theta^{*NJ} = 0$[4]. Thus, the protected forest is going to disappear as long as it has zero existence value for the local community according to equation (8a). Indeed, the local community does not care about forest conservation in this case since its welfare $R(q_{2t}) - C(\theta)$ is not dependent on forest resources. There are no incentives for the local community to undertake conservation activities. In the same way as previously determined, we obtain the optimal variables q_{1t}^{*NJ} q_{2t}^{*NJ}, x_{1t}^{*NJ}, x_{2t}^{*NJ} and θ^{*NJ} by setting $\alpha=\beta=0$.

5.1.4 Comparison of the two cases and policy implications

The major change in the maximisation problem of the local community is that under joint management the local community gets additional profits from using the forest. Conditions (8a) and (6) use the result of the local community's positive shadow value on the forest to show that the optimal anti-encroachment effort would be positive under joint management. The higher the share of revenue from secondary activity, the greater the incentive for the local community to undertake anti-encroachment efforts.

[4] NJ stands for no joint management

The positiveness of $\theta^{*JM} > (\theta^{*NJ}=0)$ suggests the possibility of designing the Joint Management Policy to enlist the support of the local community in the fight against encroachment through the use of economic incentives (Fernandez-Puente, 1996). It must be the case that when community-based forest conservation schemes are put in place, they are structured so as to adequately reward the local community to exert anti-encroachment efforts. Thus, the local community must be sufficiently rewarded in order to secure its cooperation in forest conservation (Nguinguiri, 1999). The highest optimal anti-encroachment effort is obtained when β is close to unity.

The effect of increased local community cooperation on forest conservation in the joint-management regime is to reduce the level of encroachment. This in turn enhances the stock of forest such that, ceteris paribus, the level of conservation is expected to be greater under joint management i.e $x_{1t}^{*JM} > x_{1t}^{*NJ}$ relative to the impact of anti-encroachment efforts $\theta^{*JM} > \theta^{*NJ}$. In that case, the local community does more forest conservation activities than agricultural activities $q_{2t}^{*NJ} > q_{2t}^{*JM}$, giving room to the implementation of community forest programmes where the management of the forest is entrusted to the local community. In addition, the non-zero share $1-\beta$ (see equation (8c) going to the forestry authority can be seen as a support for this structure to carry out training programmes (fire protection, green belt establishment etc) and extra extension services to strengthen the local community's ability to sustainably manage the forest. Indeed, local community conservation activities should be regulated by the forestry authority, which should assist them with designing the management plan .

5.2 The social planner optimality

The necessary conditions for the maximisation of social planner problems are reduced to equations (14) - (20). From equations (14) and (17) we can get θ^{*} [5] and x_{1t}^{*S} considering equation (15) and assuming steady state. Equations (16) and (18) solve x_{2t}^{*S} assuming steady state. q_{1t}^{*S} and q_{2t}^{*S} are obtained from equation (19) and equation (20) assuming steady state. Condition (17c) implies that the anti-encroachment efforts of the social planner will be positive and even exceed the levels in the two market based regimes i.e $\theta^{*S} > \theta^{*JM} > \theta^{*NJ}$. The social planner has a positive valuation of protected forests which is greater than those of the local community and SODEFOR as long as $B'(x_{1t})>0$. This high level of forest resource valuation requires a high level of effort from the local community as depicted in equations (17a) and (17c). Therefore, the social planner solution requires a higher effort than the other two market solution regimes.

The difference between the social planner's optimal solution and the pre-joint-management market solution is that the social planner's equation determining the optimal stock of forest has a greater anti-encroachment effort and an extra term $B'(x_{1t})$ This additional term is the marginal public good effect. The magnitude of $B'(x_{1t})$ relative to the impact of anti-encroachment effort θ^{*S} will determine the level of social optimality of forest stock and consequently determine the stock of agricultural land. The socially optimal stock of forest is supposed to be greater than the joint management market situation level.

[5] S for social planner solution

The social planner needs some information about the magnitude of $B'(x_{1t})$ to know the stock of forest that should be conserved compared to the two market-based resource-use regimes. In general, the value that is assigned by either the a) local community or b) the international community, or c) combinations thereof will differ. The standard assumption is that $B'(x_{1t})$ includes the three levels of society mentioned above. Thus, by increasing the stock of forest, joint management brought in its wake a financial reward that persuaded the local community to start some anti-encroachment efforts with a social welfare gain.

