Kibaha Tanzania's Forest Protection, Poverty Alleviation Projects, NTFPs and Charcoal Production: Modeling Multiple Tools, Goals, and Actors

Also known as: Why is it so hard to achieve poverty alleviation and forest protection?

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1. Forest Reserves and Poverty Alleviation

During the last 30 years, the number of protected areas worldwide established to protect natural systems grew dramatically. Coinciding with that expansion, many government agencies and conservation NGOs advocate for combinations of development/livelihood policies and conservation policies attempt to address rural poverty while conserving forests (Naughton-Treves, et al., 2005). For example, WWF's policy on forest and poverty states that "national and international forest policies and the conservation movement should address both the sustainable management of natural forests and rural poverty alleviation; one should never be addressed at the other' s expense" (Gutman, 2001; p.9, para 1). The economics literature discussing policies aimed at conservation and poverty, such as Community-based Forest Management (CBFM), Joint Forest Management (JFM), and their predecessor Integrated Conservation-Development Projects (ICDPs), emphasizes their failure to create incentives for conservation by rural people (see Hughes and Flintan, 2001, for a literature review; Behera and Engel, 2006; Ghimire, 1994; Johannesen, and Skonhoft, 2005; Ligon and Narain, 1999; Muller and Albers, 2004; and Shyamsundar, 1996). Despite the lack of well-established mechanisms to induce conservation through poverty alleviation projects in and around parks, many parks have managers or NGOs implementing such projects,

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often with an emphasis on compensation for lost access to resources, poverty alleviation, and generating goodwill.

In Tanzania, both forest reserve managers and marine park managers report guidelines and rules about protecting resources while reducing rural poverty. Our conversations with those managers, however, reveal some frustration with taking on this income-generation project task. That frustration stems from a lack of funds to support such activities but also from a lack of understanding by managers of how rural people will react to their projects and policies. In Tanzania's Mnazi Bay Ruvuma Marine Park, managers described themselves as managers and ecologists without adequate training or experience to act as rural development agencies. In Tanzania's Kibaha Forest Reserve, managers describe successes with some projects but remain confused as to why rural people have not responded to buffer zone planting and beekeeping policies in the expected manner. Establishing successful policies to protect forest reserves from illegal overexploitation is difficult in itself but adding the layer of poverty alleviation requires considering the decisions and constraints facing all potential forest users.

Following a series of interviews with forest managers in Kibaha Forest Reserve, GPS monitoring of enforcement patterns, and surveys of rural villagers both within and outside of the reserve's buffer zone, we develop a modeling framework that incorporates the goals and tools of the forest reserve manager and the decisions of two groups of illegal resource extractors from those reserves. Although meant to inform Kibaha's management directly, the model is sufficiently general to address a wide range of forest reserve settings with goals of forest protection and rural poverty alleviation. As in many settings, this forest provides important non-timber forest products (NTFPs) to rural people, albeit illegally. In addition, illegal extraction of logs and the in-reserve production of charcoal by non-local "outsiders" for sale in nearby Dar es Salaam causes serious forest degradation in addition to conflict with local people and forest guards. Because many forests face these two types of illegal extraction – for local home use and for sale in towns – our modeling structure considers 3 actor groups: the forest manager, the "outsider" extractors (here, charcoal producers), and the rural "insider" extractors or local villagers. The forest manager's tools include enforcement, income-generating activities, and access rights for locals.

Because empirical studies determine that distance to resources creates an important cost in the resource extraction production function, we employ a spatially explicit model of resource extraction (Skonhoft and Solstad, 1996; MacDonald et al., 1998; Kohlin and Parks, 2001). Building off of a series of spatially explicit resource extraction and enforcement models including one that contains livelihood projects, this paper models the impact of enforcement levels and locations, livelihood projects (here, beekeeping) and their location, and the rules or access rights for resource extraction on villager and outsider extraction decisions, including the interaction between the extractor groups, on resulting patterns of forest resource protection and rural livelihoods (Robinson, et al., 2002; Albers, 2010; Robinson, et al., 2011; and Albers and Robinson, forthcoming 2011). As in Albers and Robinson (forthcoming, 2011), we use beekeeping as our livelihood project because it is non-extractive and is a popular alternative income- generating project worldwide and in Kibaha Forest Reserve (see, for example, www.beesfordevelopment.org; Lietar, 2009; Bradbear, 2004).[2] In fact, Tanzania's Ministry of Natural Resources and Tourism (MNRT) manages forests through its Forestry and Beekeeping Division (MNRT, 1998; 2002a; 2002b; 2005).

