CSAE WPS/2006-15

Parks, Buffer Zones, and Costly Enforcement

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February 2006

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Abstract

The reality of protected area management is that enforcing forest and park boundaries is costly and so most likely incomplete, due in part to the pressures exerted on the boundaries by local people who often have traditionally relied on the park resources. Buffer zones are increasingly being proposed and implemented to protect both forest resources and livelihoods. Developing a spatially-explicit optimal enforcement model, this paper demonstrates that there is a trade-off between the amount spent on enforcement, the size of a formal buffer zone, and the extent to which a forest can be protected from illegal extraction. Indeed, given the reality of limited enforcement budgets, a forest manager with a mandate to protect a whole forest may in fact end up doing a worse job than one who is able to incorporate an appropriately sized buffer zone into their management plans that, combined with more effective enforcement of a smaller exclusion zone, provide the appropriate incentives for villagers to extract only in the periphery of the forest, rather than venture further into the forest.

Themes: Renewable Resources: Forestry; Spatial Issues

1. Introduction

Protected areas have been employed throughout economically poor countries with the key aims of protecting biodiversity and ecosystem services. Yet the reality in many countries is that many of these areas are little more than "paper parks", protected in name only. That is, many so-called protected areas in poorer countries are *de facto* open access resources, degraded by extraction, shrinking due to encroachment, a consequence of lack of sufficient funds to enforcement access restrictions (World Bank, 1999). Yet perfectly enforced protected areas may not be ideal either. When provision is not made to take into account the impact of a protected area on nearby communities that are traditionally dependent on forest and park resources, people's livelihoods are harmed, often resulting in conflict between villagers and park rangers. Buffer zones, often applied in Integrated Conservation and Development Projects (ICDPs), have a dual aim: both to protect forest resources and to provide resources for nearby local villagers who are excluded from protected areas (Wells and Brandon, 1992). The size of a buffer zone may simply be determined by current conditions such as the availability of land outside a protected area, or by explicit biological and livelihoods consideration.

Despite the increasing attention paid to the importance of buffer zones as part of an integrated approach to protected area management, many parks still lack a legally designated buffer zone. Yet even where formal buffer zones are not a part of a forest or park management plan, *de facto* buffer zones often arise, a consequence of villagers continuing to extract from the periphery of the protected area, albeit illegally. For instance, in Khao Yai National Park in Thailand there is no official buffer zone and most of the park budget is spent attempting relatively unsuccessfully to prevent nearby villagers from entering the park to collect non-timber forest products such as fuelwood and fruits (Albers, 2001).[1] Consequently a *de facto* buffer zone has developed inside the park.

In such situations, park and forest managers might actually manage their overall resource base better if they were to incorporate an appropriately sized buffer zone, the size of which would be influenced by available funds for enforcement effort.[2] A key

1 It not uncommon in Thai parks for there to be no official buffer zone, despite the increasing recognition of a clear need (ONEB, 1990).

2 Placing a buffer zone within a protected area is controversial and may not be possible within existing country laws and regulations. Indeed, some authors define buffer zones explicitly as "areas outside the protected area that are designed to protect parks" (Wind and

driving force behind this conclusion is that distance and enforcement spending can be considered substitutes (Albers, 1998). Both are costly for villagers: distance to reach a resource because there is a time cost; and enforcement because villagers risk being caught and punished if they extract illegally. Hence a wider buffer zone where extraction is permitted, though possibly reducing the size of an inner protected area of forest, reduces the enforcement effort required to protect the forest by increasing the distance cost of getting there.

Motivated by evidence from a number of economically poor countries, this paper develops an optimal enforcement model that is calibrated and solved to demonstrate how the amount available for enforcing protected area boundaries interacts with the optimal size of buffer zone. The model is used to explore, for example, how the width of the buffer zone, the extent of degradation in the buffer zone, and villagers' opportunity costs of labour, influence the pressure placed on forest boundaries and hence the enforcement effort required to protect a particular area of forest.

In contrast to other perspectives on buffer zones, this paper argues that the size of a formal buffer zone should be influenced by the reality of protected area management – that enforcing boundaries is costly and so most likely incomplete, due to the pressures exerted on the boundaries by local people who often have traditionally relied on the park resources but are excluded once a protected area is introduced. This paper suggests moreover that forest managers with a mandate to protect a whole forest may in fact end up doing a worse job than those who are able to incorporate an appropriately sized buffer zone into their management plans that, combined with more effective enforcement of a smaller exclusion zone, provides the appropriate incentives for villagers to extract only in the periphery of the forest, rather than venture further into the forest. That is, there is a trade-off between the amount spent on enforcement, the size of the formal buffer zone, and the extent to which a forest can be protected from illegal extraction.

This paper also considers how the size of a buffer zone can influence conflict between those responsible for protecting a forest or park and those who rely on resources within the protected areas, and whether there are trade-offs between

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Prins 1989). However, more recently, definitions of buffer zones have come to recognize that a buffer zone may be "any area, often peripheral to a protected area, inside or outside, in which activities are implemented or the area managed with the aim of enhancing the positive and reducing the negative impacts of conservation on neighbouring communities and of neighbouring communities on conservation" (Wild and Mutebi, 1996; Ebregt and de Greve, 2000).

reducing conflict and increasing resource protection. These conflict interactions can be particularly tricky if, as is often the case, the ranger lives in the same village or locale as the villagers who are extracting illegally, or if the villagers are themselves responsible for the resources, as is often the case for participatory forest management. As Dixon and Sherman (1990, p.198) note, although penalties and monitoring will always be needed to enforce regulations, policies that rely "solely on strict enforcement are not possible without unacceptably high social costs."

