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Conservation vs. livelihoods: spatial management of non-timber forest product harvests in a two-dimensional model

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Abstract. Areas of high biodiversity often coincide with communities living in extreme poverty. As a livelihood support, these communities often harvest wild products from the environment. But harvest activities can have negative impacts on fragile and globally important ecosystems. This paper examines trade-offs in ecological protection and community welfare from the harvest of wild products. With a novel model and empirical evidence, I show that management of harvest activity does not always resolve these trade-offs. In a model of continuous harvests in a two-dimensional landscape, managed harvest activity improves welfare, but is uniformly bad for other ecosystem services that are sensitive to the presence (as opposed to the intensity) of human activity. Empirical results from a unique dataset of mushroom harvesters in Yunnan, China suggest more experienced, poorer, and more vulnerable individuals tend to rely on more distant harvests. Thus, policies that limit the extent of forest travel, such as protected areas, may protect fragile ecosystems but can have a disproportionately negative effect on those most vulnerable.

Key words: ecosystem services; livelihoods; non-timber forest products; protected areas; spatial management.

INTRODUCTION

Poverty alleviation and conservation of ecosystems are often in conflict. Nearly 20% of the world's population live within biodiversity hotspots (Cincotta et al. 2000), a significant fraction of whom are extremely poor (Fisher and Christopher 2007). Most of these communities harvest wild products from the environment to support their livelihood (Vedeld et al. 2007; World Bank 2008, FAO 2011). But in these areas of vital conservation concern, harvesters' travel and extraction activities can have negative environmental impacts. Addressing these tradeoffs has been a top priority of the conservation and development community for decades (Brown 2002, Berkes 2007, Tallis et al. 2009, Pattanayak et al. 2010), and careful management of harvest activities is widely promoted as a way to simultaneously improve local livelihoods, use resources sustainably, and protect fragile ecosystems (Bhattacharya and Hayat 2004, Ticktin 2004, Cooke et al. 2008, Laird et al. 2010, Guariguata et al. 2011). Dominant management options are often to fence off people through protected areas or to limit harvesting labor. How these management activities are spatially implemented can have very different implications for welfare and ecology, but are rarely explored.

Separately, each of these issues has received a good deal of attention. For example, the ecological impacts of people in forests are well known. On one hand, the simple presence of human activity in a forest can have negative ecological impacts. Of course active extraction activities like hunting or foraging can impact ecosystem dynamics (Redford 1992, Peres 2000), but even passive presence drives fauna out of areas. Many large mammals simply avoid areas where humans roam (George and Crooks 2006, Bearer et al. 2008), and flight initiation distance for other species are well quantified (Van Dyke et al. 1986, Blumstein et al. 2003, Taylor and Knight 2003, Fernández-Juricic et al. 2005, Stankowich 2008). These impacts underpin the rationale for protected areas (UNESCO and UNEP 1974, Dudley 2008) and help set guidelines for park buffer zones and boundaries (e.g., Holmes et al. 2005). Further, the level of the intensity of human activity in an area can result in quite different direct and indirect changes in local ecology. Levels of travel and/or extraction in forests has been found to impact community ecology (Liddle 1991, Pickering and Hill 2007, Thapa and Chapman 2010), wildlife diversity (Moegenburg and Levey 2002, Jotikapukkana et al. 2010), and species' evolutionary trajectory (Ashley et al. 2003, Law and Salick 2005, Mooney and McGraw 2007). Reducing the intensity of harvest activities is often invoked as a way to manage harvests that might improve not just local ecology but also human welfare.

Human welfare derived from forest resources has received interest in the literature as well, often set within a bioeconomic model simulating the harvest of non-timber forest products (NTFPs). The bioeconomic framework, originally developed in a fisheries context (Gordon 1954, Clark 1990), has proven useful in both ecological and economic research as it can simplify

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seemingly complex resource and economic interactions and feedbacks. Bioeconomic models have been applied in diverse settings that include not just fisheries (Sanchirico and Wilen 2001, Horan et al. 2011), but also agriculture (Janssen and van Ittersum 2007, Robson 2010), invasive species (Leung et al. 2005, Fenichel et al. 2010), epidemiology (Fenichel et al. 2011), and institutional robustness (Anderies 2006). Within resource economics, spatial considerations have become increasingly recognized as important for understanding the interactions among resource availability, welfare, and ecological sustainability (Smith et al. 2009, Albers and Robinson 2013).

Several papers closely relate to the issues explored here. Robinson et al. (2002) use an optimal harvest model to examine how NTFP extraction can change under different labor and market conditions, highlighting implications for the buffer and core regions of a forest. Recently, Sirén et al. (2013) and Sirén et al. (2015) developed bioeconomic specifications that incorporate different aspects of spatial costs. Two papers explore management outcomes for harvesting in a spatial setting: Robinson et al. (2008) look at management implications in a spatial-dynamic model of NTFP harvest, and López-Feldman and Wilen (2008) evaluate welfare impacts and management institutions for point-source harvesting.

In this paper, I construct a spatially explicit model for the extraction of wild products like NTFPs. Three features make this model unique relative to those mentioned above. By designating a total amount of available labor available in a forest (a labor constraint), I implicitly model a common property setting in which villagers engage in cooperative or non-cooperative management of harvest activities. Second, a protected area or buffer zone is incorporated by making the forest boundary explicit (through a distance constraint). Finally, the model uniquely extends the harvesting context to a two-dimensional forest and is explored in detail. I examine the distribution of labor over a landscape and its implications for (1) local community welfare, (2) ecosystem services sensitive to the presence of human activity, and (3) ecosystem services that are sensitive to the intensity of human activity. I distinguish between these latter two categories for clarity but, in reality, they are nested. Presence is simply a binary condition, while intensity necessarily implies presence plus some non-zero level of activity.

In this paper, I contribute to understanding the links between local livelihoods and resource dependency, and highlight important implications for designing effective resource-use policies in ecologically sensitive areas. The next section, *A spatial bioeconomic harvest model*, sets up the harvest problem to include a spatial dimension over multiple patches of forest. *Numerical application* presents the results from a numerical simulation of the model. The model shows that managing harvest activity is actually bad for areas with other ecosystem services that are sensitive to the presence of human activity. *Empirical support* presents supporting empirical results from a unique dataset on wild mushroom harvesters in Yunnan, China. The empirical results underscore how poorer households tend to rely on more distant parts of unmanaged forests, so spatial constraints on extraction, like protected areas, can have disproportionate impacts on vulnerable households. I conclude with some implications for rural development and conservation.

A Spatial Bioeconomic Harvest Model

A two-dimensional harvest model

The model is based on a steady-state bioeconomic framework (Clark 1990) applied to an area of forest. I use a steady-state model to focus on integrating spatial aspects into the problem, and incorporating temporal and spatial dynamics creates cyclical equilibria (Robinson et al. 2008) that make other novel features difficult to assess. Still, ignoring the temporal dynamics has drawbacks, namely the inability to explore the path to steady-state and potentially interesting intertemporal aspects of resource dynamics and human behavior (e.g., sorting and congestion). These could be fruitful extensions of the initial model here that extend the standard model to alternative forest geometries.

Starting within a single patch of forest, consider a community uses an amount of labor l to search for an amount of available biomass x. With a harvest efficiency q, a harvest production function can be represented as $H(x,l) = qxl$ (Schaefer 1954). In equilibrium, harvests in any period equal the resource's growth rate, which is defined through a standard logistic function as $\tilde{H} = xr(1-\frac{x}{K})$, with r as the per-period growth rate of biomass, K as the carrying capacity within the forest patch, and ~ denoting equilibrium. At steady state, the resource stock has a deterministic relationship with labor, $x = K(1-ql/r)$, which results in the textbook inverted U-shaped relationship between harvests and stock levels. For this single forest patch, harvests as a function of labor are

$$\tilde{H} = qKl(1-ql/r) \tag{1}$$

Two features are incorporated into the model to make the forest spatially explicit. The first and most unique feature of this model is a simple way to incorporate two-dimensional features of a landscape. Prior spatial models extend a unit-width forest patch, as represented in Eq. (1), linearly out from the village to construct a one-dimensional series of forest patches (Albers and Robinson 2013; Fig. 1a). I develop a model that represents harvests in a two-dimensional forest (Fig. 1b), which may be a more realistic approximation in many contexts. To do this I first assume resources are evenly distributed throughout a forest with a constant per unit area carrying capacity $\bar{\rho}$. The total carrying capacity of a circular forest with a radius s from the village center is then $\bar{\rho}\pi s^2$.

