The Trees and the Bees: Using Enforcement and Income Projects to Protect Forests and Rural Livelihoods Through Spatial Joint Production

H.J. Albers and E.J.Z. Robinson

Forest managers in developing countries enforce extraction restrictions to limit forest degradation. In response, villagers may displace some of their extraction to other forests, which generates "leakage" of degradation. Managers also implement poverty alleviation projects to compensate for lost resource access or to induce conservation. We develop a model of spatial joint production of bees and fuelwood that is based on forest-compatible projects such as beekeeping in Thailand, Tanzania, and Mexico. We demonstrate that managers can better determine the amount and pattern of degradation by choosing the location of both enforcement and the forest-based activity.

Key Words: leakage, spatial, NTFPs, forest conservation, livelihoods, forest degradation

Reserve forest managers in developing countries often rely on a combination of enforcement of forest access restrictions and investments in alternative forest-based income-generating projects to deter resource degradation and compensate rural people for lower levels of extraction. However, the combination of limited budgets for forest management and high levels of demand for forest resources by nearby villagers typically still leads to forest degradation and rural livelihood issues despite these efforts, and rarely do initiatives manage to effectively address both issues. This paper uses a model of villagers' spatial non-timber forest product (NTFP) production functions to demonstrate that managers can influence forest quality and forest-dependent livelihoods if they take into account not just the type of alternative livelihood activity introduced but also the location of this activity. In this way, the forest manager can promote spatial joint production of NTFPs and the alternative product, and better control the resulting level and pattern of forest degradation both within the reserve and in nearby forests.

Several papers examine the decision to extract NTFPs, particularly fuelwood, from forests in developing countries and find that time spent traveling to the forest is an important component of the labor allocation decision to extraction activities (e.g., Bluffstone 1995). In a series of papers, Robinson, Albers, and co-authors develop a model of extraction in which distance and labor time are the most significant inputs into the production function (Robinson, Albers, and Williams 2008, Robinson and Lokina 2009, Robinson, Kumar, and Albers 2010). They explore the spatial implications of that model in the context of forest

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extraction from unmanaged forests, forest extraction that is completely displaced from a protected area, and forest extraction from forested areas under varying levels of community resource management. Both the modeling work and empirical observations find relatively intense use of forest resources near villages and in unprotected forests (KYNP Management Plan 1986, Ferraro 2002, Robinson and Lokina 2009). In these models, which form the basis of the extraction model here, because the extraction decision is spatial the pattern of resource degradation and of leakage to unprotected forests becomes apparent.

The pattern of forest degradation contributes to the level and types of ecosystem services the forest provides. For example, some species require nearly pristine forests for survival, which implies a preference for a pattern of degradation that has highly degraded forests in one area and nearly untouched forests in another area. In contrast, moderate degradation throughout the forest may provide the highest erosion control benefits, while carbon benefits may not depend on spatial pattern. In addition, forests vary in their sensitivity to activities that lead to degradation. Different forest manager objectives and different forest types lead to a range of optimal patterns of forest quality (Robinson, Albers, and Williams 2011). This paper emphasizes how spatial enforcement paired with spatial joint production contribute to the pattern of forest degradation, giving the manager control over that pattern, but does not assume any one type of forest or forest manager objective.

The economics literature on enforcement is quite large but rarely addresses the issues of enforcing access restrictions in a poor country context with limited property rights institutions (Robinson, Kumar, and Albers 2010). Albers (2010) models the optimal spatial location of enforcement activities for a stylized park with villagers extracting as a function of distance from their villages at the park boundary. Robinson, Albers, and Williams (2011) model the displacement of forest degradation—leakage—to unprotected forests when forest managers exclude villagers from a reserve. In practice, illegal extraction occurs within reserves due to incomplete enforcement, which alters the location and amount of forest degradation. Leakage undermines the success of conservation policies such as parks, environmental service payments, and REDD (Reducing Emissions from Deforestation and Forest Degradation) protocols, but the location and amount of leakage in response to policies in different settings is not well understood (Ewers and Rodrigues 2008, Pfaff et al. 2009). To address this gap in the literature, this paper models the impact of different patterns of enforcement within a reserve on the villagers' extraction activities and thus on the pattern of forest degradation for the case of one forest reserve and the case of a forest reserve and an unprotected forest.

Many government agencies and conservation NGOs advocate for combinations of development/livelihood policies, and conservation policies attempt to address rural poverty while conserving forests. 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. 8). In 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)—the economics literature emphasizes their failure to create incentives for conservation by rural people [see Hughes and Flintan (2001) for a literature review; also see Behera and Engel (2006), Ghimire (994), Johannesen, and Skonhoft (2005), Ligon and Narain (1999), Muller and Albers (2004), and Shyamsundar (1996)]. Labor constraints provide one mechanism through which these projects can reduce extraction from parks. For example, if the project requires or induces a large labor commitment, the agricultural household has less time for labor in extractive activities; "conservation by distraction" occurs. If the project generates enough income that participants can afford to, and do, purchase replacement goods from the markets, that market interaction decreases dependence on the natural resources. In many situations, however, an increase in income does not translate to a decrease in demand for natural resources.

Because rural households' consumption and production decisions are linked, the impact of poverty and/or conservation projects results from how the project alters those decisions. 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, often with an emphasis on compensation for lost access to resources, poverty alleviation, and generating goodwill. The decision of where and how many NTFPs to extract relates to the other decisions a household makes. Because NTFP extraction is spatial in nature, NTFP extraction often displays joint production characteristics with other location-specific actions, such as when farmers extract NTFPs as they travel to and from distant agricultural fields (Albers and Grinspoon 1997). It is the spatial nature of NTFP production that makes joint production possible with other actions that are location-based; those activities can determine the spatial pattern of resource extraction. The literature on joint production with NTFPs does not emphasize this spatial aspect and therefore does not enable managers to see how the location of projects creates an added tool for managing the pattern of resource use. We develop a spatial model of production of non-extractive resources that is based on conversations with local villagers and forest managers in the Kibaha district of the Pwani region in Tanzania, and similar observations in southern, coastal Tanzania, in Oaxaca, Mexico, and in northern Thailand.