Enforcement in practice

When forest resources need protecting, those responsible, whether government departments or village community groups, must determine their protection strategy, which most likely includes a combination of incentives and punishments – "carrots" and "sticks". Indeed, even where forest management involves cooperation or joint management with local villagers, enforcement efforts are required, either to ensure discipline among the villagers involved in the cooperative management, or to deter and punish "outsiders" who are not involved. As Clark et al (1995) write: "currently, very few participatory programs have clearly documented a lower incidence of poaching, less fuelwood extraction, etc. as a result of the programs. If participatory projects fail, it may be because, despite the benefit-sharing strategies being used, beneficiaries continue to see greater personal advantage in continuing illegal extractive activities." A clear implication is that enforcement is required, even in more cooperative protected area management regimes.

Enforcement practices in protected areas in economically poor countries vary from non-existent to serious efforts to protect resources, though typically enforcement budgets are low compared with economically richer countries (Brown, 1998).[3] The extent to which enforcement is undertaken may simply be a function of availability of funds, particularly gate receipts, though the extent to which rangers undertake their patrolling activities also depends on their own security, transportation, and remuneration. Funding for enforcement may be provided externally, or particular protected areas may be expected to raise their enforcement budgets through park entrance fees and fines on those caught undertaking illegal activities (Robinson, 2004).

However, despite the variations in levels of funding, enforcement activities tend to be concentrated at the periphery of the protected area, possibly between the forest

[3] A notable exception in sub-Saharan Africa are the Rwandan parks which generated up to US $10 million per year in the 1980s due mainly to the presence of mountain gorillas (Brown, 1998).

and a formal buffer zone if one exists, else between the forest and surrounding villages. Such boundary enforcement is prevalent for a number of reasons: rangers at the boundary are more likely to detect and deter encroachment in addition to illegal extraction; there are relatively easy paths for the rangers to follow; and villagers are more likely to extract from nearer to their homes rather than further into the forest (Albers 1998; Robinson et al, 2002). For example, in Orissa, park guards usually patrol around the forest periphery on their bicycles where there are motorable tracts (personal communications, forest manager, Orissa). In Khao Yai National Park in Thailand most of the park budget is spent on boundary enforcement (Albers, 1998).

In some forests there is little or no scope for a buffer zone, without reducing even further an already too-small forest. For example, in Bwindi Impenetrable Forest, in western Uganda, where approximately half of the remaining 600 mountain gorillas live, villagers already farm up to the boundary of the forest. Permitting a buffer zone would only reduce further the already diminished habitat of the gorillas and hence endanger them further. In these circumstances the forest authority attempts to stop all unauthorised entry into the forest, relying on patrols that spend up to a week in the forest, patrolling mainly at the boundary with the village (personal communication). In these circumstances it may be feasible to prevent villagers from entering the forest as enforcement activities are relatively well funded from tourism receipts.

2. The model

A large number of villagers, possibly with different opportunity costs of labour, live around a forest throughout which a valuable extractable resource is evenly distributed. The forest manager chooses how much of the forest to allocate to a *de jure* buffer zone from which local villagers are permitted to extract, and how much to allocate to an exclusion zone which the forest manager attempts to keep pristine (i.e. with no village extraction).[4] To protect this inner exclusion zone, N rangers patrol at the boundary between the exclusion zone and the buffer zone, such that the probability of the villager being caught is $p(N)$, where $p'(N)>0$ and $p''(N)<0$.[5] Villagers, knowing how much enforcement effort there is, but not exactly where on the boundary a ranger will be at any given time, choose their extraction strategy – whether to risk going into the protected exclusion zone, or to extract only in the buffer

[4] That is, the forest manager can be considered to be taking an integrated approach to protected area management in which the buffer zone is an integral part of the forest management plan.

[5] For ease of analysis, N need not be an integer.

zone (or not at all).[6] That is, in common with much of the law enforcement literature, a Stackelberg interaction is assumed between the forest manager responsible for enforcement, and the villagers who may choose to extract illegally. Finally, assume that villagers can only be punished if they are caught in possession of a good that they have extracted illegally from the exclusion zone (that is, simply being in the exclusion zone of the forest is not illegal).[7] The villagers therefore go into the forest, turn around at some distance, and extract the resource as they move back towards their homes. Extraction is costly for villagers because their time could also be spent undertaking other activities, whether paid labour, on-farm labour, or working in the home.

A villager's optimisation

Let a particular villager have opportunity cost of labour, k_i. Suppose that she walks into the forest at a rate of v seconds per unit distance when she is not extracting, and that she traverses through the forest at a rate of $w_i(x)$ seconds per unit distance on her way back towards her home while extracting (where x is the distance from her home) such that the time spent extracting per unit distance (rather than simply walking) can therefore be written as $(w_i(x)-v)$. Harvest intensity $h_i(x)$ is a function of $(w_i(x)-v)$, given that the longer she spends per unit distance, the more she harvests, or extracts, in that distance. Costs C_i are a function of the total time T_i the villager spends both going into the forest and extracting:

$$h_i(x) = m(x)\left(1 - \frac{1}{(1+\alpha m(w_i(x)-v))}\right) \qquad [1]$$

$$C_i = k_i\left(\frac{1}{\gamma}(T_i+1)^{\gamma} - \frac{1}{\gamma}\right) \qquad [2]$$

The risk-neutral villager maximises the expected returns to extracting, given that there is some probability of being caught at the boundary between the *de jure* buffer zone and the exclusion zone. In this model, assume that if the villager is caught, anything that she has extracted is confiscated, she may incur a fine that is proportional to the amount confiscated, and she must exit the forest without extracting further, even in the buffer zone.