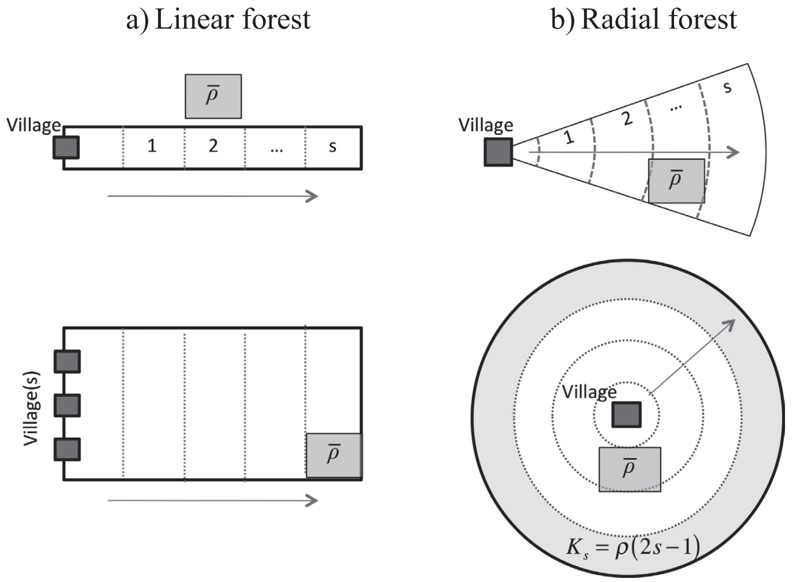


FIG. 1. Conceptual representations of the linear 1-dimensional model (a) and the radial 2-dimensional model (b).

For a forest ring defined by the distance between s and $s-\Delta$, the carrying capacity is the area of the outer circle minus the area of the inner circle: $K_s = \bar{\rho}\pi s^2 - \bar{\rho}\pi(s-\Delta)^2$. If we assume a ring is of a unit width ($\Delta = 1$; see Appendix S1: Part II.1 for a continuous specification) and allow π, a constant, to be absorbed into our measure of carrying capacity so that $\rho = \bar{\rho}\pi$, then the carrying capacity of the ring at distance s simplifies to $K_s = \rho(2s-1)$. Substituting K_s into Eq. (1), equilibrium harvests within an arc at radius s are

$$\tilde{H}_s = q\rho\,(2s-1)\left(l_s - \frac{q}{r}l_s^2\right) \tag{2}$$

The second feature is how the model incorporates the cost of spatial travel between productive patches of forest. In a spatial model, one can think of labor as divided into productive harvest labor, as represented above as l, and costly non-productive travel labor, which I denote as $\bar{l}$ The model assumes harvested resources are consumed or sold back in the community, so any travel strictly away from (orthogonal to) a village is costly travel labor. Travel from patch s to $s + 1$ requires a fixed amount of round-trip labor $\bar{l}_i$ per individual such that $\bar{l} = \sum_1^n l_i$, where there are n individuals in the community. Conversely, travel tangent to the village center (within an arc or ring) is pure harvest labor l since no additional effort is needed to return to the village. Costs could equivalently be modeled as continuous function of distance from the village (e.g., Robinson et al. 2002), but taxing only orthogonal travel $\bar{l}$ is a conceptually simple way to separate costly travel labor from productive harvest labor and makes for clear exposition of the model below.

Making carrying capacity a function of space and taxing only orthogonal travel effectively creates a two-dimensional model without adding a second spatial dimension, which makes sense for several reasons. First, in a model with no heterogeneity in resource distribution or travel costs, to harvesters all orthogonal travel paths are equal. Therefore, in equilibrium, labor would extend equidistant from the village center even if explicit second dimensions were included. Additionally, this formulation keeps the model parsimonious and tractable, while still providing a reasonable first step at modeling the distribution of labor in more complex resource geometries.

The economic system

The functions that govern decision-making can be formalized as a profit function and two main constraints on behavior,

$$\prod = \sum_{s=1}^{S} \prod_{s} = \sum_{s=1}^{S} [p\tilde{H}_s - w(l_s + \bar{l})] \tag{3}$$

$$subject\ to{:}\, d - S \geq 0 \tag{4}$$

$$L - \sum_{s=1}^{S}\left(l_s + \bar{l}\right) \geq 0 \tag{5}$$

Equation (3) denotes profits from travel and harvesting, where harvested biomass receives a price of p per unit and is harvested at opportunity cost of time w. Implicit in the decision-making process is a participation condition, which says that for any individual i to participate in harvesting profits must be positive, $\prod_i = \sum_1^S p\tilde{H}_{si} - w_i(l_{si} - \bar{l}) \geq 0$. Equation (4) indicates that the maximum distance traveled S can be no greater than the extent of the community's forest boundary d. Finally, Eq. (5) implies villages have exclusionary rights over the surrounding forest, so the forest can only be harvested by a fixed amount of total community labor L such that $\sum_{s=1}^{S}(l_s+\bar{l})\leq L$.

These distance and labor constraints are necessary for modeling real world systems in this spatial model. In the traditional aspatial bioeconomic model, the total resource base is fixed through carrying capacity K. Here, the resource base grows with distance from the village. If the size of the forest is not defined through d, then the resource base is effectively unbound, and the only way to have a tractable model is to fix the total community size L (i.e., a labor constraint must bind). Alternatively, if we allow free entry of labor, as is assumed in the standard open access harvest model, the model must have a fixed resource base, which here means we must define the size of the forest (the distance constraint must bind). Hence, labor and distance constraints cannot both be slack at the same time: a village either runs out of labor or a community has more labor than is needed given the size of the forest (both constraints can be slack only if $d=\infty$ and $L=\infty$). Distance constraints could represent fragmented forests, natural impediments like cliffs or rivers, or things like property right restrictions through community property boundaries or protected areas. The labor constraint may bind when relatively few people have access (Ribot and Peluso 2003) to a system due to heterogeneous costs of entry (e.g., potential users live far away, communities have exclusion rights over the forest, policies prohibit harvests, etc.). In these cases, we cannot assume free entry of labor. There is some empirical evidence that these kinds of labor constraints may be common (Robinson et al. 2013).

Taking these constraints and geographic considerations into account, we want to better understand the potential gains from cooperatively managing harvest activities (managing harvests to maximize profits versus competitive harvesting). Following Sanchirico and Wilen (1999), I formalize institutional arrangements through two spatial management rules.

1) Cooperative rule. Cooperative spatial management implies $\frac{\partial\Pi_s}{\partial l_s}=\frac{\partial\Pi_{s+1}}{\partial l_{s+1}}\forall s\in\{1,\ldots,S\}$. The marginal utility of harvests is equal across all harvested patches. Travel labor drops out of the cooperative equilibrium condition since it is a sunk cost.

2) Non-cooperative rule. Non-cooperative spatial management implies $\frac{\Pi_s}{l_s}=\frac{\Pi_{s+1}}{l_{s+1}+\bar{l}}\forall s\in\{1,\ldots,S\}$, so that the average utility of harvests is equal across all harvested patches. A harvester continues foraging further into the forest as long as the average benefits of traveling to and harvesting in the next patch $s+1$ are greater than the average benefits from continuing to harvest in the current patch s. In equilibrium, harvesters are indifferent between all patches.

Cooperative harvest conditions

Under cooperative conditions, harvesters collectively coordinate their activities to maximize profits from harvests. Cooperation can be formal or informal and has been well documented in many empirical settings (e.g., Wade 1987, Acheson 1988, Ostrom 1990). Cooperation implies maximizing Eq. (3) by choosing an amount of village harvest labor l and the maximum travel distance S, subject to the labor available within the village (Eq. 4) and the forest area over which a community has use rights (Eq. 5). Appendix S1: Part I.1 and II.2 present solutions to this problem for a linear and radial forest, respectively.