To take advantage of our spatial framework and to look at the potential impact of projects on the pattern of forest degradation, we consider only poverty-alleviation projects that depend on proximity to the forests and can locate within forests, which precludes projects such as in-home industries or agricultural improvements. We use beekeeping as an example because it is non-extractive and is a popular alternative income-generating project worldwide (see, for example, the website "Bees for Development,"[1] Litaer 2009, Bradbear 2004).[2] In fact, WWF employs beekeeping for poverty alleviation throughout Tanzania near both forest and marine protected areas, and the Tanzania Ministry of Natural Resources and Tourism (MNRT) manages forests through its Forestry and Beekeeping Division (MNRT 1998, 2002a, 2002b, 2005). Bradbear (2009) emphasizes the relationship between forests and beekeeping, saying that "beekeepers that have a clear financial gain from protecting habitat of the bees are interested in forest conservation" (p. 57). Such projects now represent a large component of government and NGO conservation policy but range considerably in the incomes generated, from more typical small levels to more unusual high levels such as 30 percent of income (Leisher et al. 2010, Hashoo Foundation 2010). Similar projects such as butterfly farming, as employed in Amani, Tanzania, and in northern Thailand, or planting of medicinal herbs in the forest understory, as in Xishuangbanna, China, represent other projects whose location provides opportunities for spatial joint production with NTFPs, but we are aware of no terrestrial programs that use project location to inform patterns of resource use. In a marine park setting, The Nature Conservancy and Komodo National Park locate fish aggregating devices in deep waters to "draw fishers away from the reefs" to promote reef conservation (Howard 2003).

While recognizing the need for "conservation approaches that complement effective surveillance with community participation and equitable benefit sharing" (Oestreicher et al. 2009) and that "conservation must be informed by a detailed understanding of the spatial, temporal, and social distribution of costs and benefits of conservation efforts" (Chen et al. 2007), few researchers or managers integrate location decisions about enforcement and livelihood projects. Combining spatial enforcement with a spatial joint production function from beekeeping and NTFPs, we show that, because NTFP extraction and bee husbandry can be jointly produced, the spatial location of the beehives informs both the level and location of the extraction by villagers, giving the managers an additional spatial tool for controlling the pattern of extraction. The framework takes advantage of the spatial and joint production characteristics of NTFP extraction and beekeeping to increase the effectiveness of enforcement and project spending while controlling the pattern of resource degradation within the reserve.

The Model

A village located adjacent to a forest contains N villagers who extract NTFPs from the forest. Conceptually, we represent the forest as I rays of J equally sized resource clusters radiating from the village, which expands on Robinson, Albers, and

[1] Http://www.beesfordevelopment.org.

[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.

Williams' (2008) $1 \times J$ cluster model (see Figure 1). The expansion to several pathways of clusters makes the forest two-dimensional rather than one-dimensional, allowing us to undertake a spatial analysis that accounts for more than just distance, that more closely represents what we see in practice, and demonstrates displacement of extraction from one ray or cluster leading to leakage into another ray or cluster.[3] For tractability, to reflect the existence of impassable topographic features and of forest trails/pathways, and to capture observed extraction patterns, we assume that any particular villager extracts from one ray at a time rather than zigzagging through the forest.

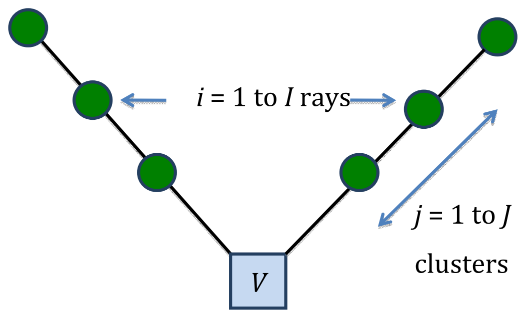

Figure 1. Spatial Pattern of *I* Rays of *J* Clusters from One Village, *V*

For ease of exposition in presenting these results, we limit our landscape to two rays ($I = 2$) consisting of 3 clusters each ($J = 3$). All N villagers face the same cost and harvest functions. For our base case, we assume no policy interventions. A particular villager chooses to collect from one ray based on the returns he or she expects from harvesting along that ray, which is a function of how many other villagers harvest on that ray. The two pieces of the extraction decision—which ray to choose and how much to extract per cluster on the chosen ray, aggregated over all the N villagers—create patterns of extraction that can differ across both rays and clusters. We impose an equilibrium condition to determine the number of the N villagers who extract from each ray (n_i). In equilibrium, the N villagers are distributed across the rays such that all villagers receive the same returns from their labor effort in the forest. Leakage between rays—the increase in extraction in one ray in reaction to a policy in the other ray—occurs when the equilibrium number of villagers in each ray changes in response to policies that affect rays differentially.

More specifically, each individual villager maximizes her expected returns to extracting from a particular ray as a function of the time it takes to travel between clusters $(i,j-1)$ and (i,j), denoted by d_j for each ray and the resource density in each cluster prior to harvest, r (with each ray identical in terms of the distance between clusters and a homogeneous initial resource density in each cluster, these variables require no i subscript), and the number of other villagers entering that ray, n_i (which results in harvesting congestion). The total harvest within the jth cluster in ray i, assuming n_i villagers each allocate l_{ij} labor units to extraction in that cluster, is

$$(1) \qquad H_{ij} = r\left(1 - \frac{1}{1 + \alpha r n_i l_{ij}}\right).$$

This logistic equation is similar to the spatial extraction equation in Robinson, Albers, and Williams (2011), where α is a parameter that determines the steepness of the curve and the function has the key properties that with zero labor there is no harvest in the cluster, and as the total labor ($n_i l_{ij}$) tends to infinity the total harvest asymptotes to r. However, it reflects "congestion" caused when more than one villager collects from a particular forest cluster. The amount collected by an individual villager from that cluster is therefore

$$(2) \qquad h_{ij} = \frac{H_{ij}}{n_i} = \frac{r}{n_i}\left(1 - \frac{1}{1 + \alpha r n_i l_{ij}}\right).$$

The total time spent by a villager both collecting and traveling in and out of the forest along ray i, who collects as far as cluster S_i, is

$$(3) \qquad 2\sum_{j=1}^{S_i} d_j + \sum_{j=1}^{S_i} l_{ij} .$$

The first term on the right-hand side of equation (3) reflects the total travel time, and the second term represents the total time spent collecting in each of the visited clusters (above we stipulate

[3] Although in our model we imagine one forest with multiple routes through that forest, each ray could be a separate forest, and so shifting of extraction from one ray to another would represent leakage into another forest.

that villagers can collect from only one ray—such a restriction could also be achieved endogenously by ensuring a sufficiently large d_1).