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6 Naturally in practice villagers may observe the rangers patrolling, wait until they have passed, and then enter or exit the exclusion zone (that is, engage in avoidance activities), but the general point remains, that the greater the patrol density, the more likely that these villagers will be caught (alternatively the greater the time cost imposed on the villagers).

7 This assumption simplifies the model without changing substantively the findings.

There are three possible scenarios for the villager's extraction behaviour: (a) she goes into the exclusion zone, thereby risking being caught with extracted resource when she returns home; (b) she turns around just before the enforcement boundary, thereby extracting legally and so not risking being caught; and (c) she turns around before she reaches the enforcement boundary thereby again not undertaking any illegal extraction and hence not risking being caught. These choices are shown schematically in Figure 1.

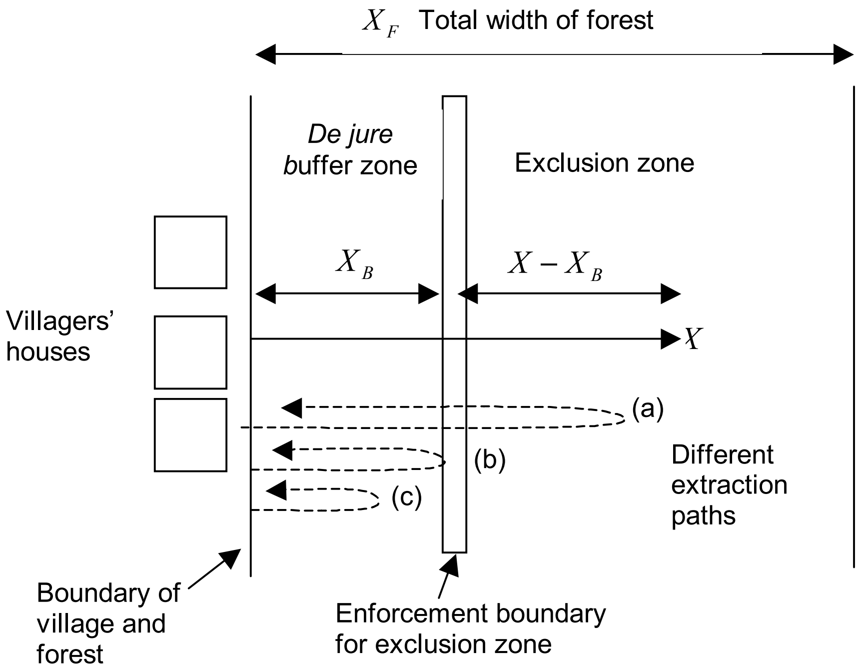

Figure 1: Schematic of spatial elements of model

To determine a villager's optimal strategy it is necessary to determine first where she would choose to turn around in the absence of enforcement effort (Albers, 1998; Robinson et al, 2002). If she chooses to turn around within the buffer zone, then enforcement at the boundary of the exclusion zone will have no impact on her extraction activities – she is unconstrained and scenario c holds. If, when there is no enforcement and so no possibility of being caught, she chooses to turn around in the exclusion zone, then it is necessary to determine whether, once there is enforcement, she would choose to turn around just before the enforcement boundary – scenario b holds – or extract in the exclusion zone and risk being caught – scenario a holds.[8]

Consider scenario a first, in which the villager chooses to extract within the exclusion zone, thereby risking being caught as she leaves this zone. Let the *de jure* buffer zone be width X_B (that is, the width of the official buffer zone – the distance from the village to the enforcement boundary) and the total distance over which the villager extracts (dropping the individual villager subscript i) be X ($X > X_B$). Notice that although the *de jure* buffer zone is defined by where the enforcement boundary is located, the *de facto* buffer zone where extraction occurs is defined by the distance that the villager goes into the forest (X in Figure 1). Recall that the probability of being caught when exiting the exclusion zone is p, where p is a function of the patrol density N. Let the initial resource density in the buffer zone be m_B – constant over distance, and in the exclusion zone is m_E – also constant over distance. Hence extraction intensity will also be constant in each of the zones. If q is the price of the extracted good, and F the fine per unit of the resource the villager is caught, the villager's expected revenues R are therefore:

$$E[R] = \begin{array}{l} (1-p)qm_B\left(1 - \dfrac{1}{(1+\alpha m_B(w_B - v))}\right)X_B \\ +(1-p(1+F))qm_E\left(1 - \dfrac{1}{(1+\alpha m_E(w_E - v))}\right)(X - X_B) \end{array} \quad [3]$$

The first term on the RHS of Equation 3 is the expected returns to extraction in the *de jure* buffer zone, and the second term is the expected returns to extraction in the exclusion zone. The villager's choice variables are X, w_E, and w_B, where w_E is the rate of traversing though the exclusion zone, and w_B through the *de jure* buffer zone.

If the villager is not caught at the enforcement boundary, her time costs comprise walking into the forest, vX, extracting in the exclusion zone, $w_E(X - X_B)$, and extracting in the buffer zone, $w_B X_B$. If she is caught, her time costs differ because she must leave the forest where she is caught at the boundary and cannot extract in the buffer zone. Her total expected time costs can therefore be written:

$$E[C] = pk\left(\frac{1}{\gamma}\left(v(X + X_B) + w_E(X - X_B) + 1\right)^{\gamma} - \frac{1}{\gamma}\right)$$

$$+(1-p)k\left(\frac{1}{\gamma}\left(vX + w_E(X - X_B) + w_B X_B + 1\right)^{\gamma} - \frac{1}{\gamma}\right) \quad [4]$$

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8 Naturally, if there is no buffer zone, the villager chooses either not to extract at all or to extract but risk being caught.

