Context-Dependent Biodiversity Conservation Management Regimes: Theory and Simulations

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Abstract: Ecosystem degradation has motivated a search for successful conservation approaches. The perceived failure of state-directed protected areas in the tropics has prompted experimentation with community management and co-management strategies. Numerous case studies suggest that none of these are effective universally. There exists, however, little analytical or empirical work to identify under what conditions one arrangement will be more effective than another. This paper develops a model of state-dependent equilibrium conservation management design that identifies the comparative advantage of different managers, in the interest of appropriately locating authority for conservation tasks as a function of prevailing biophysical, economic, and sociopolitical conditions.

Keywords: Biodiversity, Comanagement, Community management, Conservation, Contracting

I. INTRODUCTION

Many of the world's ecosystems are in rapid states of decline. The collapse of fisheries, disappearance of tropical rainforests, destruction of coral reefs, and air and water pollution threaten the lives of humans and the other species with which we share the planet. Most of these problems can be attributed to the presence of externalities, which causes a divergence between individually and socially optimal behavior and leads to under-investment in some socially desirable activities and over-investment in other, socially undesirable ones. For example, when individuals lack incentive to consider the benefits that accrue to others from the existence of a common pool resource such as a fish stock, or a public good such as biodiversity, they commonly overexploit the natural resource base. Garrett Hardin famously termed this overexploitation of open access resources "the tragedy of the commons" (Hardin 1968). Since then, much effort has been mounted towards identifying institutions that can change incentives that lead to overexploitation and thereby eliminate this externality problem. Similarly, researchers and policy-makers have explored mechanisms that increase contributions to a public good and discourage free riding.

As the problem of overexploitation of open access resources became clearly recognized, the usual prescription was to turn them over to the state, which would presumably manage these resources for the public good. State control has often meant restricting access through protected areas and national parks. These approaches have a long history of fairly successful conservation in wealthier countries such as the United States and Canada, as well as in some middle-income countries such as South Africa. Similar models were applied to tropical areas throughout the 1950s to 1970s, but have often failed to conserve biodiversity, due to poor enforcement, weak or corrupt governments, and conflicts created between those protecting the park and those requiring use of resources within the park.

The perceived failure of this state-directed “fences and fines” approach to tropical biodiversity conservation has prompted experimentation with a number of alternative approaches. In particular, various forms of community-based natural resource management (CBNRM) and co-management are being hailed as “win-win” situations that meet the needs of both wildlife and human populations and prevent the loss of biodiversity (Getz et al. 1999; Western and Wright 1992). The state-directed approach commonly disregarded the ability of some communities to manage resource use effectively, thereby destroying some functioning traditional management systems (Berkes and Folke 1998; Ostrom 1990). This recognition led to a proliferation of writing about successful cases of collective action, which has in turn fed the current fashion of decentralization and devolution of resource management authority to community groups.

Community-based conservation strategies proceed from the assumptions that local people have intimate knowledge about their environment and if they are given authority over their own resources, they will better protect them. In situations where local residents are the main beneficiaries of maintaining healthy ecosystems (e.g., rangeland grazing, soil conservation, forest woodlots), communities can often be the foundation for effective conservation management (Baland and Platteau 1996). Most international development agencies and conservation organizations now fund “community-based management” or “co-management” projects. At least 60 countries are decentralizing some aspects of natural resource management (Ribot 2002). Despite the appeal of community-based and co-management schemes, numerous case studies suggest that their effectiveness in conserving biodiversity is far from uniform and seems to depend heavily on the biophysical and socioeconomic context of conservation (Agrawal 2001; Barrett et al. 2001; Baland and Platteau 1999; Wells and Brandon 1992; Ostrom et al. 1990).

Some researchers question the utility of the search for a single, universally "best" institutional design for conservation and ask whether different arrangements are perhaps appropriate for different settings (Barrett et al. 2001; Ostrom et al. 1999; Hobley 1996). To date, however, there has been little analytical work that explores how key variables interact and determine when one arrangement will be more effective than another. Some notable exceptions are Skonhoft and Solstad (1996, 1998), who consider when different tools for reducing poaching activity (e.g., changes in probability of detection, size of penalty, prices, property rights) will be appropriate.

Empirical work has been mostly descriptive, with little analytical, much less prescriptive content. Particular case studies consider different factors that affect the success of a conservation approach, thus comparison of cases and testing of hypotheses is difficult, if not impossible (Agrawal 2001; Rasmussen and Meinzen-Dick 1995). Furthermore, context-specific institutional design can be politically unappealing. Mary Hobley writes:

> "As Ostrom (1994) so cogently argues, it is not an either/or situation but an 'and' situation where there are many arrangements that can be accommodated ranging from partnerships between government and local people to complete local control. Using this notion of a continuum there are a variety of institutional arrangements that could be selected according to the particular context. This approach requires site specificity and a high degree of social contextual understanding from the implementing or facilitating organisation. To date, although appealing to

> academics in its recognition of complexity and diversity, it has been resisted by government institutions used to the prescriptive model-based approach to development." (Hobley 1996; p100)

Some valuable work exists on design principles for particular conservation institutions. For example, Ostrom's principles for successful small-scale common pool resource institutions are well-known (Ostrom 1990). Others have proposed conditions for successful protected areas or community-based management schemes (Brandon et al. 1998; Hobley 1996). It is unclear in many of these analyses, however, whether the conditions are necessary or sufficient, whether there is a prioritization of conditions (i.e., can conditions be ranked in terms of their relative impact on success), and whether failure to meet some of the conditions suggests the need for strengthening those aspects, or for a different management approach altogether. A general theory to explain what works best where and why would help practitioners in choosing appropriate conservation designs.