5.3 Policy recommendations

The objective of this paper is to explore the policy responses that could stimulate forest conservation. Direct policy interventions concerning the size of forest stock can adjust market solutions in line with those in the social planner's optimal solution. Indeed, if $B'(x_{1t}) = 0$ then the changes that would have been required to bring the market solution in line with social optimality would have been simply to give all profit from secondary activities to the local community i.e. $\alpha \to 0$ and $\beta \to 1$. This result suggests that the activities related to the exploitation of secondary forest products such as charcoal, rafters, planks, beams, etc. should be managed by the local community (Fernandez-Puente, 1996) while logging activity should be managed by SODEFOR, but with a jointly designed management plan. This would bring about social optimality.

However, with the current (actual) situation where $B'(x_{1t})$ is positive, raising the value of secondary activity would help increase the optimal stock of protected forests. Both SODEFOR (the forest authority) and the local community derive more incentives for forest conservation from the increase in the value of secondary activities. But, in relative terms, if SODEFOR's main activity is more valuable than the secondary one, then conservation will be better as the time preference is mitigated. In addition, increasing the share of secondary activity profits going to the local community is expected to increase the stock of protected forests.

Finally, the need for a higher forest stock, partly based on including the high option and existence values of the international community, calls for the imposition of a Pigouvian subsidy on the local community in the joint management regime. The extra term $B'(x_{1t})$ in this joint management requires external financial support for forest conservation. This external funding can be viewed as payment for the international obligations regarding the existence and alternative values of forests.

6. Conclusion

The persistence of peasant encroachment on protected forest lands has raised the question whether the Joint Management Policy initiated by SODEFOR has been properly implemented. To this end, we formulated a bio-economic model with two agents (the local community and SODEFOR) and two activities (agriculture and forest conservation) in order to analyse the Joint Management Policy using dynamic optimisation techniques in continuous time.The study provided information that could be used to strengthen policies aimed at improving the level of forest conservation and helping local communities to grow themselves out of poverty.

The main result from this study is that a joint management policy and equitable sharing of forest income to the benefit of the local community will improve the management of protected forests by mitigating peasant encroachment. Indeed, the paper mainly explores the policy responses that could stimulate forest conservation. Firstly, the result shows that increasing the share of SODEFOR's profits from its secondary activity that goes to the local community, and/or increasing the value of that activity, are expected to preserve the forests, since this increases the stock of forests. Indeed, the highest optimal anti-encroachment effort from the local community happens when that profit share is close to unity. Secondly, the study suggests that SODEFOR's main activity should be relatively more valuable than its secondary one as long as it mitigates the time preference. Thirdly, the study also finds that the natural growth rate of non-protected forests must be equal to the discount rate (opportunity cost of capital). Lastly, the paper finds out the need for external funding as payment for international obligations regarding the existence and option values of forests, while taking the public good effect of forests into account.

Overall, the paper recommends the joint management initiative with profit sharing deriving from the exploitation of protected forest resources by SODEFOR and external financial support from the international community. Beyond this recommendation, the results of this study give room for the implementation of a communal forest management policy as in Cameroon, Gambia and Zimbabwe where people living on communal lands are given legal rights and technical assistance to sustainably manage their natural resources. Under this scheme, the local community will use the profits derived from these resources for rural development while at the same time contributing to forest conservation. The government's ownership rights over forest resources since the colonial period have not only failed to achieve better management, but also contributed to the impoverishment of the rural population. In fact, with the full involvement of the local community, this approach constitutes an opportunity for diversification of sources of income to limit the degree of vulnerability of the rural poor. Besides the many shortcomings (such as the lack of human, financial and material resources) of the former approach that are solved by this participatory approach, local (traditional) knowledge and skills can be used to improve the level of forest conservation. Therefore, this new approach to forest management will help in achieving the Millennium Development Goals by reducing poverty, especially in the rural areas. However, the effectiveness of these economic incentives will depend on the reinforcement of the existing institutional framework within an international context that calls for the decentralisation and democratisation of institutions.