Figure 2 is a graphical summary of cooperative spatial harvests. The model is most appropriately thought of as many small patches extending out into space, but for graphical clarity I compare a 1-patch and a simple 3-patch linear forest (where $K_s=\bar{\rho}$) to highlight the fundamental implications of the spatial model. The 1-patch case is equivalent to the traditional bioeconomic harvest model where profits are maximized when a community exerts labor l_1 such that the marginal cost of harvesting (w) is equal to the marginal benefit (the line tangent to the biomass growth curve). The thick vertical dashed line shows within-patch profits. In a spatial 3-patch forest, growth curves become stacked; harvesting begins after leaving the previous patch and expending a fixed unit of labor $\bar{l}$ to get there. I denote opportunity cost as w' since it may include the shadow value for labor when the constraint binds. In this linear

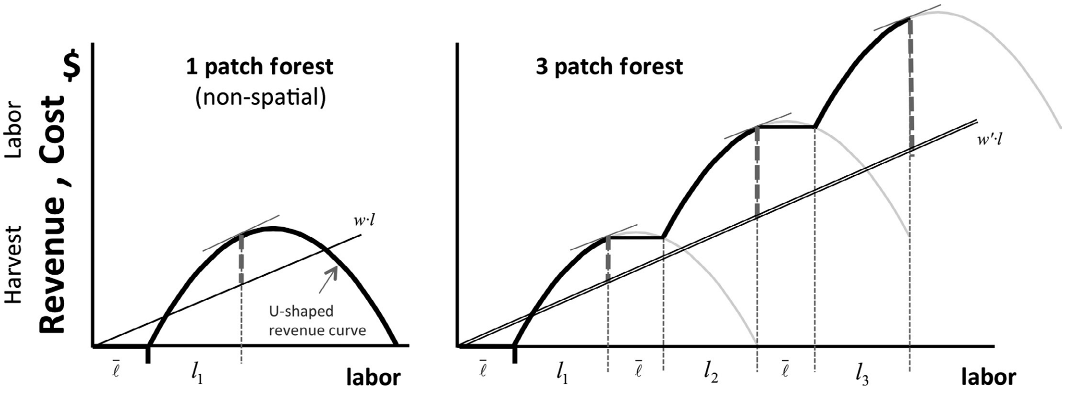


FIG. 2. Cooperative harvest conditions in a single-patch (left) and a 3-patch linear forest (right). The single patch case is the standard bioeconomic model under optimal management.

Table 1. Summary of labor conditions

	Cooperative		Non-cooperative	
	$\frac{\partial \Pi_s}{\partial l_s} = \frac{\partial \Pi_{s+1}}{\partial l_{s+1}} \forall s \in \{1, \ldots, S\}$		$\frac{\Pi_s}{l_s} = \frac{\Pi_{s+1}}{l_{s+1}+\bar{l}} \forall s \in \{1, \ldots, S\}$	
	Linear	Radial	Linear	Radial
Carrying capacity	$K_s = \bar{\rho}$	$K_s = \rho(2s - 1)$	$K_s = \bar{\rho}$	$K_s = \rho(2s - 1)$
Forest-limited S=d $L > \sum_{s=1}^{s} l_s + d\bar{l}$	$l_s^* = \frac{r}{2q}\left(1 - \frac{w}{pq\bar{\rho}}\right)$	$l_s^* = \frac{r}{2q}\left(1 - \frac{w}{pq\rho(2s-1)}\right)$		
Labor-limited S<d $L = \sum_{s=1}^{s} l_s + s\bar{l}$	$l_s^* = \frac{r}{2q}\left(1 - \frac{(w+\lambda^*)}{pq\bar{\rho}}\right)$	$l_s^* = \frac{r}{2q}\left(1 - \frac{(w+\lambda^*)}{pq\rho(2s-1)}\right)$	$l_s = \frac{r}{q}\left(\frac{1-(l_{s+1} - \frac{q}{r} l_{s+1}^2)}{l_{s+1}+\bar{l}}\right)$	$l_s = \frac{r}{q}\left(1 - \frac{(2s+1)}{(2s-1)} \frac{(l_{s+1} - \frac{q}{r} l_{s+1}^2)}{l_{s+1}+\bar{l}}\right)$
Both constraints bind S=d $L = \sum_{s=1}^{s} l_s + d\bar{l}$	$l_s^* = \frac{L}{d} - \bar{l}$	Determined by forest depth *d* (see Appendix S1: Part *II.2*.iii)		
No constraints bind $S = \infty$ $L = \infty$		n/a		n/a

Notes: For radial carrying capacity, $\rho = \bar{\rho}\pi$. In the labor-limited case, λ^* is the optimal shadow price of labor (see the Appendix S1: Part *II.2*.ii); see text for definitions of other variables.

forest $l_1 = l_2 = l_3$, but per unit area labor has a non-linear relationship with distance in the radial model.

The constraints included in the model imply four cases to examine, but only two cases are dominant. The main features and labor conditions represented by the four cases are given in Table 1. The first condition represents communities that we can call "forest-limited," where the size of the forest is relatively small relative to a community's labor pool (implying the distance constraint binds). Under cooperative management, harvesters agree to exert a limited amount of labor through the forest so that they maximize harvest profits at each point in space. Travel costs do not impact the cooperative labor allocation since they are fixed, sunk costs. As Sanchirico and Wilen (1999) note, when the resource does not have spatial interdependencies, as is the case for most NTFPs, maximizing revenue at each point in space maximizes total revenues.

In the second main case, communities are labor limited; the size of the forest is relatively large relative to the community and therefore is not fully exploited (i.e., if the community were larger, they would harvest more). Still, cooperative management implies maximizing revenue at each point in space, but now the shadow value of labor (λ^* in Table 1) is positive since an additional unit of labor would yield additional value.

There are two other cases where both constraints bind and where no constraints bind. As argued previously, the case with no binding constraints is only possible if $d = \infty$ and $L = \infty$, so I do not explore it here. The case where both constraints bind is a marginal condition that happens only when there is just enough labor to harvest into the last patch of forest, but not to fully exploit it. For a continuous forest with numerous infinitesimally small forest patches, this marginal case vanishes so I do not focus on these results, although I do present the labor conditions in Table 1 for completeness.

Non-cooperative harvest conditions

When harvest activities are not cooperatively managed, the non-cooperative rule governs harvesters' behavior. That is, to harvest further away from the village, the average profits from continuing to harvest in the current patch *s* must be less than the average profits from traveling to and harvesting in the next patch *s* + 1. In equilibrium this means

$$\frac{\Pi_s}{l_s} = \frac{\Pi_{s+1}}{l_{s+1}+\bar{l}} \rightarrow \frac{l_s - \frac{q}{r} l_s^2}{l_s} = \left(\frac{2s+1}{2s-1}\right)\left(\frac{l_{s+1} - \frac{q}{r} l_{s+1}^2}{l_{s+1}+\bar{l}}\right). \quad (6)$$

The relationship represented in Eq. (6) drives the non-cooperative results in Table 1 (for more details see Appendix S1: Part II.3).

Figure 3 compares a 1- and 2-patch forest under non-cooperative conditions for a linear forest. The growth curves are stacked similar to the cooperative case, and again, I show only two patches to emphasize the spatial extension of the traditional model. The 1-patch case for non-cooperative harvests shows l_1 is determined by the intersection of the curves that represent the total costs of harvesting ($w \times l$) and the total revenues ($p \cdot \tilde{H}$), which represents the zero economic rent condition. In the 2-patch forest, resources are harvested at a loss in the first patch and for a profit in the second patch, so that the overall balance results in zero profits. The typical zero-rent characteristic associated with non-cooperative resource management does not hold within patches, but across all patches. To illustrate this, assume we impose

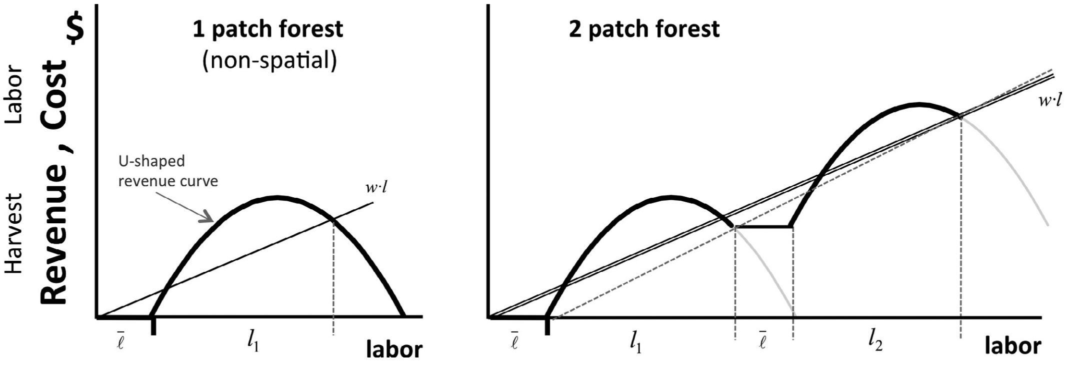


FIG. 3. Non-cooperative harvest conditions in a single-patch (left) and a 3-patch linear forest (right). The single patch case is the standard bioeconomic model under open access management.

the zero-rent condition in the first patch. Eq. (6) then implies profits would be positive for more distant patches since harvesters would allocate a quantity of labor less than rent-dissipating in the next patch, making positive profits. Thus, in equilibrium, the sum of rents over space must be zero when the labor constraint is slack.