Writing $E[V] = E[R] - E[C]$, the first order conditions are written:

$$\begin{aligned} V_{w_P} &= (1 - p(1+F))m_E{}^2 q\alpha \frac{1}{(1 + \alpha m_E(w_E - v))^2}(X - X_B) \\ &\quad - pk(v(X + X_B) + w_E(X - X_B) + 1)^{\gamma-1}(X - X_B) \\ &\quad - (1-p)k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1}(X - X_B) \end{aligned} \quad [5]$$

$$\begin{aligned} V_{w_V} &= (1-p)m_B{}^2 q\alpha \frac{1}{(1 + \alpha m_B(w_B - v))^2} X_B \\ &\quad - (1-p)k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1} X_B \end{aligned} \quad [6]$$

$$\begin{aligned} V_X &= (1 - p(1+F))m_E q\left(1 - \frac{1}{1 + \alpha m(w_E - v)}\right) \\ &\quad - pk(v(X + X_B) + w_E(X - X_B) + 1)^{\gamma-1}(v + w_E) \\ &\quad - (1-p)k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1}(v + w_B) \end{aligned} \quad [7]$$

Simplifying Equation 5, assuming an interior solution, gives:[9]

$$\begin{aligned} (1 - p(1+F))m_E{}^2 q\alpha \frac{1}{(1 + \beta(w_E - v))^2} &= pk(v(X + X_B) + w_E(X - X_B) + 1)^{\gamma-1} \\ &\quad + (1-p)k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1} \end{aligned} \quad [8]$$

Simplifying Equation 4, assuming an interior solution, gives:

$$m_B{}^2 q\alpha \frac{1}{(1 + \alpha m(w_B - v))^2} = k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1} \quad [9]$$

Similarly, Equation 5 Can be written:

$$\begin{aligned} &(1 - p(1+F))m_E q\left(1 - \frac{1}{1 + \alpha m(w_E - v)}\right) \\ &\quad = pk(v(X + X_B) + w_E(X - X_B) + 1)^{\gamma-1}(v + w_P) \\ &\quad + (1-p)k(vX + w_E(X - X_B) + w_B X_B + 1)^{\gamma-1}(v + w_B) \end{aligned} \quad [10]$$

Conceptually, Equations 8 through 10 are solved simultaneously to determine the equilibrium X, w_E, and w_B. However, analytical solutions to the simultaneous equations cannot be determined for any but the simplest formulations.[10]

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[9] Another solution would be $X = X_B$, but in this case the villager would turn around just before the enforcement boundary (scenario b) and therefore not risk being caught, hence p must be set equal to 0.

If the villager turns around just before the boundary enforcement rather than risk being caught (scenario b), then $X = X_B$ and $p = 0$ and the villager has only one choice variable, w_B, which is the solution to the following equation (see Appendix 1 for details):

$$m_B{}^2 q\alpha = k((v + w_B)X_B + 1)^{\gamma-1}(1 + \beta(w_B - v))^2 \qquad [11]$$

Whether or not villagers choose to enter the exclusion zone is determined by comparing the returns to turning around at the boundary with the returns to going into the exclusion zone for a particular probability of being caught.

If the villager chooses to turn around before the boundary rather than just at its edge (scenario c) there are two choice variables, w_B and X ($X < X_B$). Because this paper focuses on the pressure that villagers place on the boundary of the protected zone, the more interesting situation is that in which the villager is affected by the boundary enforcement and so scenario c is left to Appendix 1.

The forest manager's optimisation

The forest manager can choose the size of the *de jure* buffer zone, how much to spend on enforcement at the boundary, and possibly other indirect options for reducing pressure on the exclusion zone boundary such improving the resource density within the buffer zone.[11] The forest manager aims to maximise the returns to the forested area – both the buffer zone and the exclusion zone, taking into account the costs of enforcement. An "enlightened" forest manager might also take into account the welfare implications for villagers who extract from the forest. However, in this analysis, the impact on villagers is considered separately, then trade-offs are considered between returns to the forest resources, returns to the villagers, and conflict interactions between the forest manager and the villagers. In summary, the forest manager optimises W:

$$\underset{N, X_B}{Max}[W] = Max\{W_X + W_{X_F - X} - cN\} \qquad [12]$$

Where W_X are the returns to the forest resources where extraction occurs and $W_{X_F - X}$ the returns to pristine areas of forest where no extraction has occurred. The

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10 For example, if there is no buffer zone ($X_B = 0$) then explicit analytical solutions can be determined.

11 Assuming boundary enforcement – that is, that people can only be caught entering or exiting the protected zone rather than also while extracting within the zone – rather than what might be termed "area" enforcement simplifies the modelling of enforcement, but it does not detract unduly from the key issues addressed in this paper.

forest manager's valuation of the forest depends on the weight that he attaches to pristine and degraded forest and where and how intensively villagers extract in each of the zones (see, for example, Robinson et al., 2005). At one extreme, if the forest manager only values pristine forest (that is, where no extraction has occurred), then W_X =0. At the other extreme, if he values total biomass (rather than its distribution), then W_X is a function of the total amount harvested by the villagers but not the spatial distribution of that harvest. How he values the forest resources will influence his optimal enforcement strategy.

Explicit analytical solutions to the forest manager's optimisation cannot be calculated for any but the simplest formulations of the model, given the strategic interaction with the villagers' extraction decisions. Moreover, forest managers are typically constrained by limited budgets and specific regulations over where buffer zones can be located (specifically, whether a part of a government forest can indeed be designated an official extraction buffer zone). Hence, rather than focus on a social optimum – which is rarely attainable for forest managers with limited budgets, the following section explores the impact of different sized *de jure* buffer zones and different levels of enforcement spending on forest degradation and villager welfare under a number of conditions.