7. REFERENCES

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8. APPENDIX

1. Local Community

$$\underset{(q_{2t},\theta)}{Max}\,\pi^{d} = \int_{0}^{\infty}[\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)]e^{-\delta t}dt \quad (1)$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \quad (2)$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \quad (3)$$

First order conditions

Considering the current value Hamiltonian, we have

$$H^c = [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) - C(\theta)] + \mu_{1t}(g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta)) + \mu_{2t}(g_2(x_{2t}) - q_{2t})$$

$$\frac{\partial H^c}{\partial \theta} = 0 \Leftrightarrow -C'(\theta) - \mu_{1t}I'_{\theta} = 0 \Rightarrow \mu_{1t} = \frac{C'(\theta)}{-I'_{\theta}} \quad (6)$$

$$\frac{\partial H^c}{\partial q_{2t}} = 0 \Leftrightarrow R'_{q2t} - \mu_{2t} = 0 \Rightarrow \mu_{2t} = R'_{q2t} \quad (7)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu}_{1t} + \delta\mu_{1t} \Leftrightarrow \beta R'_{x1t} + \mu_{1t}(g'_{1,x1t} - I'_{x1t}) = -\dot{\mu}_{1t} + \delta\mu_{1t} \quad (8)$$

$$\frac{\partial H^c}{\partial x_{2t}} = -\dot{\mu}_{2t} + \delta\mu_{2t} \Leftrightarrow \mu_{2t}g'_{2,x2t} = -\dot{\mu}_{2t} + \delta\mu_{2t} \quad (9)$$

$$\frac{\partial H^c}{\partial \mu_{1t}} = \dot{x}_{1t} \Leftrightarrow g_1(x_{1t}) - q_{1t} - I(x_{1,t},\theta) = \dot{x}_{1t} \quad (10)$$

$$\frac{\partial H^c}{\partial \mu_{2t}} = \dot{x}_{2t} \Leftrightarrow g_2(x_{2t}) - q_{2t} = \dot{x}_{2t} \quad (11)$$

From equation (6) we get $C'(\theta) = -\mu_{1t}I'_{\theta}$ (6a)

Assuming the steady state solution where $\dot{\mu}_{1t} = \dot{\mu}_{2t} = 0$ and that we always have an interior solution, the co-state equations yield

$$\mu_{1t} = \frac{\beta R'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \quad (8a)$$

Considering equation (6) we have

$$\frac{\beta R'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} = \frac{C'(\theta)}{-I'_{\theta}(.)} \quad (8b)$$

If we also consider equation (13c) we get

$$\mu_{1t} = \frac{\beta R'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} = \frac{\beta R'_{x1t}}{\frac{(1-\beta)R'_{x1t}}{(1-\alpha)R'_{q1t}}} = \frac{\beta(1-\alpha)R'_{q1t}}{(1-\beta)} \quad (8c)$$

From equation (9) when we assume the steady state we get

$$g'_{2,x2t} = \delta \quad (9a)$$

2. SODEFOR's solution

$$\underset{(q_{1t})}{Max}\, \pi^{SOD} = \int_0^\infty [(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \quad (4)$$

$$s/c$$

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \quad (2)$$

First order conditions

Considering the current value Hamiltonian, we have

$$H^c = [(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})] + \mu_{3t}(g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta))$$

$$\frac{\partial H^c}{\partial q_{1t}} = 0 \Leftrightarrow (1-\alpha)R'_{q1t} - \mu_{3t} = 0 \Rightarrow \mu_{3t} = (1-\alpha)R'_{q1t} \quad (12)$$

$$\frac{\partial H^c}{\partial \mu_{3t}} = \dot{x}_{1t} \Leftrightarrow g_1(x_{1t}) - q_{1t} - I(x_{1,t},\theta) = \dot{x}_{1t} \quad (10)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu}_{3t} + \delta\mu_{3t} \Leftrightarrow (1-\beta)R'_{x1t} + \mu_{3t}(g'_{x1t} - I'_{x1t}(.)) = -\dot{\mu}_{3t} + \delta\mu_{3t} \quad (13)$$

Assuming the steady state where the co-state equation yields

$$(1-\beta)R'_{x1t} + \mu_{3t}(g'_{x1t} - I'_{x1t}(.)) = \delta\mu_{3t}$$

$$\mu_{3t} = \frac{(1-\beta)R'_{x1t}}{\delta - (g'_{x1t} - I'_{x1t}(.))} \quad (13a)$$

Considering equation (13) we get

$$(1-\alpha)R'_{q1t} = \frac{(1-\beta)R'_{x1t}}{\delta - (g'_{x1t} - I'_{x1t}(.))} \quad (13b)$$

In equilibrium with both main and secondary activities we have

$$\frac{(1-\beta)R'_{x1t}}{(1-\alpha)R'_{q1t}} = \delta - (g'_{x1t} - I'_{x1t}(.)) \quad (13c)$$