But why would someone ever harvest at a loss at all? Losses occur when the benefits from harvesting in nearby locations do not offset the costs. But it still makes sense to harvest in these locations once a harvester finds herself in that patch of forest, since the travel cost to get there is sunk. Still over-harvesting in nearer patches only happens if it makes sense to keep going into the forest to harvest for a profit further out. In equilibrium, a harvester has already figured out exactly how far it makes sense to go.

The canonical non-cooperative case results in rent dissipation, but this comes directly from assuming labor can freely enter a harvesting system. By making labor and distance constraints explicit, I effectively model a reduced-form version of common property systems. In forest-limited communities, the free entry of labor characteristic of open access systems is satisfied, meaning $\Pi = 0$. From a harvester's perspective, the zero-rent condition simply means that the competition with others is intense enough that the forest is fully harvested. That is, harvesters keep looking for forest resources until their profit just equals their opportunity cost of time.

In labor-limited communities, harvesters do not face such intense competition since there is not enough total community labor to harvest the forest completely and therefore are able to earn positive profits since they may not need to search as long. From a modeling perspective, the free entry of labor characteristic is not met and therefore, it is not necessary to dissipate all resource rent to achieve equilibrium across all patches.

Opportunity cost and travel behavior

Thus far the discussion has assumed everyone's opportunity cost of time is the same. However, one way to classify households as poor is to characterize them as having a low opportunity cost of time, w_i. A more formal treatment of the theoretical relationship between opportunity cost and spatial travel is provided in Appendix S1: Part III, but, in summary, the model suggests different outcomes under cooperative and non-cooperative conditions. In a cooperative setting, it is optimal for poorer individuals to spend more labor per patch and more total labor, but overall this results in traveling shorter distances than households with higher opportunity costs. The unmanaged case is opposite: poorer households are willing to travel farther into the forest in search of resources than their richer counterparts since travel costs are cheaper for them. We are primarily interested in livelihood outcomes in the non-cooperative case, so I focus on these settings in the sections below. Empirical measurement of this construct is discussed in *Empirical support*.

Model summary

The analytic results suggest that harvesters compete and harvest more intensely in nearby patches in non-cooperative systems due to the race to extract resources, while cooperative systems use less labor in nearby patches but allocate it more evenly further out in the forest. So in labor-limited villages, harvesters use up their effort more quickly in non-cooperative relative to cooperative cases, which distributes labor less intensely but further into the forest.

This main result has several implications. First, for other forest ecosystem services (i.e., other than resource harvests) that are sensitive to the presence of human activity, cooperative management of NTFP extraction may actually have negative ecological consequences since labor is distributed over more space. Second, for forest ecosystem services that are more sensitive to the intensity of human activity, profit-maximizing management should have positive ecological impacts since labor is everywhere more restricted. Next I construct a numerical application to explore the model in more detail.

NUMERICAL APPLICATION

The purpose of the numerical application is to help demonstrate the broad features of the model. I model three sets of forest conditions setting by fixing the forest size at $d = 10$ and varying community labor L (equal to 35, 135, and 300) to simulate conditions that move from a labor-limited to a forest-limited setting. Simulations use parameter values $r = 0.5$, $K = 500$, $q = 0.03$, $P = 10$, $w = 5$, and $\bar{l} = 1$, which reflect common, textbook bio-economic assumptions (e.g., Seijo et al. 1998: Table 2.1, Conrad 1999). Simulations were run with a number of parameter values to ensure consistency of the results. The outcomes are most sensitive to values chosen for catchability q and resource growth rate r, but the qualitative conclusions hold for a range of plausible conditions. The results below are presented in relative per-unit-area terms for comparison between the radial and linear models.

Simulation methods

Numerical simulations were developed in MatLab R2013b and use different simulation methods for each management case. In cooperative forests, I first calculate the optimal labor allocation (l_s^*) from cooperative forest-limited communities (see case II.2.i in the Appendix S1 for the mathematical solutions) and check whether enough community labor (L) exists to fulfill the optimal allocation given the forest depth of (d). If so, then communities are forest-limited and I use the analytic results from case A.II.2.i to calculate labor and profit distributions throughout the forest. If not, the labor constraint binds and I use the conditions given in case A.II.2.ii to calculate the solution. A complete analytic solution is not possible for radial labor-limited (see Appendix S1: Part II.2.ii) communities, since the number of first order conditions is endogenous to the solution, so I calculate all possible optimal solutions $\hat{l}_s^*$ and $\hat{S}^*$ for forest depths $s = \{1, \ldots, 10\}$ and evaluate which solution set gives the greatest profit. This determines the optimal solution set l_s^*, S^*. If S^* is greater than the exogenously given forest depth (d), then both constraints bind and the marginal case applies.

For non-cooperative forests, Appendix S1: Equation S.10 shows labor in patch d as a function of labor in patch $d + 1$. Using this I calculate the distribution of labor throughout a forest for the full range of plausible candidate labor values for last patch at distance d, first assuming harvesters travel to all the way to their forest boundary d. I then reduce the size of the forest interactively to calculate labor allocation over all travel space. This produces an array of within-forest labor distributions for all admissible values of travel distance and possible labor allocation combinations. Searching over the array, I find the combination of total labor and travel distance that results in non-negative profits and uses the greatest amount of labor (up to a maximum of L). This is the non-cooperative solution.

Within-forest labor and profit distributions

Within-forest labor and profit distributions are shown in Fig. 4. In these plots the village is located at the center of the bottom left axis. Bars (linear) and arcs (radial) show the distribution of labor and profits results for a specific community size (L) in a 10-patch forest. Cooperative outcomes are on the left, and non-cooperative outcomes are on the right.

The per unit-area labor allocations in Fig. 4a show that non-cooperative communities always concentrate higher amounts of effort closer to the village compared to cooperative communities. This results in shorter travel distances when a community is labor-limited: non-cooperative communities use up labor more quickly than cooperative ones. To competitive harvesters in this labor-limited setting, it never makes sense to go out further in space. Since labor is limited, competition among harvesters is less intense, and they still earn profits from the forest. If someone moves further out in space, he just leaves profits behind in nearer patches of forest, so in equilibrium everyone keeps harvests near to the village. When harvests are competitive but with larger amounts of available labor, higher magnitudes of labor are used everywhere until no resource rent remains. Cooperative harvesters, on the other hand, use a smaller amount of labor per patch and travel further into the forest.

The labor results also highlight differences between assuming a linear vs. radial landscape. In the radial model, per unit-area labor always decreases over space, implying less intense activity at further distances, even under cooperative management. In the linear model, intensity varies comparatively little over space.

The profit results in Fig. 4b also show distinctly different patterns between the linear and radial cases. Per unit-labor profit is always uniform over space in the cooperative linear case. In non-cooperative settings, per-patch profits increase as harvesters travel farther from the village as labor (and thus competition) decreases with distance. Still, when communities are forest-limited (e.g., $L = 300$ in Fig. 4), they have enough labor to fully harvest the forest and non-cooperative conditions lead to zero total profits as we expect in open access equilibria. In the non-cooperative radial model, positive profits exist when the community is small, and profits dwindle as total labor availability increases relative to the forest size. With cooperative management, profit per unit labor increases with distance in the radial setting.