Assumptions made over market functioning and resource requirement constraints affect patterns of extraction (Omamo 1998, Key, Sadoulet, and de Janvry 2000, Robinson, Williams, and Albers 2002, Robinson, Albers, and Williams 2008, Muller and Albers 2004). Intuitively, at the extreme of no labor or product markets, villagers who must collect a fixed requirement from the forest vary the pattern of extraction and the intensity of extraction in different plots in response to enforcement, without changing the total amount extracted. At the other extreme of fully functioning markets, enforcement that perfectly excludes villagers from particular plots does not affect the intensity of extraction in other plots and reduces the total extracted without inducing displacement/spillovers (Robinson, Albers, and Williams 2011). In this paper, we reflect an intermediate and typical market scenario in which villagers face no set resource requirement, but their own labor spent collecting resources in the forest has an increasing opportunity cost of time. As such, in this paper we are assuming a somewhat elastic demand for the NTFP, as has been found for fuelwood in Sri Lanka (Kohlin 1998, Gopalakrishnan et al. 2005).

With perfect markets, the value of each unit of labor time equals the wage rate, but with imperfect labor markets a rising cost of labor time applies. To capture that increasing cost of time, we convert extraction and travel labor time, into a cost, through the constant c, and the parameter β, where $\beta > 1$ (if $\beta = 1$ we would have a constant cost of time):

$$(4) \qquad C_i = c\left(2\sum_{j=1}^{S_i} d_j + \sum_{j=1}^{S_i} l_{ij}\right)^{\beta},\ \beta \geq 1.$$

We can therefore write the optimization for an individual villager along one ray, assuming no interventions, as a simple optimal stopping model in which the villager chooses how intensively to collect from each cluster and where to turn around:

$$(5) \quad \max_{l_j,s}[V] = \max_{l_j,s}\left[\begin{array}{l}\sum_{j=1}^{S_i}\frac{r}{n_i}\left(1-\frac{1}{1+\alpha r n_i l_{ij}}\right)\\ -c\left(\sum_{j=1}^{S}\left(2d_j + l_{ij}\right)\right)^{\beta}\end{array}\right].$$

In equilibrium, for our specific example in which there are two rays, either all the villagers enter just one of the rays in a corner solution, or they split between the two rays such that the marginal villager can do no better by switching rays.[4] Naturally in our symmetric base case the villagers split 50/50 such that $N/2$ enter each ray in equilibrium. More generally, for I identical rays, an additional condition in equilibrium is

$$(6) \qquad \sum_{i=1}^{i=I} n_i = N.$$

For this base case example, a villager compares the returns to collecting from the closest cluster, the closest two clusters, or all three clusters, recognizing that $N/2$ other villagers will be making the same decision. The respective relevant conditions, assuming an interior solution for a villager entering a ray i, are as follows:

- If the villager does not enter the forest at all: $l_{ij} = 0\ \forall\ j$.
- If the villager enters only the first cluster, l_{i1} is the solution to the first-order condition:

$$(7) \qquad \frac{\alpha r^2}{\left(1+\alpha r\frac{N}{2}l_{i1}\right)^2} = \beta c\left(2d_1 + l_{i1}\right)^{\beta-1}$$

and $l_{ij} = 0\ \ \forall\ \ j \neq 1$.

- If the villager enters the first two clusters, l_{i1} and l_{i2} are determined by solving simultaneously the following first-order conditions:

$$(8) \qquad \frac{\alpha r^2}{\left(1+\alpha r\frac{N}{2}l_{ij}\right)^2} = \beta c\left(2\left(d_1 + d_2\right) + l_{i1} + l_{i2}\right)^{\beta-1}$$

for $j = 1$ and 2; $l_{ij} = 0\ \ \forall\ \ j \neq 1, 2$.

- If the villager enters all three clusters, l_{i1}, l_{i2}, and l_{i3} are determined by solving simultaneously the following first-order condition:

[4] As is common in such open access models with congestion, we do not allow for villagers to coordinate within a ray such that some collect from the clusters further from the village and others collect from the clusters closer to the village.

$$(9)\qquad \frac{\alpha r^2}{\left(1+\alpha r \frac{N}{2} l_{ij}\right)^2} = \beta c \begin{pmatrix} 2\left(d_1 + d_2 + d_3\right) \\ + l_{i1} + l_{i2} + l_{i3} \end{pmatrix}^{\beta - 1}$$

for $j = 1$, 2, and 3.

The villager compares the returns to each of the options—going into none, one, two, or all three of the clusters—and then chooses the strategy that provides the highest expected returns. For the more general formulation, if n_i villagers go as far as cluster S_i in ray i (and then turn around), then the set of l_{ij}'s are determined by solving simultaneously the following first-order conditions:

$$(10)\qquad \frac{\alpha r^2}{\left(1+\alpha r n_i l_{ij}\right)^2} = \beta c \left(\sum_{j=1}^{S} \left(2 d_j + l_{ij}\right) \right)^{\beta - 1}$$

for each l_{ij}, $j = 1, \ldots S_i$.

In our formulation, with perfect labor markets, $\beta = 1$, the optimal choice of l_{ij} is no longer a function of the distance between clusters, as seen by the right-hand side of equation (10) becoming a constant. In that case, 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_{ij}, though it does affect whether the villager collects from all or none of the clusters. That lack of a distance decision with perfect markets implies that an individual villager either collects from all or none of the clusters, depending on the other parameter values. Because in practice we observe villagers making an extraction distance decision and because imperfect labor markets abound in rural Africa, Asia, and Mexico, we follow the economics literature in assuming that labor markets are imperfect, $\beta > 1$ (Robinson, Albers, and Williams 2011, Albers 2010, Omamo 1998).