To address the Kibaha setting, we broaden the enforcement-extraction-livelihood project framework to include a second group of extractors – outsiders who harvest tree materials and make charcoal within the reserve for sale elsewhere. Urban populations rely on charcoal for much of their energy needs and Kibaha's proximity to Dar es Salaam's large charcoal market makes illegal charcoal production a significant cause of degradation in Kibaha Forest Reserve (NBS, 2007; interviews and personal communication, 2009 and 2010). Charcoal extraction leaves less forest biomass for NTFP collection by local people. Forest managers instituted a buffer zone planting policy that gives rural people rights to grow trees in the buffer zone and have implemented beekeeping to support rural populations. Despite their interest in poverty alleviation, forest managers also hoped that local villagers would be sufficiently invested in the forest reserve to enforce access restrictions on outsider charcoal producers and have expressed dismay at the lack of such cooperation. We saw abandoned charcoal pits and charcoal

[2] The projects discussed here do not include bark beekeeping but instead relate to creating beehives in a manner that does not degrade the forest as occurs with using locally lopped limbs or bark for the hives.

producers leaving the reserve on bikes during all of our visits to the reserve and surrounding villages.

In interviews, villagers expressed frustration with the charcoal extractors and pleasure with the reserve management's tree planting, efficient stove, and beekeeping projects but also reported that they did not try to prevent outsider charcoal production nor contact forest guards about that production. After many such discussions, a group of women villagers described their own extraction behavior as it relates to the beekeeping projects; when they are going to check on their beehives in the reserve forest, it is natural for them to collect forest resources along the way. They also reported that they often see outsiders making charcoal but they do not report them to the forest managers because the villagers themselves are collecting illegally, albeit whilst on their way to check on their beehives. The villagers felt that if their collection of forest resources was not illegal, then they would have an unofficial mandate to report the charcoal producers to the forest manager, thereby improving the forest manager's ability to detect and punish charcoal production, given the constraints of a small enforcement budget. To address that issue, we include "access rights for locals" as a forest manager's tool that encourages local people to help enforce access restrictions against more damaging activities. The access rights decision is akin to making a choice of the IUCN classification of a protected forest.

Through this framework we can consider the tradeoffs between less restrictive protected area designations (access rights), levels and locations of enforcement, and locations of livelihood projects in creating forest degradation patterns and rural livelihoods. In the next section, we develop a non-spatial model that models the interaction between charcoal producers, village NTFP extractors, and the forest manager. That framework identifies the tradeoffs in resource degradation between increased NTFP collection from access rights and decreased charcoal production due to villager enforcement. In the following section, we begin to incorporate distance decisions into the extraction. In ongoing work, we bring in a second spatial dimension and then identify the optimal allocation of enforcement, projects, and rights over space to achieve different management goals.

1. The model

We develop a model to explore some of the key issues raised by our observations in Kibaha. To explore the interaction of NTFP extraction by villagers living near to the forest, charcoal production by groups who come from outside the community, and the forest manager who has a mandate to protect the forest and to consider rural livelihoods, we develop a model of interaction between these three distinct groups. We start with a non-spatial model such that the forest is simply a homogenous patch of land so that we can explore the interactions analytically. However, the reality is that distance, enforcement, and resource collection interact in real situations and the only way to model this appropriately is to recognize that villagers', the forest manager's, and charcoal producers' decisions over where to be in the forest depend not just on the actions of the other groups, but also on the costs of reaching the resource. For example, villagers may prefer to collect forest resources from near to their village because that reduces the distance costs associated with collecting from the forest. Charcoal producers may prefer to make charcoal deep in the forest because they know that the costs of patrollers going to these patches is high and so patrollers rarely go that far. Such a spatially multi-dimensional model is appropriate for the situations that we find in Kibaha and elsewhere. But such a model soon loses analytical tractability and so we must rely on simulation models to explore the model in detail.

2.1A single-patch model of forest extraction and protection interactions

We set up a game-theoretic model of forest use and protection in this paper in the following way. The landscape for the model is a forest that we initially envisage as comprising one homogeneous plot (but which later we divide into a number of distinct forest patches located throughout the forest for the spatial model). We identify three distinct sets of players. First are a number of villagers living adjacent to the forest who value the non-timber forest products (NTFPs) found in the forest because they can sell them in a nearby market. Collecting NTFPs does however take the villagers' time. Second are charcoal producers who come from outside the nearby villages and produce charcoal illegally in the forest. Third is the forest manager (FM) who has overall responsibility for

the forest, but a limited enforcement budget. The forest manager can determine whether or not NTFP collection by villagers is legal (charcoal production is always illegal); whether to allow and provide beehives in the forest for villagers to benefit from; and how to allocate the limited enforcement budget across multiple forest patches.

We first consider a one forest patch model with no option of beehives in the forest so that we can concentrate on the interaction of villagers, charcoal producers, and the FM. In our one-patch model, the forest manager chooses whether to allow villagers to collect NTFPs or to make the collection of NTFPs illegal, given a fixed enforcement budget (in the multi-patch model the FM would choose how to allocate the limited budget across the multiple plots). If NTFP collection is legal, then villager enforcement supplements FM enforcement (imagine that villagers let the FM know if they have seen illegal charcoal production and thus supplement the FM's detection efforts). If NTFP collection is not legal then villagers do not contribute to enforcement against the charcoal producers, in keeping with our discussions with villagers in Kibaha.