López-Feldman and Wilen (2008) and Ling and Milner-Gulland (2007) develop models similar to the linear case but result in quite different outcomes. For example, in the case of López-Feldman and Wilen (2008), cooperative and non-cooperative labor distributions are always proportional. In the current model, cooperative and non-cooperative behavior can lead to entirely different spatial distributions of labor (Fig. 4a). These differences reflect their assumption that harvesters travel to a single point, extract resources, and then return to a market. In contrast, the model developed here assumes resources are collected continually as one travels through a forest.

Finally, I use these same parameters to numerically show how the maximum distance traveled S changes with opportunity cost w under non-cooperative management. Appendix S1: Fig. S1 shows the negative relationship between the two variables: the distanced traveled increases

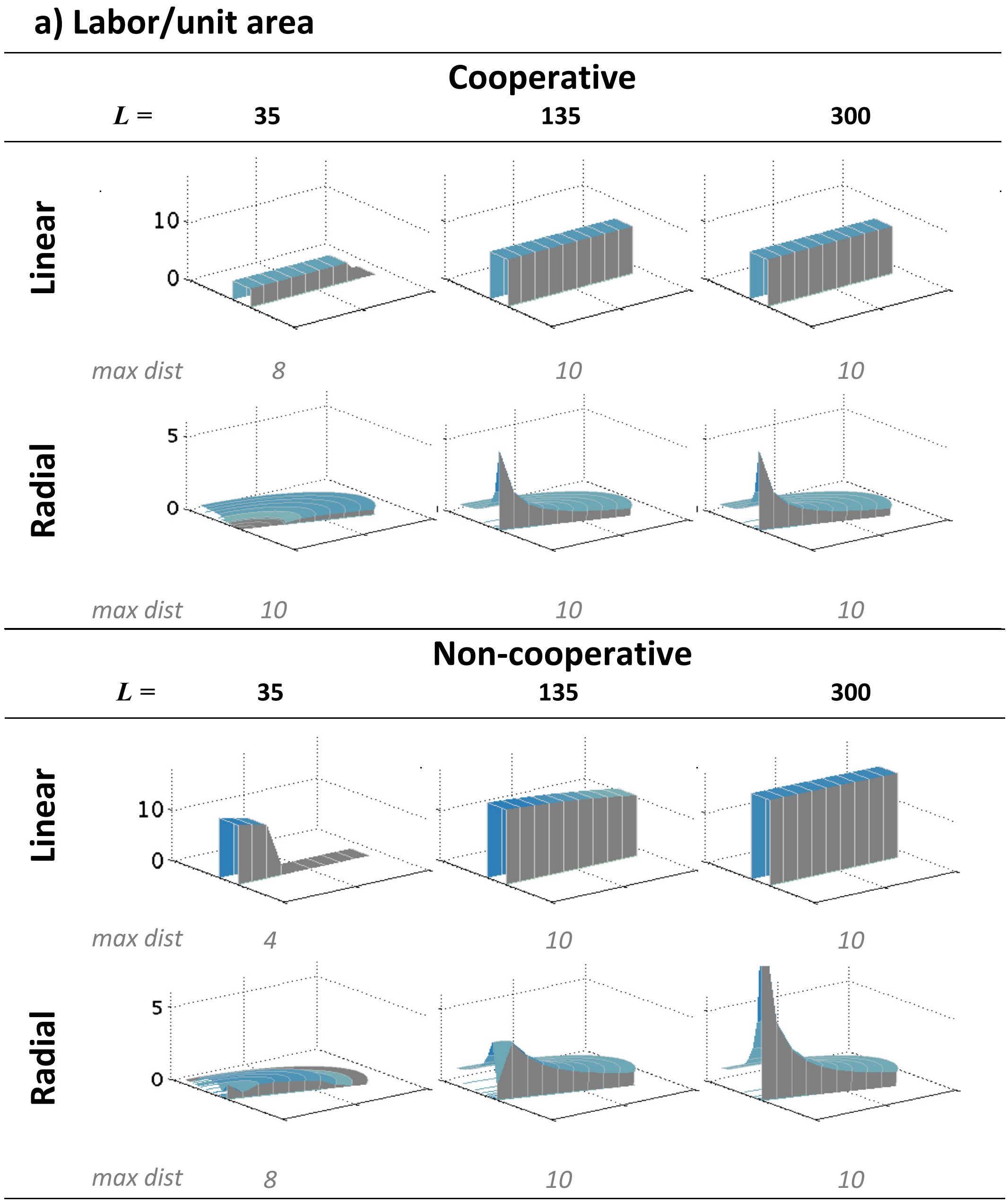


FIG. 4. Within-forest distribution of labor per unit area (a) and profit per unit labor (b). In the linear model, cooperatively managed per-unit labor (a) is always constant, while non-cooperative labor decreases with distance. In the radial model, per unit-area labor generally decreases at a decreasing rate with distance into the forest. In both models, there is always a higher intensity of labor in non-cooperative vs. cooperative situations. When a community is small relative to the forest ($L = 35$), cooperative management is less intense but allocates labor further into the forest. Profits (b) under cooperative management always dominate non-cooperative earnings, but when a community is small, non-cooperative cases can still earn positive profits. In zero-rent cases, nearer patches are harvested at a loss and balanced by profitable harvests in patches further away.

with decreasing levels of a harvester's opportunity cost of time.

The aggregate effect of community and forest size

The size of the forest can impact community-level outcomes like stopping distance, total labor allocated, and profit, as summarized in Fig. 5. These results effectively show how establishing a conservation buffer or protected area at the outer edge of the forest would affect livelihood and ecological metrics. As in Fig. 4, each column in Fig. 5 reflects the fixed amount of community labor indicated at the top of the column. Each point on a curve represents the result of a model run at for a level