This paper adapts models from the agrarian contracts literature (Bell 1989; Eswaran and Kotwal 1985) to offer a predictive and prescriptive theory of conservation design, in terms of locating authority for specific conservation tasks, as a function of prevailing biophysical, economic, and sociopolitical conditions. The purpose of the paper is to illustrate how different contextual conditions may affect which type of institutional design will be most appropriate, and to provide a simple theoretical framework for beginning to consider these questions in a more rigorous fashion.

We begin in Section II with a presentation of the basic model. Section III specifies functional forms that allow us to obtain closed-form solutions. Section IV presents model solutions and simulations. Section V concludes the paper.

II. THE MODEL

The basic problem of conservation revolves around two issues, (i) the existence of multiple tasks necessary to conserve a natural resource (e.g., resource mobilization, rule enforcement), and (ii) externalities surrounding each of the several activities involved in resource conservation or exploitation. Conservation is not a single act, but a suite of tasks demanding different sets of skills. Who should perform a given task depends, according to the principle of comparative advantage, on agents' relative ability for conducting that activity, which may be conditioned by other exogenous factors (e.g., skill or resource endowments). Just as conservation agents must, collectively if not always individually, perform multiple tasks, so do they have objectives that transcend a unitary focus on conservation. Parties evince different degrees of care about conservation, whether for intrinsic or instrumental reasons. Successful institutional designs for conservation must take into account both differences in parties' interest in conservation and differences in their abilities to undertake the tasks necessary to conserve a resource. Underlying variation in the biophysical, economic, or sociopolitical context can affect these factors, inducing variation in the most appropriate institutional design of conservation.

For the purposes of simplifying a terribly complex reality into a tractable model that highlights the key relationships at play, we consider the case of two agents who must, in some combination, perform two different conservation-related tasks. The agents in the model are "government" and "community." Both community and government welfare vary positively with ecosystem health. Government refers to the national (or local) government and community refers to a unitary composite of individuals who extract resources from the ecosystem at stake.

Of course, in reality communities and governments are composed of many actors with divergent interests and priorities. We abstract from these intra-group politics and co-ordination problems that complicate resource management, although these features can be considered to some degree in our model, as we explain later. Although our categorization is a gross oversimplification of rich socio-political-cultural reality, it will be adequate to illustrate some basic points that apply to contexts in which there are multiple scales of stakeholders in the conservation challenge.

While conservation involves a wide range of activities, in order to present a clear, tractable model of the basic problem we similarly reduce the many tasks involved in conservation to two: financing and management. Conservation financing generates funds necessary to cover the costs of conservation activities (e.g., purchasing equipment for monitoring and enforcement, providing adequate compensation to attract and retain skilled and committed staff, creating infrastructure, or making physical improvements to the ecosystem), preferably from those who benefit from conservation of the ecosystem at stake, i.e., by internalizing the positive externalities associated with conservation. This stylized financing function could also represent nonfinancial contributions such as scientific expertise and training. Management refers to making and enforcing the rules that govern resource use so as to maintain or improve the ecosystem, especially by internalizing the negative externalities associated with resource exploitation. Both these activities consume scarce resources that could be allocated to other desirable activities, so each party would rather the other incur the costs of conservation.

We assume that community members do not receive compensation for participating in conservation activities. Their benefit is derived purely from improving ecosystem health, which in turn increases their marginal productivity of labor in resource extraction. We believe this assumption to be consistent with current practices in community-based conservation, where community members are mainly encouraged to voluntarily participate in management and enforcement activities under the assumption that this will encourage feelings of ownership over the resource and avoid financial dependence on outsiders.

We assume that both agents have different abilities in the two conservation tasks. We represent community financing ability as f_c, community management ability as m_c, government financing ability as f_g, and government management ability as m_g. We assume the government is at least as efficient as community in financing, due to its superior powers of taxation and access to external donors. The community, meanwhile, is at least as efficient as government in management, due to its proximity to the resource, superior information about individual users' activities and the condition of the ecosystem, and lower cost opportunities to sanction undesirable behaviors. Obviously this assumption will not hold in all cases: which agent is more able in which task will vary. The point is that different agents have different abilities, and for the purposes of modeling, we choose a specification that we believe to be plausible for a number of cases, although we make no claims as to the universality of its applicability.

In what follows, it will be useful to think of government and community ability in the two conservation tasks as relative efficiencies. Government is at least as efficient as community in financing: one hour of community financing time is equivalent to only a fraction, f_c/f_g, of government fundraising time. Community is at least as efficient as government in managing: one hour of government management time is equivalent to only a fraction, m_g/m_c, of community management time. Government relative financing efficiency and community relative management efficiency are normalized to one without loss of generality.

The key to the design of the model and to the resolution of conservation externalities lies in recognizing that 1) multiple activities impact ecosystem functioning, from which more than one agent benefits, directly or indirectly, and 2) there exists an externality between the two agents. Neither has incentive to consider the benefits that accrue to the other from a healthy ecosystem. This results in less labor spent on conservation and more labor allocated to resource extraction in equilibrium than is socially optimal. Although the particular instruments used for resource management and enforcement (e.g., individualized resource tenure, social sanctions, fines, credible shoot-to-kill instructions to guards, etc.) and for generating the resources needed to cover conservation costs (e.g., conservation concessions, nonextractive resource commercialization, taxation, etc.) are of great importance, we abstract from those choices in this paper. We concern ourselves only with who performs the task, and not with the instrument(s) they use. We model this as a problem of labor allocation subject to a time constraint, although it could equally be recast as a general resource allocation problem.