A representative villager maximizes her expected returns to labor, subject to a total labor allocation L. She can allocate her labor to NTFP collection and to "work" that could be wage labor or farming. Any NTFPs collected are sold in a nearby market.[3] Charcoal producers maximize their expected returns to labor spent producing charcoal in the forest. The presence of charcoal production reduces the returns to villagers' NTFP collection effort. If NTFP collection is illegal then the FM's enforcement efforts reduce the expected returns to both NTFP collection and charcoal production. If NTFP collection is legal, then a combination of FM enforcement and villager enforcement increases the probability that the charcoal producers are caught. There is therefore a strategic interaction between the three sets of players that we model as a Nash equilibrium.

More specifically, suppose there are n identical villagers. Our representative villager allocates her total labor L to the collection of forest products, l_F, and/or work, l_W such that $l_F + l_W = L$. Without charcoal producers in the forest patch the total NTFP

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[3] We are therefore not considering NTFPs where there is some resource requirement, as is often the case for fuelwood, but rather the model assumes that there is a functioning and efficient market for NTFPs and villagers sell anything that they collect.

harvest by the *n* villagers would be $H_F = R\alpha(nl_F)^{\beta}$, where *R* is the resource density in the forest patch before any extraction; α is a scaling parameter; and β<1 such that there are diminishing returns to effort in the forest patch. However, with charcoal harvest H_C the total villager harvest becomes $H_F = R\alpha(nl_F)^{\beta}\left(1-\frac{\gamma H_c}{R}\right)$ where γ is simply a scaling parameter, and $H_F + H_C \le R$. This function is simply a modified Schaefer function in which there is "congestion" from multiple villagers and a coordinated group of charcoal producers. The harvest of the individual villager can therefore be written:

$$h_F = \frac{H_F}{n} = \frac{R\alpha(nl_F)^{\beta}}{n}\left(1-\frac{\gamma H_c}{R}\right) \qquad [1]$$

With no enforcement we write the charcoal harvest as $H_c = R\theta l_c^{\phi}$. Again, this is a modified Schaefer function that recognizes diminishing returns to charcoal production in a particular forest patch. However, unlike for villagers, NTFP collection does not degrade charcoal production effort.

We introduce a simple enforcement regime in which there is some exogenous enforcement budget that translates into a probability of detection for villagers (if NTFP collection is illegal) and charcoal producers of q. Punishment is simply confiscation of the illegal NTFP/charcoal. If villager collection of NTFPs is legal, village enforcement supplements FM enforcement and so we write the probability of the charcoal producers being caught as:

$$q_F = q + ml_F,\ q_F \le 1, \text{ and } m > 0 \qquad [2]$$

Where m is simply a scaling parameter.

Villager enforcement acts very much like congestion – the more villagers in the plot, the more likely that they will see and report illegal charcoal production. Writing the opportunity cost of labor for villagers as k_F and charcoal producers as k_C we can write the following set of equations that we solve simultaneously to determine the Nash

equilibrium. Our optimization functions take account of enforcement and congestion. If NTFP collection is illegal:

For the representative villager: $\max_{l_F}[W_F] = \frac{R}{n}\alpha(nl_F)^{\beta}\left(1-\gamma\theta {l_C}^{\phi}\right)(1-q) + k_F(L-l_F)$

For the charcoal producers: $\max_{l_C}[W_C] = (1-q)R\theta {l_C}^{\phi} - k_C l_C$ [3]

When NTFP collection is illegal the villagers' actions do not affect the charcoal producers' optimal labor allocation and so the first order conditions can be written:

$${W_C}' = (1-q)\phi R\theta {l_C}^{\phi-1} - k_C$$

And so for an interior solution $l_C = \left[\frac{k_C}{(1-q)\phi R\theta}\right]^{\frac{1}{\phi-1}}$ [4]

For the representative villager:

$${W_F}' = \frac{R}{n}\alpha\beta n^{\beta} {l_F}^{\beta-1}\left(1-\gamma\theta {l_C}^{\phi}\right)(1-q) - k_F$$ [5]

For an interior solution:

$$l_F = \left[\frac{k_F}{R\alpha\beta\left(1-\gamma\theta {l_C}^{\phi}\right)(1-q)n^{\beta-1}}\right]^{\frac{1}{\beta-1}} \text{ where } l_C = \left[\frac{k_C}{(1-q)\phi R\theta}\right]^{\frac{1}{\phi-1}}$$ [6]

If NTFP collection is legal then:

For the representative villager: $\max_{l_F}[W_F] = \frac{R}{n}\alpha(nl_F)^{\beta}\left(1-\gamma\theta {l_C}^{\phi}\right) + k_F(L-l_F)$ [7]

For the charcoal producers: $\max_{l_C}[W_C] = \left(1-(q+ml_F)\right)R\theta {l_C}^{\phi} - k_C l_C$ [8]