The forest manager can influence villagers' extraction with "sticks" or "carrots." In Kibaha, Tanzania, for example, traditional enforcement composed of individuals patrolling the protected area provides the stick. To incorporate enforcement into the model, as in Kibaha, we assume that villagers are considered guilty of the illegal act of resource collection if found with the resource in the park—that is, they do not have to be "caught in the act." Again, in keeping with a developing country scenario where forest managers almost always have limited enforcement budgets, the forest manager has a fixed amount of enforcement effort that can be allocated among the different resource clusters. Specifically, the forest manager allocates two patrollers to patrol one forest cluster each, where a patroller generates a probability p that villagers in that cluster are caught. Allocating both patrollers to the same forest cluster generates a probability of capture of $2 \times p$, implying no economies or diseconomies of scale for enforcement.[5] With enforcement, a villager's costs depend on whether or not she is caught by a patroller, and if so in which cluster, because if caught she does not have a chance to continue collecting forest resources in other clusters. Similarly her revenues from collecting forest resources depend on whether she is caught—if a villager is caught, we assume that the forest resources that she has collected are confiscated and she must leave the forest.[6]

Managers in Kibaha, as elsewhere, offer beekeeping as a "carrot" to encourage individuals to use the forest for a non-extractable income-generating activity rather than collecting NTFPs, although managers have not considered the location aspect of beekeeping. In our model, again due to budget constraints, the forest manager can place beehives in any one—but only one—of the clusters in one of the rays, and any villager who wants a beehive in that particular patch receives one. Beekeeping follows a simple production function with the benefits from bees, B, equal to bl_B^{ϕ}, where l_B is the exogenous quantity of labor that the villager must allocate to beekeeping if she chooses to undertake that activity (we assume no congestion in beekeeping). We assume that villagers tend to their beehives before collecting forest resources such that if they are caught extracting illegally, they still receive legally obtained benefits from the beehive.[7] With beekeeping and en-

[5] The probability of being caught is independent of how long the villager is in a particular cluster. Enforcement can therefore be thought of as "boundary enforcement" in which villagers are caught coming out of a particular cluster.

[6] We assume that the only punishment is confiscation of the illegally collected forest product and the lost travel and extraction time

[7] Naturally we recognize that beekeeping entails several months of labor activity before the honey is harvested. Because we have a single-period model we simply assume that the greater the labor effort for beekeeping, the greater the returns to the activity. This assumption allows us to undertake a single period model while still keeping the essence of the issue of joint production.

forcement, if the villager collects resources in a cluster as far as or beyond the cluster with the beehives, her optimization is

(11)

$$\max_{l_j,s}\Bigg[bl_B^{\phi}+\sum_{j=1}^{S_i}\frac{r}{n_i}\left(1-\frac{1}{1+\beta rn_il_{ij}}\right)\prod_{j=1}^{S_i}\left(1-p_{ij}\right)$$
$$-p_{iS}\cdot c\left(2\sum_{j=1}^{S_i}d_j+l_{iS}+l_B\right)^{\beta}$$
$$-\left(1-p_{iS}\right)p_{iS-1}\cdot c\left(2\sum_{j=1}^{S_i}d_j+l_{iB}+l_{iS}+l_{iS-1}\right)^{\beta}-...$$
$$-\left(1-p_{iS}\right)\left(1-p_{iS-1}\right)...$$
$$\left(1-p_{i3}\right)p_{i2}\cdot c\left(2\sum_{j=1}^{S_i}d_j+l_B+\sum_{j=2}^{S_i}l_{ij}\right)^{\beta}$$
$$-\left(1-p_{iS}\right)\left(1-p_{iS-1}\right)$$
$$...\left(1-p_{i2}\right)p_{i1}\cdot c\left(2\sum_{j=1}^{S_i}d_j+l_B+\sum_{j=1}^{S_i}l_{ij}\right)^{\beta}\Bigg].$$

Again, the equilibrium condition of the nth villager's indifference between the expected returns to each ray determines the number of villagers in each ray. The villagers consider the expected value of harvesting when they harvest in, or must travel through, a cluster with patrols. They also consider whether to allocate labor to beekeeping. Although the equilibrium condition that determines the spatial allocation of villagers across rays remains the same with the addition of enforcement and beekeeping, the location of these policy interventions alters the expected returns from extracting in particular rays and clusters and thus the number of villagers per ray. By altering that equilibrium distribution of villagers and the per-cluster incentives to harvest, the policies create leakage.

We solve a one-period two-dimensional spatial optimization in order to focus attention on the spatial relationships of interest that have thus far been ignored by managers and analysts alike. Any extraction degrades the resource from its initial condition. Specifically, in our model, the one period of NTFP collection undertaken by the villagers creates a post-extraction pattern of degradation. We discuss the level and pattern of that degradation—the inverse of the amount and pattern of extraction—as a reaction to policy. We recognize, however, that these spatial relationships will interact with dynamic patterns in complicated ways, as has been explored in simpler spatial settings (e.g., Robinson, Albers, and Williams 2008). Still, exploring the spatial model fully before including dynamic changes elucidates several general points that could be obscured in a spatial-temporal framework. In addition, here we do not specify a particular objective function for the forest manager because objective functions can vary to include goals of poverty alleviation, maximizing area of pristine forest, or other ecological factors, as in Robinson, Albers, and Williams (2011).

Results

Spatial Patterns of Resource Collection Without Enforcement and Beekeeping Policies

Our "no intervention" base case considers resource extraction with no enforcement and no beekeeping opportunities. Such a setting reflects both open access forests and forests throughout which managers permit NTFP extraction, perhaps in an extractive reserve or other less restrictive IUCN protected area classification. Even where managers encourage NTFP extraction, the extraction causes some forest degradation and the amount and pattern of that degradation contributes to the forest's production of ecosystem services. Under "no intervention," with our 2×3 spatial configuration, half the villagers extract from each radial set of clusters because the rays are identical. We choose simulation data such that villagers harvest from the first two clusters of the resource on each radial path but distance costs prohibit extraction in the most distant cluster.[8] This scenario generates a pattern of resource degradation with un-degraded resources far from the village in cluster j = 3 of each ray and moderately degraded resources in the four (j = 1,2 for both i) clusters closest to the village, as in Figure 2's "no

[8] The parameterization we use is as follows: $d_1 = 0.14$, $d_j = 0.07$ ($j \neq 1$), $r = 3$, $N = 100$, $\alpha = 0.1$, $c = 2.1$, $\beta = 1.5$, $N = 100$, $l_B = 0.01$, and $B = bl_B^{\phi} = 1.2$. These numbers are chosen to illustrate the key points of the model and to reflect reality in terms of observed patterns but not to calibrate the model to a particular situation. We use parameters that ensure that the villagers make an optimal distance decision rather than be constrained by distance in the baseline cases with and without interventions.