The state of the ecosystem, E, depends on the (labor) resources applied to each of our two stylized conservation tasks, as well as on labor applied to resource extraction, and the initial state of the ecosystem:

$$E = E[I, L^f, L^m, L_c^d] \qquad [1]$$

where I is the initial state of the ecosystem , L^f is effective community or government fundraising labor (accounting for the differential abilities mentioned earlier), L^m is effective community or government management labor, and L_c^d is community resource-extractive labor. The state of the ecosystem is increasing in both fundraising and management labor and decreasing in resource-extractive labor. We model fundraising and management labor as affecting the ecosystem directly, for tractability purposes. Fundraising labor generates capital, which can be used to purchase ecosystem-enhancing goods. Assuming capital is generated from labor through a fixed proportions technology and the price of capital is normalized, we can restrict ourselves to modeling L^f. We assume that management labor improves the state of the ecosystem through activities that cause the area to be maintained or improved, for example, restrictions on harvesting technologies or areas that can be harvested. We assume further that management labor decreases the impact of extractive labor on the ecosystem, $\partial^2 E/\partial L_c^d \partial L^m < 0$, for example by causing a shift to less destructive extraction technologies.

Besides allocating labor to conservation tasks, the community uses labor in income-generating activities, L_c^d (resource-extractive labor), and L_c^n (non-extractive labor). Non-extractive labor generates a wage, w^n, and extractive labor generates a product, D (fish, for example), which can be sold in the market at price p^d. We assume that community has access rights to the resource and can thus extract as much as they wish of the product. Management labor, however, limits the effect of the extractive labor on the resource. The resource can be viewed as common property, where all of the community members have property rights to the resource, but management by community or government can limit these rights. It is further assumed that "community" is the only resource-harvester. This is an obvious oversimplification, as outsiders often play a large role in resource-exploitation and exacerbate the difficulties of resource management. Including outsiders in our model, however, would not change the qualitative results under our assumption that the community holds comparative advantage in local management and enforcement of conservation rules. If one were to incorporate exogenous pressure on the ecosystem by outsiders (e.g., through some addition to the L_c^d term, this added cost would merely induce increased management effort by government and community, each according to their comparative advantage.

The production function for the extracted product (e.g., fish) is:

$$D = D[E, L_c^d] \qquad [2]$$

We assume the production function is concave in both inputs, thus there are diminishing marginal returns to extractive labor and ecosystem quality ($\delta D/\delta E>0$, $\delta^2 D/\delta E^2<0$, $\delta D/\delta L_c^d>0$, $\delta^2 D/\delta L_c^{d2}<0$). Extractive labor inputs increase production by more than do ecosystem "inputs" ($\delta D/\delta L_c^d>\delta D/\delta E$). We assume the marginal product of extractive labor is increasing in ecosystem quality ($\partial^2 D/\partial L_c^d \partial E>0$). For example, as there are more fish in the lake, less labor is required for a given catch and the marginal productivity of a given amount of labor is higher. If resources are expended on conservation, thus increasing E, this thereby increases the community's incentive to allocate labor to extractive production at the margin. Hence the externality effects that give rise to the resource management problem.

The community's objective is assumed to be income maximization, where income is[1]:

$$Y_c = w^n L_c^n + p^d D \qquad [3]$$

Community chooses the quantities of labor that maximize its income, subject to the labor constraint:

$$L_c = L_c^d + L_c^n + L_c^f + L_c^m \qquad [4]$$

where L_c is total labor time. This captures the essence of the community's management challenge: given its finite resources on the one hand, and its dependence on the natural resource stock, on the other, is the community best-served by expending scarce resources on various conservation tasks, or can it be better served by leaving this to others or partnering with others by sharing responsibility and authority.[2]

Government provides labor for conservation tasks, L_g^f and L_g^m, and labor, L_g^o, for other government services. We assume it has a limited amount of labor, L_g, which is defined by its budget constraint.[3] Government welfare, which may represent its perceived responsibility to its constituency, is defined over the provision of these other services and the state of the ecosystem[4]:

$$W_g = W_g[E, L_g^o] \qquad [5]$$

We assume a fixed proportions production technology for government services so that provision of government services can be adequately modeled through the choice of L_g^o.

Conservation occurs under one of three possible types of arrangements, or pseudo-contracts, between government and community: the government performs both conservation tasks (government management), the community performs both conservation tasks (community management), or each performs the task in which they have a comparative advantage (co-management). For tractability, we assume complete specialization in the case of co-management. Obviously, in reality conservation contracts lie along a continuum, with many permutations involving other combinations of agents and tasks. However, these three contracts will suffice for illustrating our basic points.

The government offers one of these “contracts” to community, and the community chooses the amount of labor to apply to its various tasks. For example, if the government chooses government management, community will allocate labor between resource extraction and wage labor. If the government chooses community management, community allocates labor between conservation financing, management and resource extraction and wage labor. Note that the community can choose to allocate none of its labor to conservation tasks, which is equivalent to rejection of the contract. For this reason, community participation constraints are not necessary to this model. The government knows the community’s objective function and offers the contract that maximizes its own welfare[5].

The familiar solution technique in such noncooperative game settings is to derive the offeree’s best response function and then to solve the offerer’s optimal contract offer conditional on that known best response (Eswaran and Kotwal, 1985). The first step in solving this particular model is to solve the community's income maximization problem, subject to its labor constraint and obtain optimal community labor allocations conditional on government labor allocations. Then we solve the government's welfare maximization problem, subject to its labor constraint and the community's optimal response. We derive government welfare for each contract case. Government should choose that arrangement offering it the highest level of welfare. Note that in this principal-agent model, the "optimal" contract is therefore that which maximizes government welfare, which is a function of ecosystem health, but not of community income. This could represent the case, for example, of a government agency that has the mandate to protect the environment subject to a budget constraint. No claim is being made that the "optimal" contract is that which is socially optimal.