We find the Nash equilibrium for an interior solution by solving the first order equations simultaneously:

$$l_F = \left[\frac{k_F}{R\alpha\beta n^{\beta-1}\left(1-\gamma\theta {l_C}^{\phi}\right)}\right]^{\frac{1}{\beta-1}} \text{ and } l_C = \left[\frac{k_C}{\left(1-\left(q+ml_F\right)\right)\phi R\theta}\right]^{\frac{1}{\phi-1}}$$

$$l_v = \left(\frac{k_v n}{R\alpha\beta n^{\beta}\left(1-\gamma\theta {l_c}^{\phi}\right)}\right)^{\frac{1}{\beta-1}} \qquad [9]$$

$$l_c = \left(\frac{k_c}{\left(1-\left(q+m\left(l_v+l_B\right)\right)\right)R\phi\theta}\right)^{\frac{1}{\phi-1}}$$

We graph the reaction functions for legal and illegal NTFP collection showing the equilibrium levels of labor allocated to charcoal and NTFPs under the different regimes (Figure 1).[4] We can see that the forest manager faces a trade-off. Allowing legal NTFP collection in exchange for villagers contributing to enforcement against charcoal producers increases time villagers spend collecting NTFPs and reduces the amount of charcoal protection. Which regime is preferred by the FM depends on the total NTFP and charcoal harvest and the FM's objective function – in particular how charcoal production and NTFP extraction affect the ecosystem services provided by the forest.

This figure also shows graphically what we have demonstrated in the equations above. When villagers are not involved in enforcement the charcoal producer's reaction function is vertical – the villagers' actions do not affect the charcoal producers' production decision. The greater the effectiveness of villager enforcement, that we can proxy with *m*, the more the charcoal producers' reaction function rotates anti-clockwise as shown in Figure 1.

[4] To draw the graphs we use the following parameter values: R=20; α=0.6; β=0.2; γ=0.9; n=100; k_F=3; p_F=1; θ=0.6; ϕ=0.35; φ=0.6; k_C=15; q=0.2; m=22.

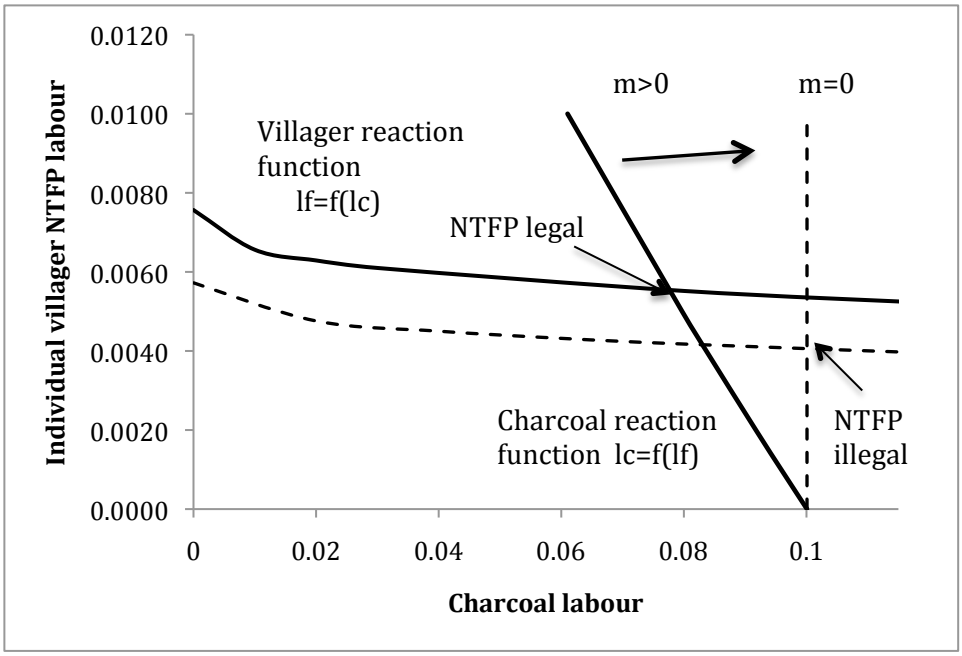
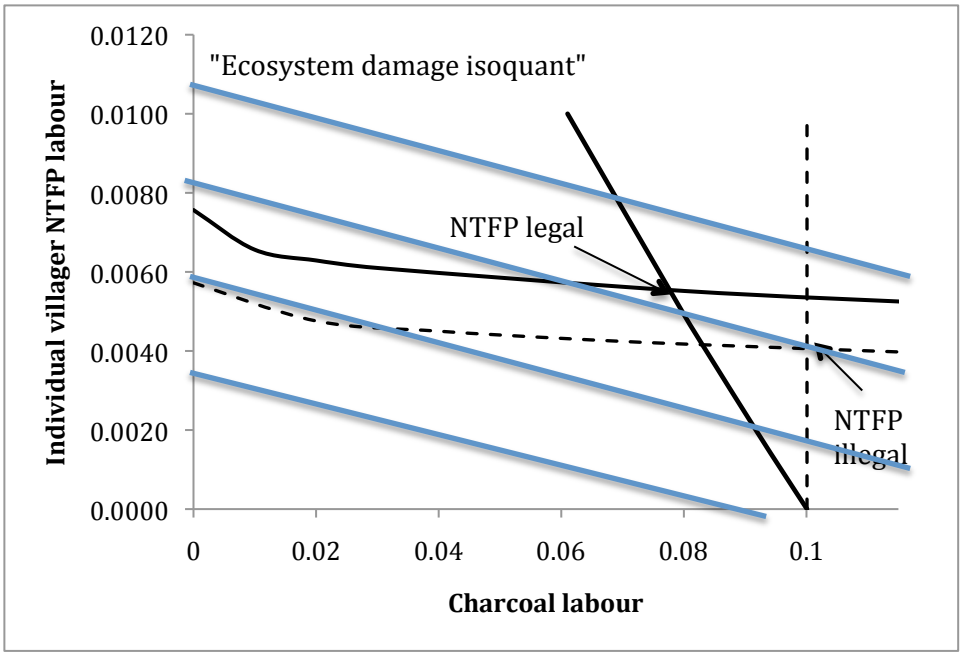