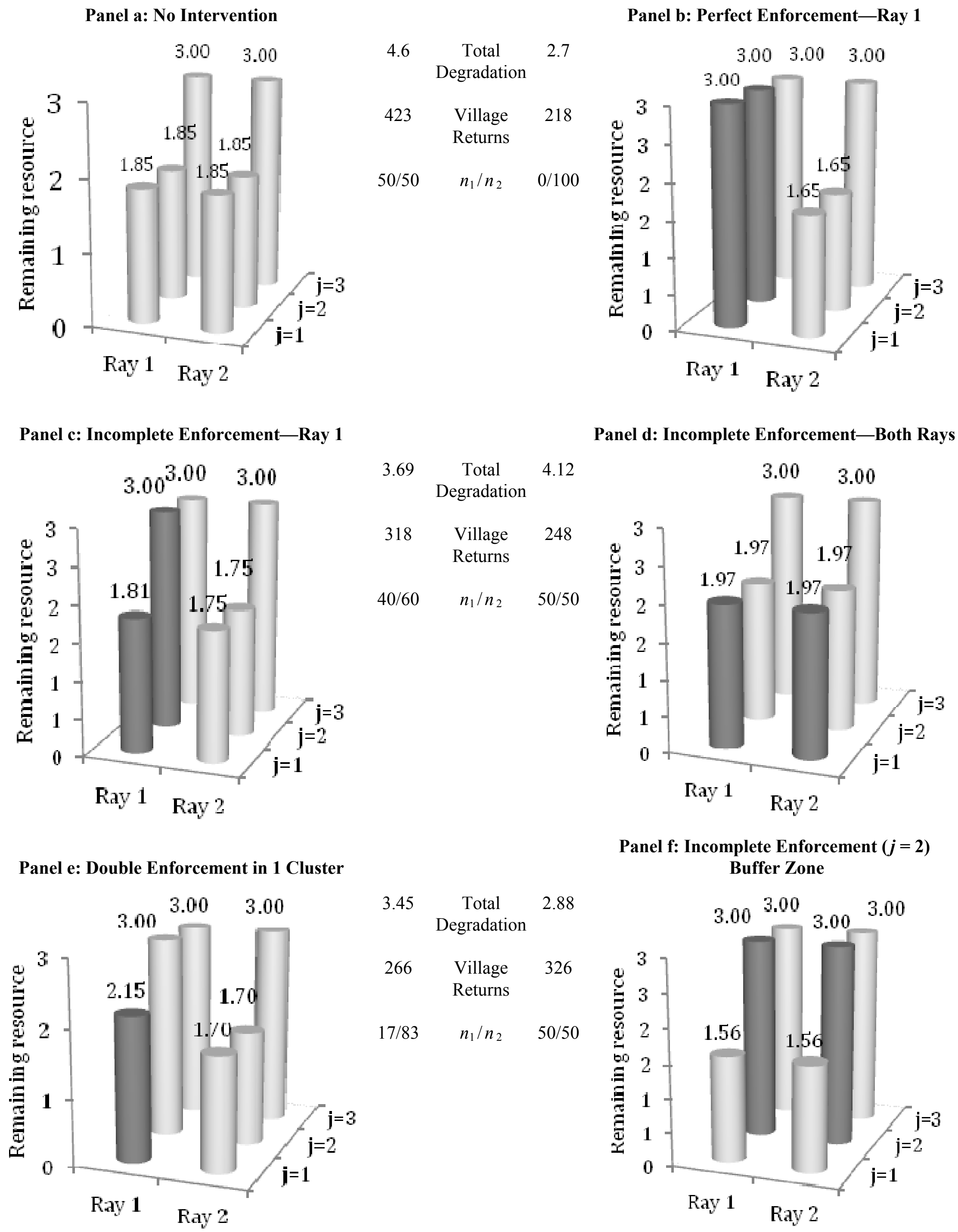

Figure 2. Impact of Enforcement Patterns on Post-Extraction Forest Patterns

Note: "Total degradation" is the total amount of resource extracted across all rays and clusters, while the height of the columns shows the resource remaining after extraction per cluster. Light gray columns represent patches with no enforcement. Dark gray columns represent clusters within which patrols generate a probability of enforcement. "Village returns" are the resource values less the labor costs that the villagers receive. The equilibrium distribution of villagers across rays is represented by n1/n2 with a total of 100 villagers.

intervention" case (panel a). This baseline corresponds to the no-enforcement case in Albers (2010), with the un-degraded clusters being protected by distance costs, which creates a "natural core" of untouched resources.

Resource Patterns with Different Patterns of Enforcement

As a starting point, we assume an extreme case in which the forest manager can allocate enforcement patrols into two clusters and create perfect enforcement in each, implying $p = 1$. If the forest manager has jurisdiction over the whole forest—that is, both rays—then he can simply keep all villagers out of the forest by placing that enforcement in the cluster $j = 1$ of each ray, thereby ensuring that there is no degradation because there is no forest resource extraction. If the forest manager manages only ray 1 of the forest, however, then he can protect fully that ray, but the 50 percent of villagers who extract from ray 1 without enforcement now displace their extraction into ray 2 (Figure 2, panel b). This reaction to enforcement demonstrates leakage at its most basic level—people move their extraction in response to the enforcement policy. Although the number of extractors in ray 2 doubles, due to the competition for resources discouraging some extraction, the level of degradation in the unprotected forest does not increase in one-for-one fashion with the enforcement in ray 1. An assessment of the amount of avoided degradation in ray 1 resulting from the enforcement of that forest reserve ray finds that that degradation declined by 3.3 units (2 clusters times 1.15 units of degradation) compared with a no-enforcement scenario (compare panel a and panel b in Figure 2). However, if the relevant landscape includes both rays, then the increase in degradation in ray 2 in response to the policy—the leakage—partially offsets the enforcement's avoided degradation with leakage of 0.4 units $[(1.85-1.65)\times 2]$ of degradation into ray 2's unprotected, no-project forest.