III. FURTHER SPECIFICATIONS

In order to solve the model, we must specify functional forms. So we let

$$E = I[L^f L^m / L_c^d] \qquad [6]$$

where L^f is effective community or government fundraising labor ($f_c/f_g \, L_c^f$ and L_g^f, respectively) and L^m is effective community or government management labor (L_c^m and $m_g/m_c \, L_g^m$, respectively). This simple representation of the ecosystem is the most parsimonious representation that maintains the key properties that labor allocated to fundraising or management improves the state of the ecosystem, while labor allocated to resource extraction decreases ecosystem quality. We assume a fixed proportions production technology so that changes in E can be readily measured in units of labor.

The production function for the extracted product is Cobb-Douglas:

$$D = E^{\alpha} L_c^{d\beta} \quad \text{where } 0 < \alpha, \beta < 1 , \beta > \alpha \qquad [7]$$

Community welfare is thus defined as $Y_c = w^n L_c^{\ n} + p^d E^{\alpha} L_c^{\ d\beta}$. We assume that at $L_c^{\ d}=0$, the derivative from the right hand side ($\beta p^d E^{\alpha} L_c^{\ d\beta\text{-}1}$) must be greater than w^n, so that the community always chooses a positive level of resource-extractive labor. We define government welfare as

$$W_g = AE^{\chi} + BL_g^{\ o} \qquad \text{where } A>B,\ 0<\chi<1 \qquad [8]$$

Our specification of government welfare obviously disregards the politics inherent in government decisions of what activities it values. Governments have different objectives and different preferences, and these change over time. Any collective choice, however, can be represented in its reduced form, and our objective function could represent a variety of government preferences. For example, the parameters A and χ effectively represent government's relative preference for ecosystem services, the values of which could vary across periods or regimes.

The relative importance of the pattern of comparative advantage and the relative abilities of the two agents is conditioned by exogenous factors such as the scale of the externality, ρ (the degree to which conservation of the resource yields benefits to people outside of the community or government), the size of the ecosystem, η, community instability, σ (weakness of leadership, excessive immigration/emigration, lack of traditional ties, etc.), and government undependability, μ (degree to which outsiders believe government will not use funds for their stated purposes). Without loss of generality, let $\rho \geq 1$ and the other three parameters fall into the closed unit interval [0,1]. These variables have been deemed relevant to the success of community management by a number of studies (Agrawal 2001; Rasmussen and Meinzen-Dick 1995).

We make the following additional simplifying assumptions, which are illustrated in Table 1. The parameter ρ is conceived of as the size of the population interested in conserving this ecosystem or, relatedly, the aggregate willingness to pay of the global population for conservation of the resource. As the scale of the externality increases, both community and government ability in raising funds increases because a larger population derives benefits (perhaps existence or option value) from the resource ($\delta f_i/\delta\rho>0$). Thus it will take less effort per monetary unit raised, on the part of either government or community, to generate funds for conservation when the resource has widespread appeal.[6] We further assume that community ability increases at a decreasing rate ($\delta^2 f_c/\delta\rho^2<0$), as opposed to the government's constantly increasing ability ($\delta^2 f_g/\delta\rho^2=0$), reflecting government's absolute advantage in inducing those outside the ecosystem to contribute to its conservation. This captures the notion that when the size of the externality is small (i.e., locals receive most of the conservation benefit), there is less difference between government and community efficiency in generating resources for conservation than when the size of the externality is large. If the benefits of conservation flow mainly to local resource users (e.g., conserving soil and water on a farmer's plot), then government is unlikely to possess superior capacity to generate the resources necessary to conduct conservation operations. On the other hand, if the share of benefits that accrue to locals from maintaining an ecosystem (e.g., preserving a large tract of biodiverse rainforest) is relatively small, then government may be better positioned to recoup the costs of conserving this ecosystem. The basic idea is that government's comparative advantage in raising conservation funds grows with the share of the benefits from the resource accruing to persons outside the community. All else held constant, a large externality will tend to lead to greater inflow of funds than a small externality, and government will be better able to take advantage of this broader pool of prospective funding.

As the size of the ecosystem increases, government and community management ability both decrease, because size increases the complexity of the task. But this decrease is slower for government, since government's jurisdiction covers a greater area than that of the community ($\delta m_i/\delta\eta<0$, with $\delta m_c/\delta\eta < \delta m_g/\delta\eta$). As government dependability decreases, perhaps due to corruption, incompetence, or political instability, government financing capacity declines ($\delta f_g/\delta\mu<0$). Similarly, as community instability increases, its capacity to make and enforce rules, and thus its management ability, decreases ($\delta m_c/\delta\sigma<0$).[7] The community stability and the government dependability parameters could partly reflect the degree of group heterogeneity, as discussed earlier. For example, a community with many competing interests may be considered as having low cohesion or stability, resulting in a high value of the parameter, σ. Similarly, the presence of individual agendas and rent-seeking behavior in government could be seen as contributing to government undependability, or a high value of the parameter, μ.