Figure 1: Villager and charcoal producer reaction functions and equilibria as a function of villager access rules

If the forest manager does not take account of villager welfare, whether or not the forest manager chooses to make villager NTFP collection legal depends on the relative costs imposed by the villagers' and charcoal producers' extraction with and without legal villager collection, taking into account the charcoal enforcement benefits that are associated with legal NTFP collection. Conceptually we can impose on Figure 1 what we call "eco-isoquants" that show combinations of charcoal and NTFP extraction for which the FM is indifferent in terms of the ecological damage imposed by NTFP extraction and charcoal production. For example, in Figure 2a we show an example of eco-isoquants such that the FM prefers to keep NTFP collection illegal (for these eco-isoquants, the FM prefers to be on an isoquant closer to (0,0) where the damage is least). In Figure 2b the isoquants are steeper and here the FM prefers to allow NTFP collection to be legal.



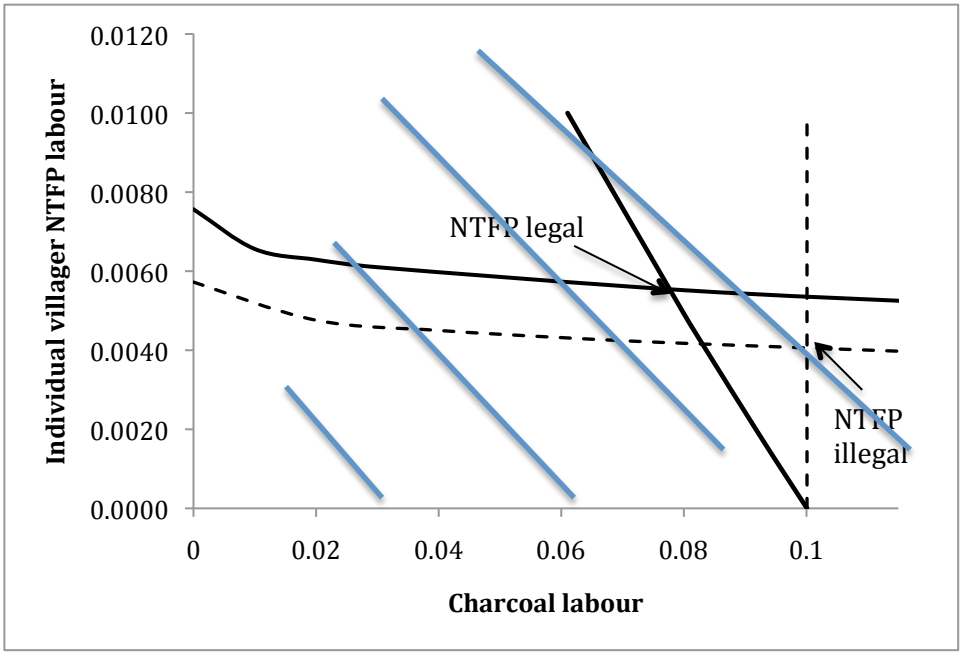


Figure 2a and 2b: Reaction functions and two possible eco-isoquants

Our model suggests that, if the FM is concerned only with the ecological damage caused by NTFP extraction and charcoal production, then whether or not it is better to legalise NTFP collection in the forest depends on how this interacts with villagers' willingness to be involved in enforcement against "outsiders" who come and

produce charcoal in the forest. Making NTFP collection legal can encourage villagers to be involved in enforcement because charcoal reduces villagers' returns to NTFP extraction. But villagers therefore collect more NTFPs, in part because NTFP collection is not longer illegal, and in part because time spent collecting NTFPs has two benefits – more NTFPs collected and more deterrence against charcoal production. Steeper eco-isoquants reflect situations where charcoal production is more damaging than NTFP extraction and so it is natural that in these situations we are more likely to find that the legalization of NTFP extraction reduces overall ecological damage to the forest.