3. Simulation exercises

To illustrate the key trade-offs faced by the forest manager, a number of simulation exercises are undertaken, varying the size of the *de jure* buffer zone, the amount spent on enforcement, and the extent of degradation within the buffer zone.

Simulation 1: Varying size of buffer zone for a given level of enforcement effort

Consider a fixed number of rangers (for the specific calibration, N =1) patrolling at the edge of the buffer zone and the exclusion zone such that the probability of being caught remains constant wherever the *de jure* buffer zone is located. Assume further that the village is homogenous, comprising villagers with identical opportunity costs of labour, so that one representative villager's patterns of extraction can be considered. Also assume that the resource density is initially the same in the buffer zone as in the exclusion zone (these assumptions will be relaxed and explored later). The width of the buffer zone is then varied from zero (that is, the enforcement boundary is adjacent to the village such that no legal extraction is permitted anywhere in the forest) to 10 units and the corresponding impact on villager well being and forest resources determined.[12] Figure 2 illustrates the impact of varying the width of the buffer zone on villager welfare (the expected returns to the villager), overall levels of extracted biomass (expected total harvest), and the width of the forest in which no extraction occurs (X_F less the distance the representative villager goes into the forest).

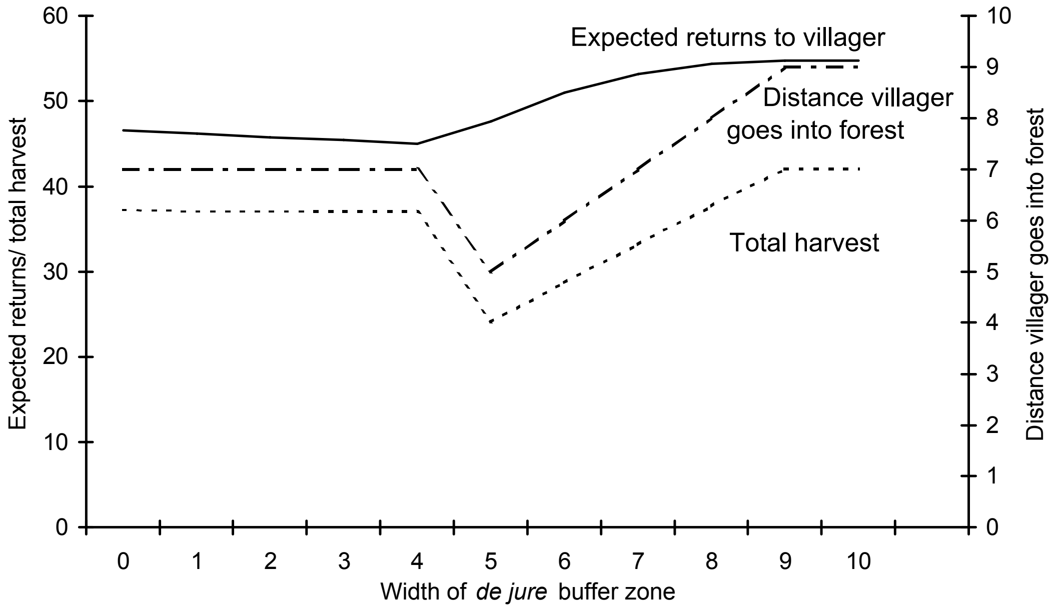

Figure 2: Relationship between width of buffer, size of pristine area, and returns to villagers

Figure 2 demonstrates that if the *de jure* buffer zone is relatively small (up to 4 units wide), the villager chooses to extract in both the buffer zone and the exclusion zone (the distance she goes into the forest shown on the RHS of the graph is greater than the width of the *de jure* buffer zone) – though risking being caught – rather than only in the *de jure* buffer zone. Hence for *de jure* buffer zones of up to 4 units wide, the villager extracts both in the exclusion zone and, if not caught and evicted, in the buffer zone (scenario a). In this case, the width of the buffer zone has little impact on

[12] To solve the model numerically, a discrete version of the continuous distance model is first constructed. In this case, the forest is divided up into 10 equal length strips parallel to the village. The villager's optimisation is solved as an optimal stopping model: the returns to the villager from going each distance 1 though 10 into the forest are calculated for a specific size of buffer zone. The distance that provides the optimal returns is chosen and the corresponding returns and impact on the forest recorded.

the villager's extraction behaviour and hence little impact on the pattern of forest degradation: whether there is no buffer zone or a buffer zone up to 4 units, villagers extract up to a distance of 7 units into the park despite enforcement and the possibility of being caught.

For intermediate sizes of the *de jure* buffer zone (5 to 9 units wide), the villager chooses to turn around just before the exclusion zone – that is, the greater legal access to forest resources due to a wider buffer zone combined with the level of enforcement is sufficient for her to choose to extract from the full width of the buffer zone rather than go into the exclusion zone (scenario b). In these circumstances, the distance of extraction is the same as the width of the formal buffer zone and there is no illegal extraction because the villager chooses only to extract legally within the designated buffer zone.

If the buffer zone is larger than 9 units, the boundary enforcement is no longer binding (and is therefore unnecessary). The villager is unconstrained, choosing to extract only up to a distance of 9 units from her house despite the wider formal buffer zone (scenario c). Because distance is costly for the villager, even without enforcement she does not go any further into the forest. That is, the exclusion zone is protected by distance alone (Albers 1998; Robinson et al, 2002).