In accordance with our previously discussed assumptions, we assume that community financing ability, f_c, equals $\rho^{1/2}$, government financing ability, f_g, equals ρ/μ, community management ability, m_c, equals $1/\sigma\eta$, and government management ability, m_g, equals $1/\eta^{1/2}$. Community relative financing efficiency, f_c/f_g, thus equals $\mu/\rho^{1/2}$, and government relative management efficiency, m_g/m_c equals $\sigma\eta^{1/2}$. Recall that community relative management efficiency and government relative fundraising efficiency are normalized to one.

While this is only a stylized model and the tasks and assumptions about abilities are somewhat arbitrary (though their relative magnitudes appear realistic for many cases), the purpose of this paper is to illustrate that different relative abilities in conservation activities and other contextual variables yield different equilibrium conservation schemes. This basic point holds regardless of the particular tasks chosen or the assumptions about who is more efficient at what task. The results we present in the next section are directly related to the particular functional forms chosen, but the qualitative patterns that emerge are generalizable and important. In what follows, we therefore emphasize only the qualitative results; the particular numerical values convey no real information.

IV. MODEL SOLUTIONS AND SIMULATIONS

We now solve the principal-agent optimization problems for the three possible conservation "contracts."

Contract Option #1: Government Management ($L_g^f>0$, $L_g^m>0$, $L_c^f=0$, $L_c^m=0$)

Under this contract, the community's income maximization problem becomes:

$$Max\ Y_c = w^n L_c^n + p^d E^{\alpha} L_c^{d\beta} \qquad [9]$$

$$s.t. \quad L_c = L_c^d + L_c^n$$

$$E = I[L_g^f(\sigma\eta^{1/2})L_g^m / L_c^d]$$

Solution of the first order necessary conditions yields community optimal labor allocations and maximal community income under government management.[8]

$$L_c^{d}* = \left[\frac{w^n}{(\beta-\alpha)p^d I^{\alpha} L_g^{f\alpha}(\sigma\eta^{\frac{1}{2}})^{\alpha} L_g^{m\alpha}}\right]^{\frac{1}{\beta-\alpha-1}} \qquad [10]$$

$$L_c^{n}* = L_c - \left[\frac{w^n}{(\beta-\alpha)p^d I^{\alpha} L_g^{f\alpha}(\sigma\eta^{\frac{1}{2}})^{\alpha} L_g^{m\alpha}}\right]^{\frac{1}{\beta-\alpha-1}} \qquad [11]$$

$$Y_c{*} = \; w^n L_c^{n*} + p^d I^\alpha L_g^{f\alpha} (\sigma\eta^{\frac{1}{2}})^\alpha L_g^{m\alpha} L_c^{d*\beta-\alpha} \qquad [12]$$

Knowing this best-response labor allocation rule, government then solves its own welfare maximization problem:

$$Max\ W_g = AE^\chi + BL_g^{o} = \qquad [13]$$

$$s.t. \qquad E = I[L_g^f \sigma\eta^{1/2} L_g^m / L_c^{d}{*}]$$

$$L_g = L_g^f + L_g^m + L_g^o$$

Solution of the first order necessary conditions yields government optimal labor allocations and maximal welfare under government management:

$$L_g^f{*} = \left[\frac{[B(\beta-\alpha-1)]^{\beta-\alpha-1} w^{n\chi}}{[A\chi(\beta-1)]^{\beta-\alpha-1} (\beta-\alpha)^\chi p^{d\chi} (I\sigma\eta^{\frac{1}{2}})^{\chi(\beta-1)}} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}} \qquad [14]$$

$$L_g^m{*} = \left[\frac{[B(\beta-\alpha-1)]^{\beta-\alpha-1} w^{n\chi}}{[A\chi(\beta-1)]^{\beta-\alpha-1} (\beta-\alpha)^\chi p^{d\chi} (I\sigma\eta^{\frac{1}{2}})^{\chi(\beta-1)}} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}} \qquad [15]$$

$$L_g^o{*} = L_g - 2 \left[\frac{[B(\beta-\alpha-1)]^{\beta-\alpha-1} w^{n\chi}}{[A\chi(\beta-1)]^{\beta-\alpha-1} (\beta-\alpha)^\chi p^{d\chi} (I\sigma\eta^{\frac{1}{2}})^{\chi(\beta-1)}} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}} \qquad [16]$$

$$W_g{*} = BL_g + AI^\chi (\sigma\eta^{\frac{1}{2}})^\chi \left[\left[\frac{B(\beta-\alpha-1)}{A\chi(\beta-1)}\right]^{2\chi(\beta-1)} \left[\frac{w^n}{(\beta-\alpha)p^d}\right]^\chi \left[\frac{1}{I\sigma\eta^{\frac{1}{2}}}\right]^{2\chi^2(\beta-1)=\alpha\chi} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}}$$

$$-2B \left[\left[\frac{B(\beta-\alpha-1)}{A\chi(\beta-1)}\right]^{\beta-\alpha-1} \left[\frac{w^n}{(\beta-\alpha)p^d}\right]^\chi \left[\frac{1}{I\sigma\eta^{\frac{1}{2}}}\right]^{\chi(\beta-1)} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}} \qquad [17]$$

Once we have repeated this exercise for the other two possible contracts, we can compare W_g* under each arrangement to establish which conservation contract best serves government's interests. In general, there is no unambiguous ordering possible between the maximal government welfare attainable under each of the contracts. The equilibrium conservation contract depends fundamentally on the context, as captured by the model's parameters. The optimization problems for the other two cases are as follows. We leave detailed presentation of contracts 2 and 3 to the Appendix.[9]

Contract Option #2: Community Management ($L_g^f=0$, $L_g^m=0$, $L_c^f>0$, $L_c^m>0$)