We find in Kibaha, as in many such situations, that the forest manager has the option of offering villagers a livelihood project as a "carrot" to compensate for lost livelihood benefits from reduced access to forest resources. In Kibaha, the forest managers introduced beekeeping to the villagers. Beekeeping is a popular livelihood option from the forest manager's perspective because the returns to beekeeping are higher the less degraded the forest – thereby giving villagers an incentive not to undertake degrading forest-based activities; and because of "conservation by diversion" in which villagers allocate some of their labor to bees – the hope being that in exchange they allocate less to collecting forest resources. In most of the examples we found in Kibaha, the forest managers placed the beehives relatively deep in the forest rather than on the villagers' land or in the buffer zone.

We add beekeeping as an option in the model in the following way. Villagers involved in beekeeping allocate a fixed amount of labor, l_B to that activity. The returns to beekeeping depend on this labor and the extent of degradation in the forest caused by charcoal production. We write the returns to beekeeping as $Bl_B\left(1-\mu\theta {l_C}^{\phi}\right)$ where B is a constant that translates bee keeping effort into villager income. If NTFP collection is legal the optimization for the representative villager and charcoal producer are, respectively:

$$\max_{l_F}\left[W_F\right]=\frac{R}{n}\alpha\left(nl_F\right)^{\beta}\left(1-\gamma\theta {l_F}^{\phi}\right)+Bl_B\left(1-\mu\theta {l_C}^{\phi}\right)-k_F\left(l_F+l_B\right) \qquad [10]$$

$$\max_{l_C}\left[W_C\right]=\left(1-\left(q+m\left(l_F+l_B\right)\right)\right)R\theta {l_C}^{\phi}-k_C l_C$$

We can solve these equations simultaneously as a Nash Equilibrium as before and get similar conditions, assuming an interior solution:

$$\frac{R}{n}\alpha\beta n^{\beta} {l_F}^{\beta-1}\left(1-\gamma\theta {l_C}^{\phi}\right)-k_F=0 \Rightarrow l_F=\left[\frac{k_F}{R\alpha\beta n^{\beta-1}\left(1-\gamma\theta {l_C}^{\phi}\right)}\right]^{\frac{1}{\beta-1}} \qquad [11]$$

$$\left(1-\left(q+m\left(l_F+l_B\right)\right)\right)R\phi\theta {l_C}^{\phi-1}-k_C=0 \Rightarrow l_C=\left[\frac{k_C}{\left(1-\left(q+m\left(l_F+l_B\right)\right)\right)R\phi\theta}\right]^{\frac{1}{\phi-1}}$$

We can see from the villager's optimization that if the villagers have a constant opportunity cost of labor (as is assumed in this model) then they will choose bee keeping if the returns to bee keeping are better than the returns to working and NTFP collection but the time spent on NTFP collection will only be reduced (all other things equal) if the villager is labor constrained.

The villager's reaction function does not change. However, the charcoal producer's does, if villagers keep bees, because the probability of being caught is now greater given that villagers spend longer in the forest because of the beehives. The charcoal producer's response function therefore shifts if villagers do indeed take up the bee keeping projects and collect NTFPs legally (Figure 3).

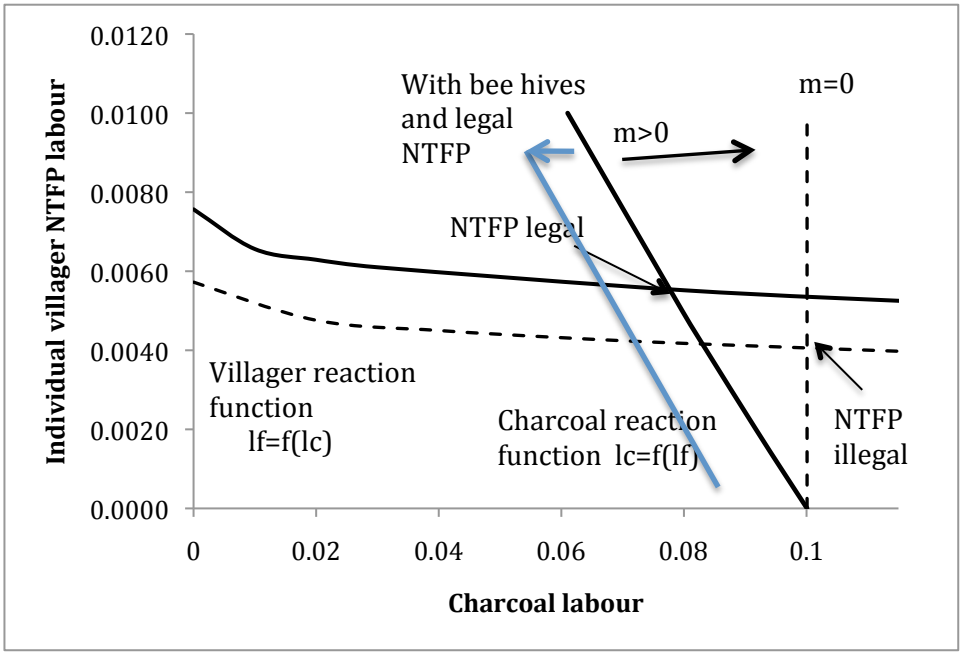


Figure 3: Equilibrium collection with beekeeping as an option (NTFP collection legal)