If the forest manager controls the entire forest—in this case, both rays—he could choose to create a buffer zone for extraction near the village by placing enforcement in cluster $j = 2$ of each ray (Figure 2, panel f). Compared with a situation where one ray is fully protected (Figure 2, panel b), villagers receive higher returns from the buffer zone enforcement pattern due to lower travel costs and reduced congestion. The forest manager can make trade-offs between the less fragmented forest with higher returns to villagers in the buffer zone case and the lower level of total forest degradation in the fully protected ray case.

Due to limited budgets, enforcement rarely leads to complete deterrence in developing country forest reserves. Assuming perfect enforcement therefore typically overstates the amount of degradation avoided and the amount of leakage into unprotected forests. To model the more common case of incomplete enforcement, here the two patrollers each catch 20 percent of villagers in a chosen patrolled cluster, $p=0.2$. Villagers consider their expected returns from harvesting or traveling through clusters with this incomplete enforcement. The deterrence effect and the amount of leakage caused by the incomplete enforcement depend on the location of those enforcement activities due to the interaction with distance costs.

The same amount of enforcement has a very different impact on total degradation, returns to villagers, and the spatial patterns of degradation and fragmentation, depending on its spatial allocation (Figure 2, panels c–f). These enforcement results confirm several findings from related models but demonstrate them in a more spatially explicit setting and establish the role of leakage, distance costs, and congestion. First, distance costs protect some areas of forest from extraction and augment enforcement activities by allowing lower probabilities of detection to deter extraction at greater distances. Second, incomplete enforcement leads to illegal extraction in and beyond patrolled areas, although higher levels of enforcement reduce the number of extractors and/or amount of extraction in the patrolled areas. Third, enforcement leads to displacement of extraction into other forests, called leakage, which offsets the reduction in degradation in the patrolled region. Fourth, due to congestion costs—more people extracting leads to lower biomass and lower returns—leakage's degradation does not perfectly offset reduced degradation elsewhere. Fifth, the location of enforcement activities determines not just the total amount of forest degradation but also the pattern of degradation throughout the forest, whether the forest manager manages the whole forest or only a portion.

Introducing Bees with Enforcement

Governments or NGOs introduce poverty alleviation projects or alternative income-generating projects either within protected forests or in areas near protected forests, but few programs consider how the projects augment or undermine enforcement activities or how the location of the project influences the resulting pattern of resource degradation. Here, we consider how various spatial patterns of enforcement and beekeeping interact in terms of total degradation, returns to villagers, and fragmentation.

With one ray of the forest patrolled, as in Figure 2's "double enforcement in ray 1" case (panel e), the forest manager or an NGO provides beekeeping in the unpatrolled forest ray—as in a case with one village-controlled forest ray with the bees and one protected area forest ray with enforcement (Figure 3, panel a). The beekeeping improves rural livelihoods, thereby partially "compensating" rural people for their lost access to resources in the protected forest. The opportunity to participate in beekeeping creates an additional trade-off between labor in extraction activities, labor in beekeeping, and labor in other activities. That trade-off implies that rural people stop harvesting at a higher level of return from resource extraction because of the value of allocating labor to beekeeping. Placing beekeeping in the unpatrolled forest induces changes in extraction behavior, and resource degradation patterns, throughout the forest rather than just in the cluster with the beekeeping (compare Figure 2, panel e, to Figure 3, panel a).[9]

Beekeeping creates a draw to ray 2, resulting in fewer villagers extracting in ray 1, which leads to less degradation in ray 1 despite no change in management in that ray (Figure 3, panels a–c). Beekeeping also draws villagers and extraction to its location (cluster) and villagers may extract resources more intensely there than someplace without bees. The returns in the bee cluster, however, are high enough that no villagers incur the travel costs to extract in more distant clusters, leaving cluster 2 in ray 2 untouched despite having no enforcement activities there. The beekeeping project improves rural livelihoods while decreasing extraction and total forest degradation through labor allocation decisions—"conservation by distraction." The beekeeping project also pulls extraction to its location, reducing pressure on patrolled and more distant unpatrolled parts of the forest in a spatial spillover or "reverse leakage," thereby contributing to the pattern of forest degradation.

Because distance creates a cost for villagers, placing the bees in more distant clusters decreases their impact on levels of total degradation and on livelihoods (Figure 3, panels b and c).[10] Placing beekeeping in more distant clusters still induces a reduction in the extraction in the non-beekeeping forest ray by drawing villagers to the ray with bees, although a smaller cross-ray displacement of extraction occurs as the beekeeping moves into more and more distant clusters. The location of the beekeeping contributes to the pattern of degradation in the ray with the bees. Although fewer villagers extract from ray 2 at more distant bee locations, the remaining extraction spreads across the clusters between the village and the beekeeping cluster. Locating the beekeeping in cluster 3 induces extraction there, extending the distance over which extraction occurs (Figure 3, panel c). Such a pattern of dispersed degradation might be desirable in locations where the forest's environmental services face a threshold biomass level below which the forest generates few benefits (Robinson, Albers, and Williams 2011). The location of alternate income-generating activities can determine the pattern of resource degradation throughout the forest and can prevent areas of heavy degradation near villages.

In other situations, forest managers may enforce at a boundary between a protected forest and a buffer zone and place "enrichment" activities such as beekeeping in that buffer zone (Figure 3, panel d). In equilibrium, some villagers displace their extraction from ray 1 to ray 2 in a spatial spillover due to the beehives' location in

[9] We assume that the returns to beekeeping are not affected by forest quality, and so we do not consider a trade-off between forest resource collection and beekeeping in this paper. If we allowed degradation due to forest resource collection to diminish the returns to beekeeping, then villagers would recognize this trade-off and adjust their patterns of extraction and the number of beehives accordingly. Because of the relatively complex spatial interactions in this model, it is not possible to predict how patterns of extraction and beekeeping would change. However, this possibility is addressed in a future paper.