If the government offers community this contract, then the community's income maximization problem can be represented as:

$$Max\ Y_c = w^n L_c^n + p^d E^\alpha L_c^{d\beta} \qquad [18]$$

$$s.t. \quad L_c = L_c^d + L_c^n + L_c^f + L_c^m$$

$$E = I[(\mu/\rho^{1/2}) L_c^f L_c^m / L_c^d]$$

Government uses the community's known optimal choice of L_c^d*, L_c^f*, and L_c^m* to solve its own welfare maximization problem:

$$Max\ W_g = AE^\chi + BL_g^o \qquad [19]$$

$$s.t. \quad E = I[(\mu/\rho^{1/2}) L_c^f* L_c^m* / L_c^d*]$$

$$L_g = L_g^o$$

Contract Option #3: Co-Management ($L_g^f>0$, $L_g^m=0$, $L_c^f=0$, $L_c^m>0$)

In this final of the three contractual options facing government, the community's problem becomes:

$$Max\ Y_c = w^n L_c{}^n + p^d E^\alpha L_c{}^{d\beta} \qquad [20]$$

$$s.t. \qquad L_c = L_c{}^d + L_c{}^n + L_c{}^m$$

$$E = I[L_g^f L_c{}^m / L_c{}^d]$$

The government's problem and its optimal choices and maximal welfare conditional on these community best-responses are:

$$Max\ W_g = AE^\chi + BL_g{}^o \qquad [21]$$

$$s.t. \qquad E = I[L_g^f L_c{}^m{*}/L_c{}^d{*}]$$

$$L_g = L_g{}^o + L_g^f$$

Government chooses the contract that maximizes its welfare. Gathering together the results from the optimization problems, government welfare under the three types of contracts is as follows:

1. government management

$$W_g{*} = BL_g \ + AI^\chi (\sigma\eta^{\frac{1}{2}})^\chi \left[\left[\frac{B(\beta-\alpha-1)}{A\chi(\beta-1)}\right]^{2\chi(\beta-1)} \left[\frac{w^n}{(\beta-\alpha)p^d}\right]^\chi \left[\frac{1}{I\sigma\eta^{\frac{1}{2}}}\right]^{2\chi^2(\beta-1)=\alpha\chi} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}}$$

$$-2B\left[\left[\frac{B(\beta-\alpha-1)}{A\chi(\beta-1)}\right]^{\beta-\alpha-1} \left[\frac{w^n}{(\beta-\alpha)p^d}\right]^\chi \left[\frac{1}{I\sigma\eta^{\frac{1}{2}}}\right]^{\chi(\beta-1)} \right]^{\frac{1}{2\chi(\beta-1)-(\beta-\alpha-1)}} \qquad [22]$$

2. community management

$$W_g{*}= \ BL_g + A\left[\frac{\alpha^{\beta-\alpha-1} w^n (I\mu \big/ \rho^{\frac{1}{2}})^{(\beta-1)}}{p^d(\beta-\alpha)^{\beta-\alpha}}\right]^{\frac{\chi}{\alpha+\beta-1}} \qquad [23]$$

3. co-management

$$W_g{*}= BL_g + \left[\frac{(\beta-\alpha)^{\chi}B^{\chi}}{\alpha^{\chi}\chi^{\chi}I^{\chi}A}\right]^{\frac{1}{\chi-1}} - \left[\frac{(\beta-\alpha)^{\chi}B^{\chi}}{\alpha^{\chi}\chi I^{\chi}A}\right]^{\frac{1}{\chi-1}} \qquad [24]$$

One can now readily determine which contract will be chosen at different relative efficiencies subject to any particular set of starting values. For what follows, we use a base case where $I= 2$, $w^n = 1$, $p^d = 2$, $L_c= 1$, $L_g= 1$, $A = 1.4$, $B = 1$, α=0.1, β=0.4, and χ=0.5.

One key point to make is that the equilibrium contract turns fundamentally on the relative efficiency of each party in the two constituent tasks necessary for successful conservation. This can be depicted graphically, as in Figure 1, which partitions the relative efficiency space according to the contract type that prevails, given the base case scenario.[10] These results are not unique to the parameter values; the general pattern results for most choices of values. What does change with different combinations of parameter values, is the switchover point between contracts, a key point which we explore below, and which is presented in Table 2.

When both relative efficiency values are low, meaning there is a great difference in agent efficiency in both tasks, co-management is optimal because specialization according to comparative advantage generates substantial aggregate gains, even though the positive externalities associated with ecosystem quality means neither party enjoys the full benefit of its efforts. This will be the case when both $\mu/\rho^{1/2}$ and $\sigma\eta^{1/2}$ are small, i.e., when government credibility is high and/or the scale of the externality is large, and the size of the ecosystem is small and/or community stability is high.

A co-management scheme that is somewhat representative of our specification of co-management is the Soufrière Marine Management Area in the Caribbean island nation of St.

Lucia. In response to threats to reefs on the west coast of the island of St. Lucia, local fishermen, hoteliers, dive operators, government agencies, and community groups negotiated an agreement to form the Soufrière Marine Management Area. Management activities are primarily carried out by a community-based local NGO (the Soufrière Regional Development Foundation, SRDF), with technical assistance from the Department of Fisheries. The SRDF is comprised of representatives of all major stakeholders and makes decisions about rules in the area. External funding has been provided by USAID (through the Government of St. Lucia ENCORE project), the French government and the Caribbean Conservation Association. In this case, the size of the protected ecosystem is fairly small (fringing coral reefs along 10km of coastline), government credibility is fairly high, the scale of the externality is large (coral reefs provide tourism opportunities, ecosystem services, as well as local benefits such as fishing), and the community, although not necessarily homogeneous or stable, seems to have its various interests represented effectively by the SRDF (SMMA 2003; Brown and Pomeroy 1999; Pomeroy 1999).