In scenario b, the *de jure* and *de facto* buffer zones are the same – defined by patrols (and in practice most likely some physical marker) marking the boundary of the exclusion and the buffer zones. Extraction only occurs in the official buffer zone, and the exclusion zone is fully protected and remains pristine. In contrast, in scenario a, the *de facto* buffer zone is larger than the *de jure* buffer zone – that is, some of the exclusion zone, rather than being protected, is degraded by illegal extraction. In scenario c the opposite holds – the *de facto* buffer zone is in fact smaller than the *de jure* zone.

If the forest manager is concerned with maximising the area of pristine forest for a given level of enforcement effort, then, for a given level of enforcement effort, an intermediate size *de jure* buffer zone may, in fact, be more effective than a larger or smaller buffer zone. This may seem counter-intuitive, but the result is a consequence of the interaction of costly enforcement and spatial considerations (specifically, distance is costly for villagers). When the buffer zone is small, villagers choose to risk being caught rather than constrain themselves in the small legal extraction zone. For intermediate sized buffer zones, the buffer zone is sufficiently large that villagers choose to extract more intensively in the buffer zone rather than more extensively into the exclusion zone with the added risk of being caught, but the buffer zone is sufficiently small that it is still a binding constraint. For the given level of enforcement effort, a *de jure* buffer zone that is 5 units maximizes the area of pristine forest.

Indeed, if the forest manager is concerned with minimising the total amount of biomass extracted, whether from the buffer zone or exclusion zone, then it is also optimal to have an intermediate buffer zone of width 5 units. Again, although perhaps counterintuitive, the logic is similar. If the buffer zone is small, then the villagers choose to go into the exclusion zone risking being caught. And given that they can only be caught at the boundary on the way out, they might as well extract relatively deep into the exclusion zone. In contrast, when the buffer zone is larger, they choose to extract more intensively in the buffer zone rather than risk being caught.

A further benefit of having a buffer zone of width 5, rather than a smaller buffer zone, is that conflict is reduced. When the buffer zone is smaller than 5 units wide, villagers choose to go into the protected zone and some get caught, resulting in conflict between the villager dependent on the resource and the ranger responsible for protecting the resource. These conflict interactions are costly for a number of reasons.[13] First, using official channels to process an individual who is caught illegally extracting is costly and time consuming and diverts effort that could be used for patrolling and deterrence. Second, rangers may give villagers the option to pay a bribe rather than be formally charged. The payment will most likely be less than the formal punishment (though the administration time will be less costly), reducing the deterrence effect of the official enforcement regime, and if the agency relies on fine revenue to supplement its income then this is lost. A third cost that is not always recognised in the literature is that punishment can cause bad will between rangers and villagers. This is especially problematic if the ranger lives in the same village as those extracting illegally. Finally, the ranger’s job can be a dangerous one. Although unusual, it is not unheard of for rangers to be attacked or even killed by people extracting or hunting illegally.

The implications of these finding are that buffer zones can make sense, not only in terms of allowing villagers to extract legally from a part of the forest, but also in terms of protecting a larger area of forest and greater biomass than if, in theory, efforts are made to prevent all extraction. This result occurs because in practice enforcement is costly and so it is unlikely that all extraction can be prevented. If the

[13] Not all of the consequences of these conflict interactions – when a villager is caught – are captured in the model. However, if the forest manager can reduce conflict without compromising protection of the forest resources, then there is an overall improvement.

reality is that some extraction will always occur unchecked, then most likely the best option is to formalise some extraction, and place the enforcement effort where it can deter all extraction in a particular part of the forest.

The above analysis assumes homogeneity of villagers. However, when villagers' opportunity costs of labour vary, then they are likely to choose to go different distances into the exclusion zone, with and without enforcement effort. In this case the forest manager must consider the trade-offs of preventing all extraction in the exclusion zone against accepting illegal extraction by a relatively small number of villager with lower opportunity costs of labour. The forest manager's optimal choice will be strongly influenced by the weight that he puts on pristine, slightly degraded, and more degraded forest resources.

Simulation 2: Determining the "pressure" on the enforcement boundary

The probability of being caught (proportional to enforcement effort and hence enforcement cost) that is necessary to deter a villager from going into the exclusion area can be considered a proxy for the pressure that is exerted on the boundary between the buffer and exclusion zones. That is, the greater the probability of being caught that is required to stop a villager from entering the exclusion zone, the greater can be considered the pressure on the boundary. The pressure on the boundary will be affected by, among other factors, the relative resource density inside and outside the exclusion zone (that is, the extent of degradation within the buffer zone), and the size of the buffer zone.

Figure 3 plots the minimum probability of being caught required to deter a villager from entering the exclusion zone given different widths of the buffer zone and assuming that the resource density is the same inside and outside the exclusion zone. The figure demonstrates clearly that there is a trade-off between the width of the *de jure* buffer zone and the cost of enforcement required to protect fully the inner exclusion zone of the forest – the larger the buffer zone, the smaller the enforcement budget required.