[10] In some ecological settings, the forest managers could place the beehives in the village itself, thereby separating the project from the forest. In this case, the beehives no longer influence how many villagers enter each ray. In equilibrium, assuming no enforcement, the same number of villagers enter each ray (N/I). Because villagers dedicate some labor time to beekeeping and less labor time to extraction, they harvest and degrade less (if $\beta > 1$) and beekeeping creates "conservation through distraction." But overall, forest managers lose an important strategic tool for influencing the pattern of extraction and the resulting degradation in forests that they control and in neighboring forests.

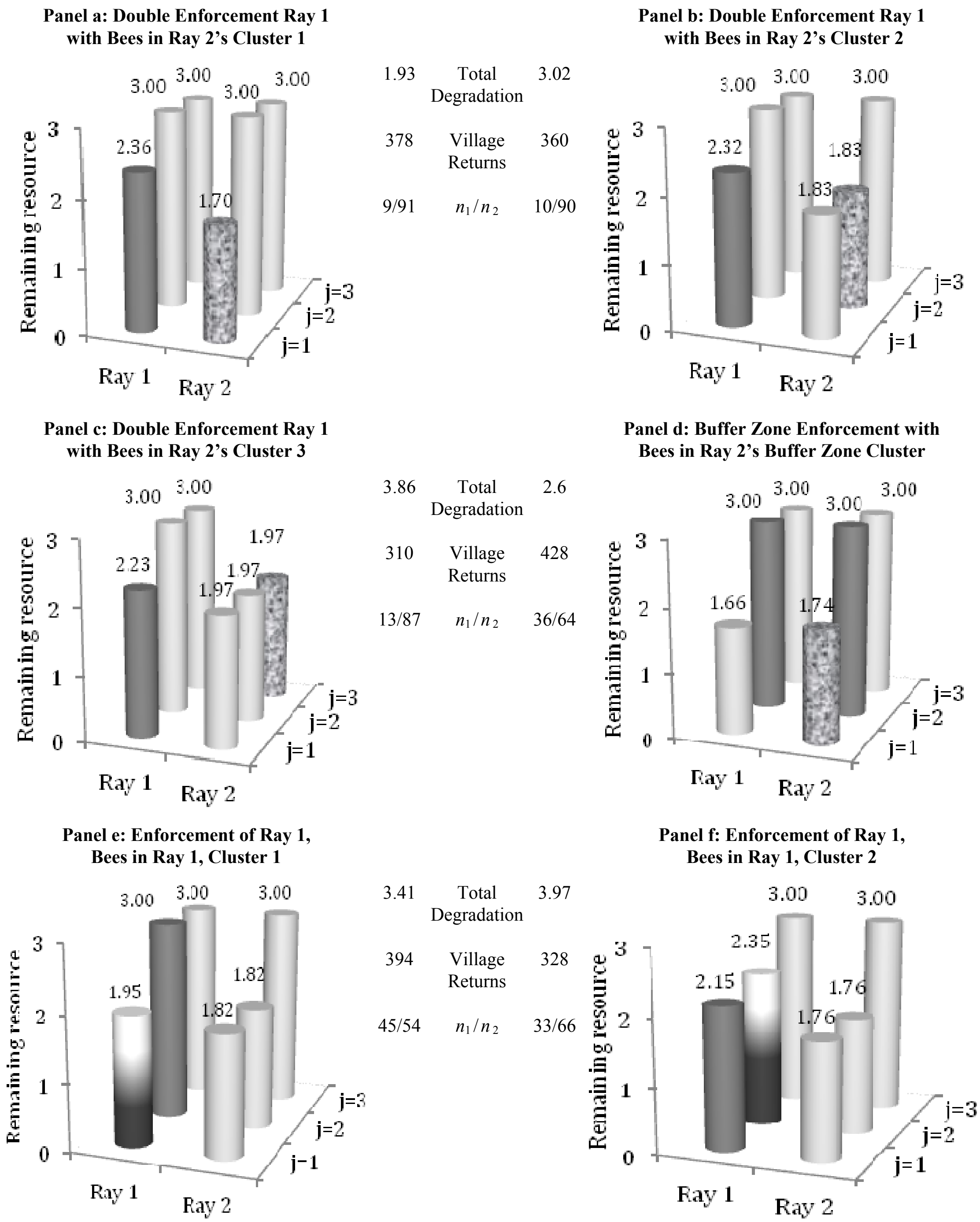

Figure 3. Impact of Beekeeping Location and Enforcement Patterns on Post-Extraction Forest Patterns

Note: Clusters with beekeeping are mottled, enforcement clusters are dark gray, and clusters with both enforcement and beekeeping are dark/light striped. "Total degradation" is the total amount of resource extracted across all rays and clusters, while the height of the columns shows the resource remaining after extraction per cluster. Light clusters have no enforcement or beehives. "Village returns" are the resource values less the labor costs that the villagers receive. The equilibrium distribution of villagers across rays is represented by n_1/n_2 with a total of 100 villagers.

ray 2's portion of the buffer zone. Individual villagers harvesting NTFPs in ray 2 reduce their labor allocation to NTFPs and, overall, extract less from ray 2 despite the increased number of villagers using ray 2. The beekeeping reduces the forest degradation throughout the buffer zone, with a larger impact in the beekeeping cluster for this parameterization.

Many forest managers now face rules about allocating some of their budget to enforcement and some to poverty alleviation projects. In that case, managers may impose patrols and projects in the same locations. As compared to the enforcement strategy in Figure 2, panel c, placing beekeeping anywhere in an enforced ray 1 increases rural livelihoods. Placed in cluster 1, the beekeeping draws villagers from ray 2 to ray 1, thereby decreasing extraction and degradation in ray 2, but their labor allocation to resource extraction declines and the beekeeping actually decreases the degradation in ray 1 (Figure 3, panel e). Placed in cluster 2, however, the beekeeping offers lower benefits and therefore draws fewer villagers and less degradation away from ray 2 than beekeeping in cluster 1 (Figure 3, panel f). Having bees in cluster 2 covers the distance (and enforcement risk) costs of extracting in cluster 2 and so this location draws extraction from cluster 1 into cluster 2. With this parameterization, the increase in degradation in cluster 2 due to the benefits from beekeeping there leads to a higher total level of degradation in the forest than without beekeeping. The pattern of degradation is more dispersed across ray 1 with bees in cluster 2 than with bees in cluster 1.