2.2 A multi-patch model

We focused above on the single patch model because it allows us to explore analytically the interaction between charcoal producers, villagers who collect NTFPs, and the forest manager responsible for enforcement. However, in practice, forests are not homogeneously accessible. Villagers typically choose a path along which to travel through the forest to collect forest resources, and charcoal producers choose an area where they produce charcoal. Similarly forest managers rarely have enough manpower to patrol the full area of forest and so must choose where to focus their enforcement effort. Finally, forest managers increasingly have (or take) the option of allowing NTFP collection in specific parts of a forest, whilst attempting to protect other parts. We therefore expand our model to accommodate a multi-patch forest in which villagers can choose which route to take and how far into the forest to go.

Here, in this current version of the paper,[5] we consider a forest that has depth but not width (following therefore Robinson et al., 2008, rather than Albers and Robinson, forthcoming). We divide the forest into forest patches that are a time distance *d* apart (that is, villagers must now explicitly allocate some of their labor to going through the forest to get to the forest resources, in addition to time spent collecting the resource, and more distant forest patches incur greater time distance costs). We let the total time spent by a villager both collecting and traveling in and out of the forest who collects as far as cluster *S*, be:

$$\text{Total labor time T} = 2\sum_{j=1}^{S_i} d_j + \sum_{j=1}^{S_i} l_j \qquad [12]$$

[5] We are currently developing the model with a two-dimensional forest as per Albers and Robinson, forthcoming. However, this single-dimensional forest model provides a number of important insights concerning the interaction of forest managers, villagers, and charcoal producers.

The first term on the right hand side of Equation 12 reflects the total travel time going between clusters and the second term represents the total time spent collecting in each of the visited clusters.

The FM chooses where to allocate its limited enforcement effort and whether to make NTFP collection legal or illegal. Enforcement of more distant clusters is less effective as the patroller must use up time getting to the more distant clusters that could otherwise be used patrolling in the particular cluster. Having this information, simultaneously the villagers and charcoal producers make their decisions. The villagers choose from which clusters to collect and how much to collect in each cluster. Charcoal producers choose one cluster from which to produce charcoal and how much charcoal to produce.

In our single-patch model above, for analytical tractability, we allowed for perfect labor markets such that the value of each unit of labor time equals the wage rate. However, when distance is an explicit part of the villager's decision process, with perfect labor markets (β = 1) the optimal choice of l_j is not a function of distance and so if it is worth the villager's while to go to the first cluster, the villager will always be better off going to the next cluster rather than turning around because distance no longer affects l_j though it does affect whether the villager collects from all or none of the clusters (as demonstrated in Albers and Robinson, forthcoming). We therefore follow the literature in assuming that labor markets are imperfect, $\beta > 1$, a reasonable assumption for Kibaha and other such rural locations (Robinson et al., 2011; Albers, 2010; Omamo, 1998). We therefore write the cost function, where *c* is a constant, as:

$$C = c\left(2\sum_{j=1}^{S} d_j + \sum_{j=1}^{S} l_j\right)^{\beta},\ \beta > 1$$

Charcoal producers also take account of the distance costs of going further into the forest. However, our experience is that charcoal producers are less sensitive to these costs than villagers and so the cost is small, but finite. We accommodate this cost by reducing the effectiveness of the charcoal producer's labor by δ per cluster into the forest that the charcoal producers go.

As with the single-patch model we consider different equilibria depending on whether village NTFP collection is legal or illegal, and whether villagers are given beehives as an option. We also give the FM the option of zoning the forest. A natural zoning option is that NTFP collection is legal within a "buffer zone", that is, in the first cluster of each ray, but not further into the forest.

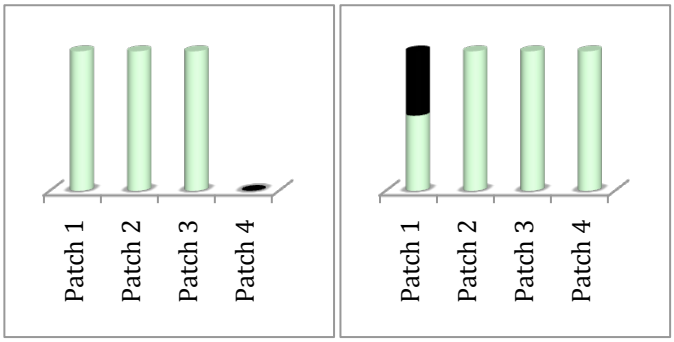
Multi-patch optimization when NTFP collection is illegal

Following Albers and Robinson (forthcoming), but allowing only a single ray of forest patches, we write the optimization for an individual representative villager as an optimal stopping model in which the villager chooses how intensively to collect from each cluster and where to turn around taking into account that charcoal producers will be making a simultaneous decision, and whether there is enforcement in the patch (for the moment we assume that you can only be caught "in the act" rather than in possession of forest products otherwise the forest manager might always enforce at the boundary of the village so as to have a chance of catching all the charcoal producers).