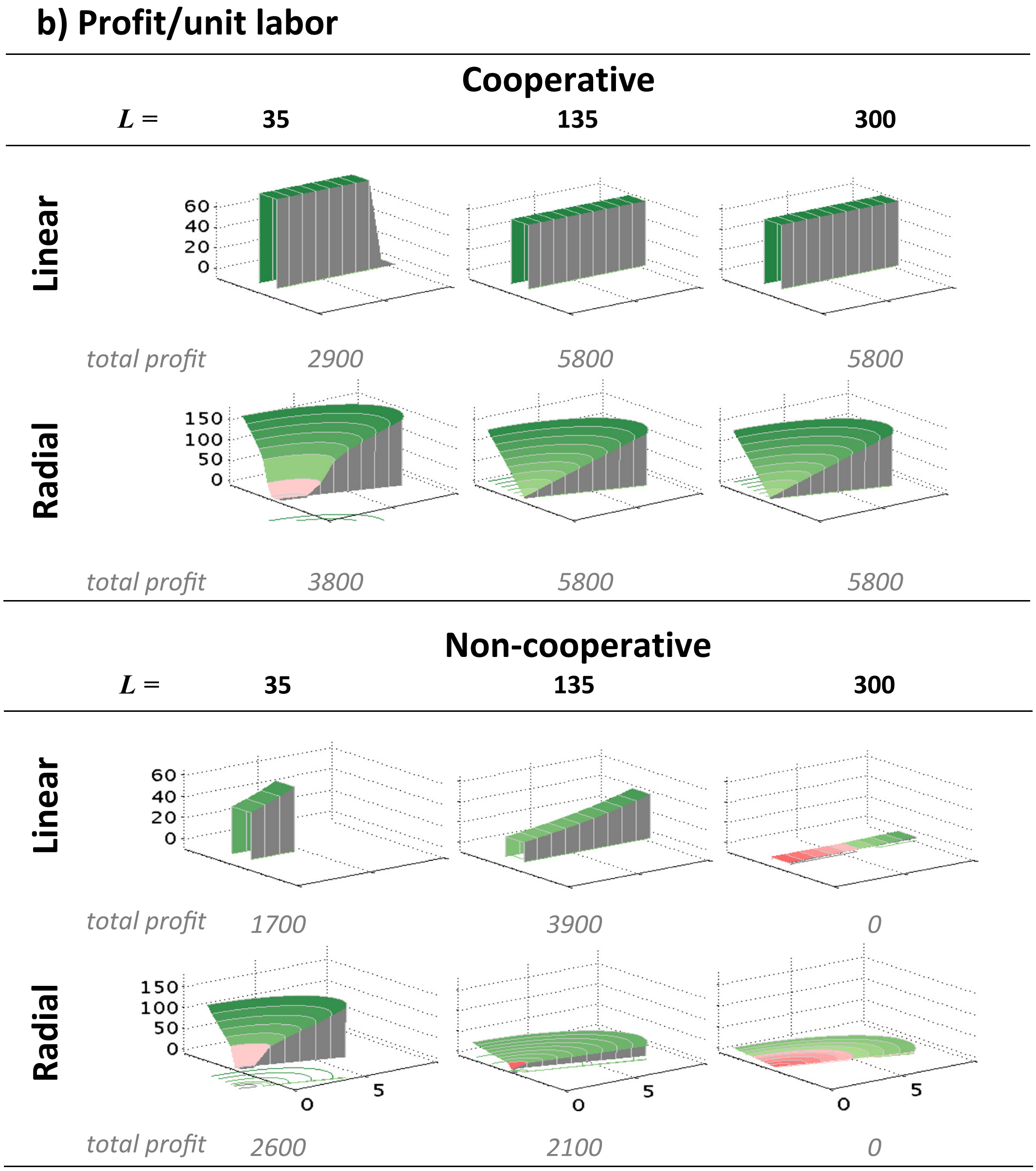


FIG. 4. (Continued)

of community labor L and a forest size as indicated on the x-axis (from $d = 1$ to $d = 10$). For example, all the management and geometry cases predict that a community with a total of 35 units of labor and a forest with a boundary at $d = 5$ will allocate labor all the way to the forest boundary, except in the linear non-cooperative case, which stops at $d = 4$. A summary of the main results follows.

1) Maximum distance. When communities have limited amounts of labor (relative to the forest size), harvesters travel farther in radial than linear forests since the radial model implies less competition for a greater amount of resources as one travels further in the forest. Cooperative harvesters always travel farther than non-cooperative ones.
2) Labor. By definition, cooperative harvesters limit the amount of labor they use to harvest to maximize resource growth (and therefore harvests) over time. Therefore, they never allocate more labor in a system than non-cooperative harvesters. When communities are large (i.e., forest-limited), in the non-cooperative case, villagers have an incentive to participate as long as they can make profits from harvesting. Harvesters exert more labor until reaching the zero-profit condition typical of open access systems. We also see that forest geometry does not affect aggregate labor allocation, which makes sense since total resource

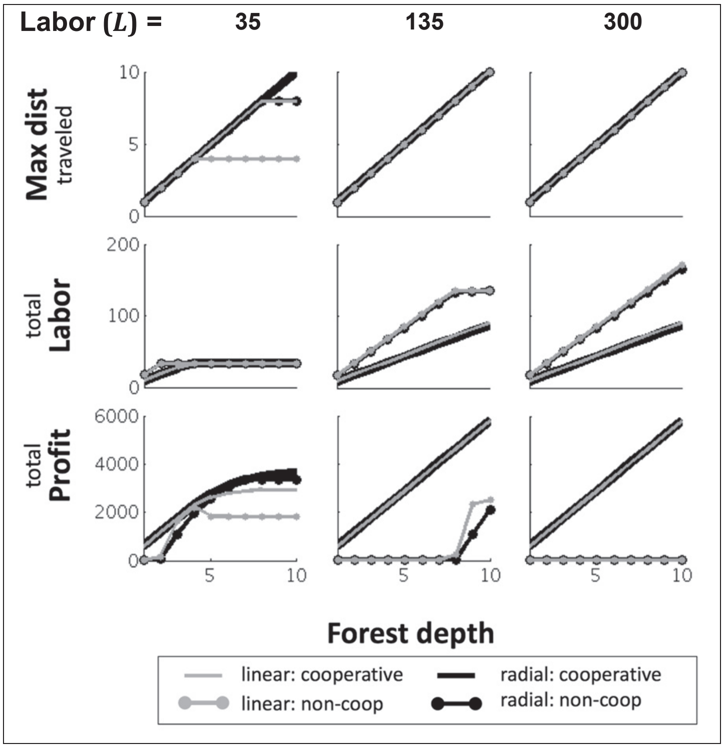


FIG. 5. Total forest travel distance, aggregate labor, and total profits. Each column represents a fixed amount of community labor (L). The nine graphs depict cooperative and non-cooperative outcomes for a range of potential forest sizes (1–10) for the two forest geometries. Each point on a plot is a solution for a forest with a particular set of constraints.

availability is the same in the linear and radial models (and in fact shows that the simulation methods are internally consistent).

3) Profit. In both the linear and radial models, forest-limited cooperative profits increase proportional to the size of the forest, and non-cooperative profits are zero. When communities are labor-limited, however, non-cooperative systems earn positive profits. For instance, the second column in Fig. 5 (L = 135), shows that a non-cooperative community can fully harvest the forest (labor is not constrained) when d = 7, so profits are zero. But in forest size d > 8, competition is not as intense, and earnings are positive. In general, non-cooperative profits are highest when the forest depth d coincides with the patch where the labor constraint first fully binds.

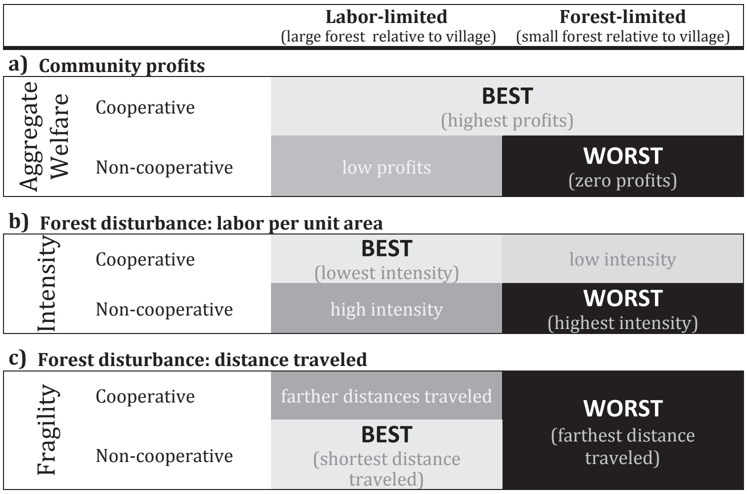
Implications for conservation and livelihoods

Figure 6a compares welfare outcomes from the two management regimes and the labor and distance constraint conditions (qualitatively, the aggregate results presented in Fig. 6 generalize to the linear or radial context). For village welfare, the most fundamental lesson is that even when harvesters are non-cooperative, they still earn profits when the forest is large (they are labor-limited). To be sure, gains could be much greater when a community cooperatively manages harvests, but a forest without spatial restrictions always welfare-dominates the same forest with restrictions.

To link the model's results to other aspects of conservation, I use the patterns of labor distribution as an indication of the level and extent of forest disturbance induced by harvesting. I distinguish between two types of ecosystem services (aside from the products harvested) that forests may provide: ones sensitive to the intensity of human activity and others sensitive to the presence of human activity. As noted above, the former may include impacts on ecosystem function, vegetative and wildlife diversity, and the evolution of species. The latter, simple human presence, has been shown to impact a range of larger megafauna and can negatively affect particularly fragile endemic species or ecosystems. In both cases, harvesting NTFPs, a locally beneficial ecosystem service, can impose externalities on these other regional or global ecosystem services provided by forests that may benefit non-local populations.

With respect to the intensity of harvest activity (Fig. 6b), non-cooperative conditions always result in higher per-area labor compared to cooperative management, yielding greater disturbance. Labor constraints reduce the intensity of activity, suggesting the cooperative labor-limited case yields the best outcome for intensity-sensitive forests.