These results demonstrate that the placement of alternative income-generating projects like beekeeping can augment enforcement in controlling the pattern and amount of forest degradation. The beekeeping project reduces total degradation and improves rural livelihoods, which may partially compensate villagers for lost resource access in forest reserves and may generate goodwill between the forest manager and villagers. But if the forest manager makes a location decision about the beekeeping projects, he can draw extractors into some areas of the forest, perhaps those with less sensitive resources, while reinforcing enforcement and distance's deterrence of extraction in other areas, perhaps those with more sensitive resources. The forest manager can control the pattern of degradation within and beyond a forest reserve, the amount of degradation, and rural livelihood levels by making location decisions about enforcement and poverty alleviation projects.

Conclusion

We develop an explicitly spatial framework to provide insights for managers into policies to alter not just the amount of extraction-related degradation of their forests through enforcement but also the pattern of the degradation through location decisions about both enforcement and poverty-alleviation activities. The pattern of NTFP extraction contributes to the pattern of forest degradation and to the forest's production of ecosystem services. Because enforcement and alternate livelihood projects are two primary tools for forest management in these settings, we examine the interaction of those policies in a framework of joint production of NTFPs and another forest-based product.

As in related spatial enforcement and spatial extraction research, here villagers do not extract from more remote portions of the forest due to distance costs, which protects the interior of forests from degradation. In addition, to deter extraction, more distant forest areas require lower levels of enforcement than forests near villages. Distance and enforcement interact to determine the level of degradation at different locations within the forest. As we observe in practice, illegal extraction occurs in forests with too low a patrol density to deter extraction, although any level of enforcement reduces the amount of forest degradation in and beyond the patrolled area of forest.

In the econometric evaluation of parks and other forest conservation policies, the issue of leakage—the displacement of deforestation and degradation activities to other forests—presents daunting difficulties (Gaveau et al. 2009, Pfaff et al. 2009). The analysis here demonstrates how the amount and location of displaced forest-degrading activities respond to different levels and patterns of enforcement in part of the forest through an explicitly spatial production function for NTFPs. We find that enforcement reduces degradation overall but that leakage partially, but not completely in this homogeneous forest, offsets the lower degradation levels within the patrolled forest. Enforcement does not displace extraction in a one-for-one manner in this framework because displaced villagers must compete for resources in the unpatrolled forest. More people extracting in the unpatrolled forest leads to lower biomass and lower returns, and that congestion cost implies that this displaced extraction—leakage—does not perfectly offset reduced degradation elsewhere. In addition to dampening the total amount of forest degradation, the location of enforcement activities determines the pattern of degradation throughout the forest, whether the forest manager manages the whole forest or only a portion.[11]

In recent years, governments and NGOs have implemented poverty alleviation projects near forest reserves, often with the aim of compensating rural people for lost access to forest resources within the reserve and sometimes with the aim of creating incentives for conservation of forest resources. This analysis of beekeeping projects, which are popular across Africa, Asia, and Mexico, demonstrates that projects that offer a high enough return can pull labor out of resource extraction activities, thereby reducing the total amount of forest degradation.[12] In addition, because NTFP extraction derives from a spatial decision, the location of the alternative income project turns the labor allocation decision into one of joint production of beekeeping and NTFPs across space. Individual villagers who perform beekeeping and forest extraction in an area of the forest extract less from the forest than those who do not undertake beekeeping. Locating the beekeeping project in a particular area of the forest, however, draws villagers to that part of the forest, which increases the number of villagers there, which at least partially offsets the individual decline in the NTFP extraction and resulting forest degradation. Still, the drawing of people to one area of the forest reduces the number of villagers extracting in other parts of the forest, and, although they as individuals may extract more, the level of forest degradation in areas of forest without beekeeping declines. Making the location of the income project part of a forest manager's decision allows the manager to influence the level and location of forest degradation both near the project location and throughout the forest.

The optimal location of both enforcement and projects depends on the forest manager's objective function and the forest's ability to create ecosystem services as a function of amounts and patterns of degradation. In general, locating the projects close to villages leads to the highest welfare gains, the largest reduction in total forest degradation, and the most concentrated forest degradation. In some ecological settings, however, concentrating degradation close to the villages can limit ecological benefits, and managers may prefer to locate the project farther from the village to induce a more dispersed, low level of degradation throughout the forest. Similarly, forest managers may choose a location for projects and enforcement to protect a particular area of the forest due to its scenic or ecological value. In that case, enforcement at or between the village and the priority site combined with projects in a different area of the forest create the lowest levels of disturbance in the priority area through a combination of the spatial "carrot" drawing people to the project and the "stick" of enforcement deterring extraction there. Although defining an optimal pattern of enforcement and projects requires information about the objective function, the responsiveness of villagers to labor opportunities and to enforcement, and the impact of the spatial pattern of degradation on forest ecosystem benefits, this framework provides general guidance for locating projects and enforcement to generate patterns of resource degradation.

In a world of very limited budgets for forest management and high levels of poverty and resource dependence, a framework that adequately addresses the spatial costs and decisions that underlie extraction can identify patterns of policies that lead to improved forest quality while addressing rural people's welfare. Although many poverty alleviation projects do not aim to induce conservation, the addition of a spatial aspect to those projects provides a new tool for resource managers to employ in conjunction with the location of enforcement activities. Through the combined project and enforcement location decisions, the forest manager gains more control over the spatial pattern of forest degradation. Because for-

[11] If villagers require at least some minimum amount of the resource, enforcement does not reduce the total forest degradation but can alter the pattern of the degradation.

[12] Although atypical in rural areas of developing countries, if labor markets function perfectly, a household simply hires labor and continues to extract the same amount of resource, and the project has no impact on forest degradation.

est managers may value different patterns of forest degradation in different ecological and economic settings, having policy tools to manipulate that pattern strengthens their ability to provide benefits from the forest. In addition, the explicitly spatial model of forest degradation, enforcement, and projects could frame discussions of evaluating the success of forest reserves because this model depicts the level and location of forest degradation leakage that results from different patterns of reserves, enforcement, and buffer zones.

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