$$\max_{l_F,S}\left[W_F\right] = \sum_{j=1}^{S_j}\frac{R}{n}\alpha\left(nnl_{F,j}\right)^{\beta}\left(1-\gamma\theta l_{C,j}{}^{\phi}\right)\left(1-q_j\right)+k_F\sum_{j=1}^{S}\left(L-\left(2d_j+l_j\right)\right)^{\tau}$$

Charcoal producers consider the expected returns to producing charcoal in each of forest patches and choose that patch which provides them with the highest expected returns to their labor. Naturally, when NTFP collection is illegal and so villagers are not involved in enforcement, the villagers' choice of where to collect does not affect the charcoal producers. Therefore if there is no enforcement charcoal producers will choose to produce charcoal in the cluster closest to the village. Knowing that this is the charcoal producers' choice wherever the villagers collect, we can then determine the villagers' optimal strategy. To solve the model numerically we let there be four patches and we calibrate the model so that villagers have a "natural core" at the third patch such that they collect from patches one, two, and three, but not the more distant fourth patch when there is no enforcement and no charcoal production (Albers, 2010). Our particular parameterization gives us the pattern of resource extraction shown in Figure 4. Figure 4a shows the pattern of resource extraction by villagers if there is no enforcement and there are no charcoal producers. Figure 4b shows how this pattern of extraction changes when charcoal producers enter the

forest and produce charcoal from patch 1, closest to the villager, still with the assumption that there is no enforcement (green is level of NTFP, black is charcoal). The villagers extract less from patch 1 and now enter patch 4 to extract as well. The charcoal production's degradation displaces NTFP production into other patches.



a. No charcoal
No enforcement

b. Charcoal
No enforcement

Figure 4: Spatial patterns of resource extraction and charcoal production with no enforcement

Ongoing Work.

We are currently further developing the spatial model and exploring all of the choices available to the FM in terms of levels and location of beekeeping, access rights, and enforcement.

We now incorporate the FM's enforcement. Conceptually the FM optimizes by determining the optimal response of the villagers collecting NTFPs and the charcoal producers to each enforcement permutation and picking the one that gives the greatest ecosystem service benefits. We can solve such a model by developing a Matlab program with an algorithm that searches over all combinations of patrol location and charcoal location and intensity for villagers' optimal response in terms of the number of villagers entering each forest patch and the intensity of NTFP extraction in each. This allows us to explore how the placement of patrol effort determines where villagers collect NTFPs and where in the forest charcoal producers go. However, in this preliminary version of the paper we explore a few patterns of enforcement for the FM and compare the impact of enforcement

depending on whether or not NTFP collection is legal and whether or not villagers are given beehives.

First, unless the FM has sufficient budget for enforcement to occur in every patch of the forest, charcoal producers, if they know the FM's enforcement strategy in terms of where the patrols will occur, can avoid being caught by choosing to produce charcoal in any patch where there is no enforcement. Enforcement effort is therefore most likely to affect villagers collecting NTFPs.

Second, if NTFP collection is legal such that villagers are involved in enforcement against the charcoal producers, then the FM must choose whether to augment the villagers' enforcement effort in the same patches or to focus enforcement where there are no villagers. Villagers prefer not to collect where charcoal occurs because the charcoal production diminishes returns to NTFP collection. Therefore villagers are better off if their presence completely deters the charcoal producers from collecting from a particular patch. But the FM wants the total charcoal production reduced, not simply displaced to another part of the forest.

The FM can choose the location of beehives to encourage villagers to enter parts of the forest that they would not otherwise enter, and thereby create additional enforcement against charcoal there, or to discourage them from entering parts of the forest that they would enter without the beehives. In Kibaha beehives were placed relatively far into the forest, but resource collection by the villagers remained illegal. This location for beehives, paired with no access rights, spreads resource extraction farther into the forest without the benefits of reducing charcoal production at those distances/locations.

Although our results are not complete enough to report in this conference draft, we continue to explore patterns of forest reserve actions and the reaction of the charcoal extractors and NTFP extractors. Preliminary results show that the forest manager can achieve more conservation and higher levels of rural livelihoods by making spatial location decisions for all of his tools simultaneously including access rights, enforcement, and livelihood projects. Failure to integrate these decisions and failure to account for the spatial responses and interactions of extractors leads to lower levels of conservation and livelihoods.

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Appendix 1.

Some descriptive statistics about beekeeping projects in and near Kibaha Reserve Forest in Tanzania.

Table 1: Location of beehives in the sampled villages

	Percentage
On own land	11%
In the buffer zone	6%
In the reserve forest	71%
Other	12%
Total	100%

Table 2: Time taken to reach the beehives

	0 to 10 minutes	10 to 30 minutes	30 to 60 minutes	60 to 120 minutes
On own land	2	1	1	0
In the buffer zone	1	1	0	0
In the reserve forest	4	13	6	2
Other	0	1	2	1
Total	7	16	9	3