3. Social planner's solution

$$\underset{(q_{1t},q_{2t},\theta)}{Max}\ \pi^{Social} = \int_0^{\infty}[\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) +$$

$$(1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})]e^{-\delta t}dt \qquad (5)$$

s/c

$$\dot{x}_{1t} = g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta) \qquad (2)$$

$$\dot{x}_{2t} = g_2(x_{2t}) - q_{2t} \qquad (3)$$

First order conditions

Considering the current value Hamiltonian, we have

$$H^c = [\alpha R(q_{1t}) + \beta R(x_{1t}) + R(q_{2t}) + B(x_{1t}) - C(\theta) + (1-\alpha)R(q_{1t}) + (1-\beta)R(x_{1t})] +$$
$$\mu_{4t}(g_1(x_{1t}) - q_{1t} - I(x_{1t},\theta)) + \mu_{5t}(g_2(x_{2t}) - q_{2t})$$

$$\frac{\partial H^c}{\partial \theta} = 0 \Leftrightarrow -C'(\theta) - \mu_{4t}I'_\theta = 0 \Rightarrow \mu_{4t} = \frac{C'(\theta)}{-I'_\theta} \qquad (14)$$

$$\frac{\partial H^c}{\partial x_{2t}} = -\dot{\mu}_{5t} + \delta\mu_{5t} \Leftrightarrow \mu_{5t}g'_{2,x2t} = -\dot{\mu}_{5t} + \delta\mu_{5t} \qquad (18)$$

$$\frac{\partial H^c}{\partial q_{1t}} = 0 \Leftrightarrow R'_{q1t} - \mu_{4t} = 0 \Rightarrow \mu_{4t} = R'_{q1t} \qquad (15)$$

$$\frac{\partial H^c}{\partial q_{2t}} = 0 \Leftrightarrow R'_{q2t} - \mu_{5t} = 0 \Rightarrow \mu_{5t} = R'_{q2t} \qquad (16)$$

$$\frac{\partial H^c}{\partial x_{2t}} = -\dot{\mu}_{5t} + \delta\mu_{5t} \Leftrightarrow \mu_{5t}g'_{2,x2t} = -\dot{\mu}_{5t} + \delta\mu_{5t} \qquad (18)$$

$$\frac{\partial H^c}{\partial x_{1t}} = -\dot{\mu}_{4t} + \delta\mu_{4t} \Leftrightarrow R'_{x1t} + B'_{x1t} + \mu_{4t}(g'_{1,x1t} - I'_{x1t}) = -\dot{\mu}_{4t} + \delta\mu_{4t} \qquad (17)$$

Considering equations (15) and (14) we get

$$R'_{q1t} = \frac{C'(\theta)}{-I'_\theta} \qquad (19)$$

Considering the steady state where $\dot{\mu}_{4t} = \dot{\mu}_{5t} = 0$ equation (17) leads to

$$\mu_{4t} = \frac{R'_{x1t} + B'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \qquad (17a)$$

Considering equations (17) and (15) we get

$$R'_{q1t} = \frac{R'_{x1t} + B'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \qquad (17b)$$

Considering steady state solution, equation (14) and (17) lead to

$$\frac{C'(\theta)}{-I'_{\theta}} = \frac{R'_{x1t} + B'_{x1t}}{(\delta - (g'_{1,x1t} - I'_{x1t}))} \qquad (17c)$$

From equation (18) assuming steady state where $\dot{\mu}_{5t} = 0$ we get

$$g'_{2,x2t} = \delta \qquad (20)$$

Second order conditions

The first order conditions are also sufficient for optimality if the programme is concave. In dynamic optimisation problems, we can resort to the functional forms of the objective function and the constraints to check these conditions of concavity. Indeed, if these functions are all concaves relative to the state and control variables and the co-state variables are all positives then the necessary conditions are also sufficient to obtain the trajectory that maximises the objective function.

That is the case in these problems since all functions are concaves and the co-state variables are all positives. Therefore, in our three optimisation problems (local community, SODEFOR and social planner programmes) the necessary conditions are also sufficient for optimality.

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MATE MASIE
"What I hear, I keep" - symbol of wisdom, knowledge and understanding

NEA ONNIM NO SUA A, OHU
"He who does not know can know from learning" symbol of life-long education and continued quest for knowledge

NYANSAPO
"wisdom knot" - symbol of wisdom, ingenuity, intelligence and patience

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