Through specialization, co-management exploits the comparative advantage of each party in a given task. However, co-management will not always be optimal, due to the externality problem inherent in this approach. Since agents only consider their private return from their contribution of conservation labor, they will provide less labor than is socially optimal. Government and community both want to free ride under co-management, but since they both value ecosystem quality, there is a limit to their willingness to free ride. If their free riding entails enormous losses of ecosystem health (as in the case when the other party's relative efficiency equals zero), then the gains from free riding are, under the relatively mild modeling assumptions imposed, excessive relative to the costs. But as the efficiency differences between the two parties lessen and the gains from specialization decrease, then it may become optimal to move towards a system where one agent performs both tasks.

As government becomes less efficient at fundraising, i.e. $\mu/\rho^{1/2}$ increases, but community is still relatively efficient at managing, i.e. $\sigma\eta^{1/2}$ is low, community management becomes optimal. This will be the case when government credibility is low and/or the scale of the externality is small, and the size of the ecosystem is small and/or community stability is high. An example of this could be found in some community forestry schemes in Nepal. For example, the Kamal Nahar Forest User Group (FUG) in Haththipur in the Terai Region of Nepal was made responsible for the 'development, conservation and utilization' of a national forest in 1997. Although the ownership of the forest land remains with the state, the FUG is responsible for all management of the area. Some user groups receive external funding for community forestry, but in Haththipur the village residents pay the costs of management and they feel that the benefits will eventually outweigh these costs. In this case, the size of the ecosystem is small (canal side plantation of 5.5 ha), the scale of the externality is small (the "forest" is of little value to anyone outside the community), government credibility is somewhat low, and community stability is fairly high (the community is fairly homogeneous and well-organized, and in-migration is low and confined to nearby villages) (Chakraborty et al. 1997).

As community becomes less efficient at managing, i.e. $\sigma\eta^{1/2}$ increases, but government is still relatively efficient at fundraising, i.e. $\mu/\rho^{1/2}$ is small, government management becomes optimal. This will be the case when government credibility is high or the scale of the externality is large, and the size of the ecosystem is large and/or community stability is low. This could represent the case of the United States, for example, where the system of national parks financed and managed by the central government has been relatively successful for ecosystem protection. In this case, government credibility is high, the scale of the externality is fairly large (national parks benefit Americans and others with recreation opportunities and ecosystem services), the size of the ecosystem is often fairly large (e.g., Yellowstone), and community stability is fairly low (there is substantial migration within the U.S.).

While the basic pattern described above will result quite generally, the point of switchover from one contract to another depends on the levels of the other parameters, i.e., on other elements of the biophysical, economic, and sociopolitical context of conservation. Thus, as the values of the parameters of the model are changed, the contract space changes from that depicted in Figure 1. So whether government management or community management or co-management is optimal depends not only on the relative efficiency of the parties in the two tasks, but also on other exogenous factors that help to define the context. We conducted simulations on the critical values and found several interesting results, which are discussed below and presented in Table 3. Note that some of these results are sensitive to the range within which the parameter of interest is varied. In all figures, the solid lines represent the base case scenario from Figure 1, to permit easy comparison.

We first consider a change in p^d, the market price of the exploited resource. At low levels of p^d, government management prevails. Figure 2 demonstrates this result with p^d=1.7. A falling market price for the extracted resource, relative to the wage rate for non-extractive labor, gives community less of an incentive to invest in the environment, since extractive labor is yielding relatively lower returns. It instead prefers to allocate most of its labor to non-extractive activities and receive wages w^n. Thus unless community is highly efficient in management, relative to government, government chooses to perform the conservation activities itself to ensure that an adequate amount of labor is allocated to conservation. As the value of p^d decreases even further, community management (as well as co-management) drops out of the picture, and government becomes the sole provider of labor for conservation tasks. On the other hand, when p_d rises, community prefers to allocate its labor to resource extraction, thus they will value ecosystem quality more highly (since returns to extractive labor depend positively on the state of the ecosystem) and will choose to allocate high levels of labor to conservation management and fundraising. Government thus becomes assured of a relatively high level of ecosystem quality, and can allocate its labor to providing other services. Figure 2 shows how the area covered by government management diminishes. In this case (p^d=2.3), community management dominates the scene. At higher levels of p^d, the contract space is covered entirely by community management.

These results may seem counterintuitive in the context of standard open access resource models, which typically show that price increases fuel greater exploitation, implying that greater management is required to maintain the stock. Therefore one might not expect government to turn management over to communities. In our model, however, as prices increase, community not only exploits more, it also has a greater interest in maintaining the more valuable stock. Any individual should have the incentive to harvest more under higher prices, but the community has the ability to regulate and manage harvest under the common property assumptions underpinning our model.

We now consider a change in A. This effectively represents the relative importance the government places on protecting ecosystem quality. At low levels of A, community management prevails. Figure 3 shows that at A=1.3, community management covers most of the contract space, with government management and co-management only occurring when community is highly inefficient in fundraising. As A decreases further, community management covers the entire contract space. On the other hand, as A increases, the area covered by community management and co-management diminishes, to be replaced by government management. Figure 3 illustrates this result with A=1.6. When government cares relatively little about ecosystem quality, it is less willing to provide conservation management and fundraising labor and turns these responsibilities over to community. As government becomes more interested in providing a high quality of environment, however, it takes over these responsibilities, to ensure the level of ecosystem quality it desires.