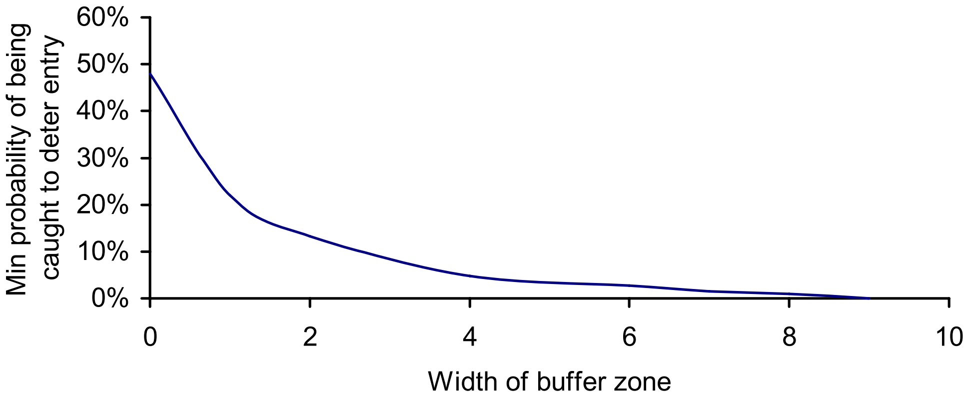

Figure 3: Minimum probability required to deter villager from entering the exclusion zone as a function of the width of the buffer zone

Figure 3 assumes that the resource density is the same in the buffer zone as in the exclusion zone. But in practice the buffer zone is likely to be degraded, thereby changing the pressure on the boundary and hence the enforcement required to protect the exclusion zone. Another exercise is undertaken to show how degradation in the buffer zone affects the enforcement required to prevent entry into the exclusion zone. This is done by fixing the size of the buffer zone (in this case to a width of 3 units) and varying the level of degradation relative to pristine forest (Figure 4).

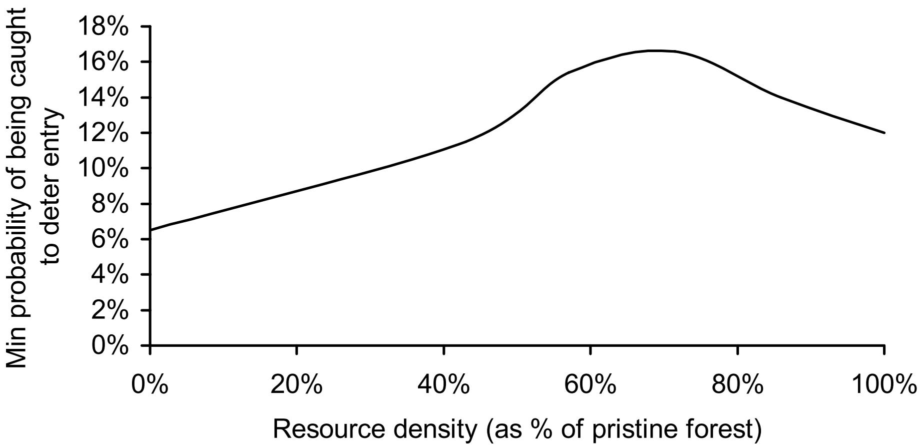

Figure 4: Impact of varying level of degradation in the buffer zone on enforcement required to stop all villagers entering the exclusion zone

Figure 4 demonstrates a distinct non-linearity that can be explained as follows. When the buffer zone is highly degraded, relatively little enforcement effort is required because villagers incur a fixed "distance cost" passing through the buffer zone with very little extraction benefit in return. For less-degraded buffer zones, relatively more enforcement is required to prevent villagers entering the exclusion zone because there are now more extraction benefits to passing through the buffer zone. However, when the resource density in the buffer zone is more than 70% of that of the pristine forest, further increases in resource density actually reduce the enforcement effort required to prevent villagers going into the exclusion zone. In these circumstances, villagers risk more by extracting illegally in the exclusion zone because of the relatively high opportunity cost of not being able to extract in the buffer zone if they are caught.

These findings have implications for policies that advocate enhancing resource densities in buffer zones. When the buffer zone is very degraded, enhancing the resource in the buffer zone may put the protected zone at risk if the enforcement effort is not increased in parallel. That is, degradation of the buffer zone may in fact protect the inner exclusion zone. However, if the buffer zone is less degraded, enhancing the buffer zone further may actually reduce pressure on the boundary thereby reducing enforcement costs. *A priori* it is not possible to predict the impact of a policy intervention that improves resource extraction within the buffer zone.[14]

4. Discussion and policy implications

Buffer zones, peripheral to protected areas, are increasingly being used to enhance the positive and reduce the negative impacts of conservation on local communities, and vice versa (Wild and Mutebi, 1996). This paper demonstrates that, whether outside or within a designated protected area, the decision over the optimal size of a buffer zone be should made in conjunction with the level of enforcement funding available to a forest or park manager in addition to considerations over the impact on villagers' livelihoods. If the decision over the sizing and placing of a buffer zone does not take into account the realities of costly enforcement and the pressures placed on the boundaries of protected areas, a *de facto* buffer zone is likely to arise inside the protected area resulting quite likely in an inefficient allocation of

[14] In common with many other papers, this paper assumes that villagers make a marginal decision over how much to extract and where. However, if villagers have a resource requirement, the results could be similar or the opposite – for example, enhancing the buffer zone could reduce the pressure on the boundary as villagers can more easily extract their requirement from this area, or it could also increase the pressure as villagers sell the excess over and above that required.

enforcement resources and sub-optimal level of resource stock for the given park budget. Yet currently many countries have regulations that do not allow for formal buffer zones to be established within a protected area system (Ebregt and de Greve, 2000). Unless these regulations are relaxed, forest and park managers may be forced to use their enforcement budgets inefficiently, resulting in increased degradation, worsened local livelihoods, and increased conflict.

Buffer zones can also play an important role in reducing conflict between those who are responsible for protecting forest resources and those who have traditionally relied on these resources for their livelihoods. Indeed, this paper has demonstrated that there are situations in which an appropriately sized buffer zone can improve livelihoods, enhance forest resources, and reduce conflict. Although the benefits of reducing conflict are rarely quantified, any actions that reduce conflict without compromising the other aims of a protected area system are likely to be welcomed.