Figure 6c compares model outcomes with the fragility of forest in mind, where the distance traveled is the metric used to measure negative outcomes. In forests that are small



		Labor-limited (large forest relative to village)	Forest-limited (small forest relative to village)
a) Community profits			
Aggregate Welfare	Cooperative	**BEST** (highest profits)	
	Non-cooperative	low profits	**WORST** (zero profits)
b) Forest disturbance: labor per unit area			
Intensity	Cooperative	**BEST** (lowest intensity)	low intensity
	Non-cooperative	high intensity	**WORST** (highest intensity)
c) Forest disturbance: distance traveled			
Fragility	Cooperative	farther distances traveled	**WORST** (farthest distance traveled)
	Non-cooperative	**BEST** (shortest distance traveled)	

FIG. 6. Model comparison for welfare and ecology for welfare (a), forest disturbance in terms of intensity (b), and forest disturbance in terms of fragility (c). Each cell represents one modeling case. Shaded cells show the outcome relative to other cells. Positive outcomes are shaded lightly; negative outcomes are darker.

relative to the community size, harvesters tend to forage throughout all the forest. In larger forests where communities are labor-limited, cooperative management results in less intense activity, but requires further travel into the forest (see also Fig. 5). Thus, interestingly, cooperative management is uniformly bad for particularly fragile ecosystem services. A lack of local management may provide greater regional and global benefits since non-cooperative conditions keep a larger portion of the forest pristine.

EMPIRICAL SUPPORT

Empirically testing some of the core outcomes of the spatial harvest model presents challenges. First, it is difficult to know whether a village is labor- or distance-constrained in the aggregate, especially since in reality harvesters adopt a range of livelihood strategies based on household-specific preferences, opportunity costs, local market conditions, and other constraints. Second, the researcher would also ideally want to know how resources (in addition to labor) are distributed throughout the forest to judge the profitability of any particular travel path as implied by the model. The data requirements presented by these challenges are difficult to overcome.

Hence, I used individual-level data to see who relies most on particular parts of the forest. Participation in harvesting will certainly vary based on individual characteristics. For example, the analytic model predicts opposite relationships between the distance traveled and harvester's opportunity cost in cooperative vs. non-cooperative settings (see Appendix S1: Part A.III). In a cooperative setting, poorer harvesters travel shorter distances than richer households. The unmanaged case is the opposite: we expect poorer households to travel farther into the forest. Here I use a unique dataset to test this latter prediction.

In the model, households that are poorer vs. better off are indicated by their opportunity cost of time w_i, defined as the value of alternative uses of a harvester's labor. If one's value of labor in some other use is high, then their overall income-earning ability is higher, and these individuals are usually assumed to be better off. Villagers with low opportunity costs are considered to have lower wage-earning potential and are thus often considered poorer.

Yet it is not always clear how we can most effectively measure the opportunity cost of time for quasi-subsistence communities with thin or missing labor markets (Singh et al. 1986) where local residents do not have job opportunities. For individuals that hold off-farm jobs during the harvest season, a good estimate of the marginal opportunity cost of harvesting is their off-farm wage rate. For individuals primarily engaged in agriculture, one common way to estimate opportunity cost is to use a detailed account of households' farm activities to construct an agricultural production function, with which one can estimate the marginal product of labor as an agricultural wage rate (Jacoby 1993, Skoufias 1994). However, the estimated wage rate is an average over the whole growing season and does not easily take into account intraseasonal variation in farm labor, for example, between planting and harvesting times.

Further, the opportunity cost measure only takes into account transitory income and does not consider the wealth status of households. At least since Friedman (1957), economists have argued that expected or permanent income may also be important for explaining how people make consumption, expenditure, and economic decisions. Transitory income can fluctuate and is subject to random shocks, and therefore a single observation may not even be a good indicator of income-earning ability. Household assets, on the other hand, have been shown a more stable

Table 2. Average partial effects from a two-part truncated normal hurdle model

	Distance [S_{ij}, km]		Normalized distance [$S_{ij}/\max(S_j)$]	
Dependent variable	Full sample	Farmers	Full sample	Farmers
ln(wage or farm opportunity cost)	−0.13 (0.35)		−0.008 (0.025)	
ln(farm opportunity cost)		−0.14 (0.32)		−0.009 (0.022)
ln(asset index)	−2.27 (0.59)***	−2.19 (0.57)***	−0.159 (0.040)***	−0.154 (0.037)***
ln(dependency ratio)	−0.65 (0.93)	−0.54 (0.95)	−0.036 (0.064)	−0.030 (0.067)
ln(years harvesting)	0.57 (0.29)*	0.59 (0.32)*	0.035 (0.017)**	0.037 (0.021)*
Gender (male = 1)	0.52 (0.35)	0.59 (0.38)	0.031 (0.026)	0.034 (0.024)
Years education	0.15 (0.09)*	0.15 (0.08)*	0.012 (0.005)**	0.012 (0.005)**
Age	0.18 (0.08)**	0.18 (0.09)**	0.011 (0.004)**	0.010 (0.005)**
N	690	522	690	522
Number of non-harvesters	385	228	385	228
Number of harvesters	305	294	305	294
Pseudo log-likelihood	−1211	−1038	−370	−228

Notes: Bootstrapped standard errors in parenthesis, and *** $P < 0.01$, ** $P < 0.05$, * $P < 0.10$. All estimates represent $\partial E[S|S > 0]/\partial\theta$, where $\theta = w_{ij}, Y_{ij}, Z_{ij}$, which is the average partial effect conditional on participating in harvesting.

indicator of wealth (Carter and Barrett 2006) as they are not as responsive to short-term fluctuations (Booysen et al. 2008). Asset indices have been shown to be at least as good at predicting nutritional status and welfare as expenditure data in some settings (Sahn and Stifel 2003), and assets have been used in a variety of contexts to explore poverty dynamics (Adato et al. 2006). Therefore, a measure of households' permanent income (via an asset index) may also help explain decision-making in addition to more transitory measures like opportunity cost of time. The analytic model does not include permanent income, but this has a clear relationship with one's value of time. Permanent income should be correlated with one's time value over a longer period and is also aggregated to the household level. Therefore, it is a more stable and longer term average indicator of one's value of time. In the empirical estimations that follow, I take into account both these ways of how we might assess poverty to better understand how resource extraction impacts poorer households.

Data and setting

The data come from a random sample of households from rural villages in northwest Yunnan, China, that were known to collect wild matsutake mushrooms (see village locations in Appendix S2: Fig. S1). The original dataset includes some villages with private rights over forest plots and some with open access to a village commons (i.e., villages were effectively closed systems, but within a village there were no rules on harvest). This analysis is restricted to common-access villages where harvesters are free to pick mushrooms anywhere within the village forest, but non-villagers are not allowed. Including villages with private household forests is not appropriate for this analysis: travel behavior in this case is dictated by the location of a households' forest plot instead of competition among villagers and individual characteristics.

Household surveys collected weekly time budgets and livelihood activity information from each individual within the household during matsutake harvest season. This included how far each harvester typically travels into the forest, detailed information on crops, farm inputs and expenditures, and other off-farm labor activities. After harvesting in the forest, harvesters return to the village market to sell their mushrooms to buyers.

Others have provided greater context on mushroom harvesting in this region (Yeh 2000, Yang et al. 2008, 2009, Robinson et al. 2013), however, it is worth mentioning several factors here. The region falls within an internationally recognized biodiversity hotspot with unique and endemic megafauna, complex ecosystems, and fragile species (Xu and Wilkes 2004). Village forest boundaries are well established and always abut another forest user: another village's forest, a state forest, private forest, or a protected area (Xu et al. 2010). Harvesters almost always travel through the forest on foot. However, for reasons noted, in practice it is difficult to know if communities can be characterized as forest- or labor-limited.

As a measure of opportunity cost (i.e., transitory income), I use the hourly wage from off-farm employment activity for wage earners. For individuals engaged primarily in agriculture, I derive an implied wage rate from farm work from an agricultural production function (following Jacoby 1993). As a measure of permanent income, I construct a household asset index (Filmer and Pritchett 2001, Vyas and Kumaranayake 2006) from a catalogue of the quantity of various durable goods owned by a household.

The dataset contains a cross-section of 690 individuals between the ages of 12 and 65 that harvest matsutake (44%), work on the farm (76%), and/or engage in wage-earning activities (27%). The average harvester engages in far less off-farm work, has a slightly higher implied farm wage (opportunity cost), is more likely to be female, and is about 10 yr younger than then the average non-harvester (Appendix S2: Table S1).