This paper focused on two key instruments that forest managers can use to manage resources within a protected area context – the size of a peripheral formal buffer zone, and the resource density within the buffer zone. However, there are other indirect actions that will influence the buffer zone's effectiveness, such as increasing villagers' opportunity costs of time, changing market access, and alternative sources of forest products (Robinson et al, 2002). Although not explicitly addressed in this paper, the spatial model that has been developed could easily accommodate such possibilities.

Appendix 1

If the villager turns around just before the enforcement boundary (scenario b), she has just one choice variable, w_B. She maximises the following:

$$\underset{w_B}{Max}(V) = \underset{w_B}{Max}\left[m_B q X_B\left(1 - \frac{1}{\left(1 + \alpha m_B\left(w_B - v\right)\right)}\right) - k\left(\frac{1}{\gamma}\left(\left(v + w_B\right)X_B + 1\right)^{\gamma} - \frac{1}{\gamma}\right)\right]$$

Differentiating with respect to w_B gives:

$$m_B{}^2 q\alpha X_B\left(1 + \beta\left(w_B - v\right)\right)^{-2} - kX_B\left(\left(v + w_B\right)X_B + 1\right)^{\gamma-1} = 0 \text{ for an interior solution}$$

If the villager turns around before the enforcement boundary (scenario c) rather than just at the edge of the boundary, she has two choice variables, w_B and X. She maximizes the following:

$$\underset{w_B, X}{Max}(V) = \underset{w_B, X}{Max}\left[m_B q X\left(1 - \frac{1}{\left(1 + \alpha m_B\left(w_B - v\right)\right)}\right) - k\left(\frac{1}{\gamma}\left(\left(v + w_B\right)X + 1\right)^{\gamma} - \frac{1}{\gamma}\right)\right]$$

Differentiating with respect to w_B and X results in the following first order conditions for an interior solution:

$$\alpha m_B{}^2 q\left(\frac{1}{\left(1 + \alpha m_B\left(w_B - v\right)\right)^2}\right) = k\left(\left(v + w_B\right)X + 1\right)^{\gamma-1}$$

$$m_B q\left(1 - \frac{1}{\left(1 + \alpha m_B\left(w_B - v\right)\right)}\right) = k\left(\left(v + w_B\right)X + 1\right)^{\gamma-1}\left(v + w_B\right)$$

These can be solved simultaneously to determine w_B and X:

$$\left(w_B - v\right)\left(1 + \alpha m_B\left(w_B - v\right)\right) = \left(v + w_B\right)$$

Hence $w_B - v = \sqrt{\dfrac{2v}{\alpha m_B}}$ and $X = \left(2v + \sqrt{\dfrac{2v}{\alpha m_B}}\right)^{-1}\left\{\left[\dfrac{\alpha m_B{}^2 q}{k}\left(1 + \sqrt{2\alpha m_B v}\right)^{-2}\right]^{\frac{1}{(\gamma-1)}} - 1\right\}$

References

Albers, H. J. 1998. "Spatial Extraction and Enforcement in Developing Country Protected Areas." draft presented at the World Congress of Environmental and Resource Economists, Venice, Italy (June).

Albers, H. J. 2001. A Spatial-Intertemporal Model for Tropical Forest Management Applied to Khao Yai National Park, Thailand, Resources For the Future Discussion Paper 01–35 (October).

Brown, D. 1998. Participatory Biodiversity Conservation – Rethinking the Strategy in the Low Tourist Potential Areas of Tropical Africa, ODI Natural Resource Perspectives, No. 33.

Clark, C.; Davenport, L.; and Mkanga, P. 1995. "Designing Policies for Setting Park User Fees and Allocating Proceeds among Stakeholders -The Case of Tarangire National Park, Tanzania", a report to the World Bank, October.

Dixon, J.A., and P.B. Sherman. 1990. *Economics of Protected Areas: A New Look at Benefits and Costs.* Covelo, Calif.: Island Press.

Ebregt and De Greve. 2000. "Buffer Zones and their Management: Policy and Best Practices for Terrestrial Ecosystems in Developing Countries", International Agricultural Centre, Theme Studies Series 5, Forests, Forestry and Biological Diversity Support Group, Wageningen, the Netherlands (October).

ONEB. 1990. Nomination of Natural Property to the World Heritage List: Thungyai-Huaikhakhaeng Wildlife Sanctuary. Office of the National Environment Board, Bangkok.

Robinson, E. J. Z.; Albers, H. J.; and Williams, J. C. 2002. "The Influence of Markets and Policy on Spatial Patterns of Non-Timber Forest Product Extraction", *Land Economics* **78**, 260-271.

Robinson, E. J. Z. 2004. "Wanted Dead and Alive: Are Hunting and Protection of Endangered Species Compatible?" Centre for the Study of African Economies Working Paper Series 2004-20, University of Oxford.

Robinson, E. J. Z.; Albers, H. J.; and Williams, J. C. 2005. "Analysing the Impact of Excluding Rural People from Protected Forests: Spatial Resource Degradation and Rural Welfare" Centre for the Study of African Economies Working Paper Series 2005-3, University of Oxford.

Wells, M., and K. Brandon with Lee Hannah. 1992. "People and Parks: Linking Protected Area Management with Local Communities." Washington, DC: World Bank/WWF/USAID.

Wild R.G. and Mutebi, J. 1996. Conservation Through Community Use of Plant Resources. UNESCO People and Plants Working paper, no. 5

World Bank. 1999. *"Paper Parks" Illustrate Magnitude of Threat to World's Forests*, reported in Worldwide Forest/Biodiversity Campaign News, downloaded from website http://forests.org/archived_site/today/recent/1999/resindno.htm.