Econometric model

Just over half of the individuals in the dataset do not harvest and thus have zero travel distance. Estimating an ordinary least-squares regression would yield biased estimates due to the truncated nature of the data. In this context a two-part or hurdle model (Cragg 1971) is appropriate: first villagers choose to harvest (a probit model), then they decide how far to travel when searching (a truncated normal or lognormal model). Other potential models for dealing with limited dependent variables include a standard Tobit model and a Heckman sample selection model (although the issue here is not one of selection bias since I am not missing data, but simply observe a corner solution response from a random sample of households; see Wooldridge 2010: p. 697). Appendix S2 compares the results from these models, and I indeed find a truncated normal hurdle model most appropriate for this dataset (although qualitative results from the models are similar). Statistical analyses were performed in Stata 11 (StataCorp 2009).

For the hurdle model, consider a binary variable q that determines whether the travel distance s is zero or strictly positive. When choosing how far to travel in the forest, each villager i in household j appears to follow $S_{ij} = q \cdot S^*_{ij}$, where S^*_{ij} is a continuous latent variable. Thus when an individual participates in harvesting, ($q = 1$), $S_{ij} = S^*_{ij}$. The truncated amount equation looks at how these factors influence the distance one travels into the forest. In the first stage, the problem is to estimate $P(q = 1 \mid \theta)$, the probability that $q = 1$ conditional on observed set of covariates θ. Taking the probability of participation into account, we can then estimate $E(S \mid \theta, S > 0)$ using a truncated normal regression model. An assumption of the two-part model is that q and S^*_{ij} are independent, conditional on explanatory variables θ, but we can include all variables θ in both the first and second-stage equations while allowing the parameters on those variables to freely vary between equations (Wooldridge 2010).

In this case θ contains an individual's opportunity cost w_{ij} or other household Y_j or individual-level factors Z_{ij}. A summary estimation equation can be written as $S_{ij} = \alpha + \beta W_{ij} + \delta Y_j + \gamma Z_{ij} + \varepsilon_{ij}$, where $S_{ij} = 0$ if S^*_{ij} is negative. The results from several specifications of the main truncation equation (conditional on $s_{ij} > 0$) are presented in Table 2. Full results from both first- and second-tier equations are presented in Appendix S2: Tables S2 and S3, along with results from the other models for comparison.

Table 2 presents two specifications of the dependent variable: distance traveled and distance normalized by the maximum harvest distance in each village since village forests are different sizes. The table also gives results based on two samples: the full population sample and an estimation that excludes wage-earners so that I look at farmers only. All values are the average partial effects conditional on $S_{ij} > 0$ from a truncated normal hurdle model. Bootstrapped standard errors are calculated following Burke (2009).

Econometric results

Table 2 shows a negative but imprecisely estimated relationship with the transitory measure of opportunity cost of time. There is also no precise relationship between a household's dependency ratio (the ratio of elderly and children to the number of laborers) and the distance an individual travels in the forest. Although women are more likely to participate in harvesting (see the participation equation estimates in Appendix S2: Tables S2 and S3), there do not seem to be systematic differences in travel distance by gender once a villager decides to harvest.

Across both sets of dependent variable specifications and samples considered, the clearest factor correlated with a harvester's distance traveled is households' asset index, the measure of permanent income or wealth. The results from the full sample in the raw distance model implies that, at the sample mean, a 10% increase in a harvester's asset index is associated with an approximate decrease in travel distance by 0.21 km ($= \beta \times \ln(1.10)$).

The other variables that have consistent and meaningful associations all have a significant positive effect on the distance traveled. The results imply that, at the mean of the data, a 10% increase in the number of years' experience harvesting is associated with an increase of 0.06 km traveled, and an increase in a year of education and a year of age are associated with approximate increases of 0.15 km and 0.18 km in travel into the forest, respectively.

These results suggest that limiting harvesters' travel distance through spatial forest restrictions may have disproportionate effects on those that are older, more asset-poor, and who have relied on the forest for a number of years. Policies or exclusion zones that restrict activities like NTFP harvesting may place heavier burdens on the most vulnerable members of a community. Although there is evidence that protected areas can also mitigate some market vulnerabilities (Naughton-Treves et al. 2011, Ferraro and Hanauer 2014), the relationships shown here give insight into the potential impacts of establishing such conservation measures.

CONCLUSIONS

In this paper, I propose a model for the spatial harvest of wild products and provide empirical results for factors correlated with harvesters' travel distances. The theoretical model contributes to our understanding of the spatial nature of resource harvest in several ways. First, it flexibly handles distance and labor constraints, at least one of which must be present in real systems. Which constraint is present may be difficult to assess empirically and will depend on the local social, economic, and ecological context: the size of the forest, the number of harvesters in an area, the price of the resource, residents' alternative opportunities, etc. Second, the model incorporates spatial travel and, uniquely, forest geometry. Finally, the institutional context is explicit, and the results show how management can dramatically affect the distribution of harvest labor over space.

The numerical simulation contrasts results from two landscape geometries, highlighting differences in the distribution of labor over space. A linear (one-dimensional) landscape under optimal cooperative management implies constant degradation over space. In the radial (two-dimensional) model, labor allocation declines non-linearly with distance from a village in both the cooperative and non-cooperative cases as harvesters spread out their labor. However, aggregate labor and profit outcomes do not differ appreciably between the two forest geometries.

The model results reveal several trade-offs between managing the area to maximize local welfare from harvesting wild products and other ecological concerns. First, while managing harvest activity (unsurprisingly) improves welfare, it is uniformly bad for other aspects of ecosystems that are sensitive to the presence of human activity, since harvesters use less labor but travel further distances under cooperative management. Alternatively, ecosystem services that are sensitive to the intensity of human activity co-benefit from cooperative management, since these conditions always result in lower harvest intensities relative to a non-cooperative case.

A second trade-off can come from the spatial management of the forests when forest managers restrict areas of the forest where activities take place. For example, World Heritage Sites, UNESCO's Biosphere Reserves, and IUCN protected areas commonly designate limited-activity buffer zones and a no-activity conservation core (Ebregt and de Greve 2000, UNEP and World Conservation Monitoring Centre 2014). The model suggests that while this can limit the extent of forest disturbance, establishing exclusionary boundaries at the forest edge almost surely has a negative impact on community profits from the forest (although it is possible for longer term benefits to be realized through, for example, increased tourism or improvements in other ecosystem services).

The model only explores protected areas at the outer edge of a forest, but it does give some insight into other potential configurations of protected areas. A non-harvestable protected area at the inner edge of a forest (adjacent to the village) would increase the initial travel cost to reach productive forest, and thus reduce the overall harvest profits. However, households with lower opportunity costs should be more willing to absorb this upfront cost of traveling through the protected area to get to harvestable resources since travel is effectively cheaper for them. Alternatively, a protected area in the middle of a forest would be like a productivity desert, increasing the cost of travel around or through those places to get to more distant resources. We need a more complicated model to appropriately assess the patterns of labor distribution in this case, but in general, the overall cost of harvesting would increase and still generally favor those willing to invest more time to get to harvestable resources. Interestingly, while protected areas in general reduce the overall profits from a system, ones that do not limit the extent of the forest (but just increase the cost of harvesting) seem to have a comparatively lower effect on low opportunity cost harvesters.

The empirical results support the idea that the extent of the forest matters for poorer households. Older, poorer individuals rely on resources further from the village, and imposing distance-based restrictions on foraging may place a disproportionate burden on poor and vulnerable populations. In the study population examined here, the measure of opportunity cost did not have a measurable impact on travel distance but the less volatile measure of wealth (via an asset index) did. Opportunity cost is a measure of transitory income, which can fluctuate, is subject to random shocks, and in developing settings, may simply vary with seasonal agricultural activities. Thus, an estimated farm wage rate may be prone to measurement error in ways that a more stable measure of wealth is not.

Fundamentally both new conservation initiatives, which aim to integrate people and human uses into conservation areas (Kareiva 2014), and the more traditional fences and fines protected area strategies (Soule 2013) have roles to play in conservation. But, as this paper shows, we must be conscious of the impacts each of these strategies have on well-being and development options for local populations.

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Supporting Information

Additional supporting information may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1890/14-2483.1/suppinfo

Data Availability

Data associated with this paper have been deposited in Dryad: http://dx.doi.org/10.5061/dryad.26256