At low levels of I, the initial quality of the ecosystem, the contract space is dominated by community management. This can be seen in Figure 4 for I=1.4. As I increases, however, government management prevails. Figure 4 shows these results for I=2.6. This can be explained in that as I increases, the ecosystem is more valuable so government takes over conservation responsibilities to ensure it is protected.

Devolution of state conservation authority and responsibilities should thus not necessarily be taken as a sign of government commitment to conservation, as some CBNRM advocates suggest. As this simple model demonstrates (through the variations in A and I), it might instead signal state abdication of responsibility due to disinterest. Michael Dove argues that the resources over which communities are granted authority are often those resources with no other claimants. He argues that "today's search for 'new' sources of income for 'poor forest-dwellers' is often, in reality, a search for opportunities that have no other claimants – a search for unsuccessful development alternatives " (Dove 1993). For example, community forestry in Nepal began with the Department of Forests handing over to communities land that was either barren or covered by degraded forests, with the objective of aforestation (Hobley 1996). Furthermore, devolution may simply be politically or economically attractive to governments by passing on the costs of conservation to the poor in the name of participation and self-help

(Hobley 1996).

The simulations discussed above illustrate that the optimal biodiversity conservation contract is context-dependent. Even in such a parsimonious model as the one developed here, the equilibrium contract proves a complex function of interacting parameters describing the biophysical, economic and sociopolitical setting. Cross-sectional externalities and heterogeneity in skill at performing essential conservation tasks generate predictable variation in the optimal conservation management regime that seems to correspond reasonably well with observed patterns.

V. CONCLUSIONS

This paper illustrates how the choice of conservation management regime is conditioned by a number of contextual and ability-related variables. We model the problem as one of identifying the contract between a government and a community, each of which allocate fundraising and management labor for conservation, that optimally balances the inefficiencies due to the externality inherent in shared enjoyment of a healthy ecosystem against the efficiency gains realizable from skill differences in performing different activities necessary to protect the environment. When both agents are relatively efficient in just one of the essential activities for conservation, then co-management is the equilibrium contract. As the efficiency differences between the parties lessen, it becomes optimal for one or the other party to undertake both activities so as to reduce the externality problems associated with co-management. Whether we should expect a move toward community-based or state-managed conservation depends on the underlying biophysical and socioeconomic context. Changes in exogenous model parameters can induce substantial adjustments in the equilibrium partitioning of relative efficiency parameter space between different arrangements. Seemingly identical relative abilities produce different equilibrium arrangements in different contexts while differing relative abilities often generate different conservation management designs within a single biophysical, economic and sociopolitical context.

The critical relative efficiencies, at which point it becomes desirable to switch from co-management to government or community management, depend on the values of the other model parameters. For example, we saw that a decrease in the market price for the exploited resource leads to switchover to government management at lower levels of government management efficiency than occur at higher prices. The same is true for increases in government value of ecosystem quality. Better understanding of these switchover points could improve the choice of conservation contract design for a given site.

This model offers a strong caution against a one-size-fits-all approach to conservation management and the current fashion of devolution of management authority and CBNRM and co-management schemes without careful consideration of context. The model provides a possible explanation for why the national parks system of government biodiversity conservation may have been effective in the some settings, such as the United States, but not others, such as much of tropical Africa, and why, analogously, community-based conservation has not been uniformly successful.

Enhancements such as allowing intra-community heterogeneity, intertemporal preferences, bargaining between the community and the government over contract terms, and non-linear ecosystem dynamics, may improve the model's predictive and prescriptive power with respect to effective biodiversity conservation management design. But the parsimonious model presented here lays out the basic foundation of a useful predictive and prescriptive theory.

Empirical testing is the most important next step, both to improve the assumptions of the model and to test model predictions. For now, however, this model serves simply to illustrate why the preferred conservation contract may be context-specific. Neither government management, nor community management, nor co-management, is appropriate under all conditions.

VI. APPENDIX: SOLUTIONS TO CONTRACT OPTIONS

Contract Option #2: Community Management (L_g^f=0, L_g^m=0, L_c^f>0, L_c^m>0)

If the government offers community this contract, then the community's income maximization problem can be represented as:

$$Max\ Y_c = w^n L_c{}^n + p^d E^\alpha L_c{}^{d\beta} \tag{25}$$

$$s.t. \qquad L_c = L_c{}^d + L_c{}^n + L_c^f + L_c{}^m$$

$$E = I[(\mu/\rho^{1/2}) L_c^f L_c{}^m / L_c{}^d]$$

Solution of the first order necessary conditions yields community optimal labor allocations and maximal income under community management.

$$L_c{}^d{*} = \left[\frac{w^{n\,2(\beta-\alpha-1)}\alpha^{-2\alpha(\beta-\alpha-1)}}{p^{d\,(\beta-\alpha-1)}(\beta-\alpha)^{-2\alpha(\beta-\alpha)+\alpha+\beta-1}(I\,\mu\big/\rho^{\frac{1}{2}})^{\alpha(\beta-\alpha-1)}}\right]^{\frac{1}{(\beta-\alpha-1)(\alpha+\beta-1)}} \tag{26}$$

$$L_c{}^n{*} = L_c - \left[\frac{w^{n\,2(\beta-\alpha-1)}\alpha^{-2\alpha(\beta-\alpha-1)}}{p^{d\,(\beta-\alpha-1)}(\beta-\alpha)^{-2\alpha(\beta-\alpha)+\alpha+\beta-1}(I\,\mu\big/\rho^{\frac{1}{2}})^{\alpha(\beta-\alpha-1)}}\right]^{\frac{1}{(\beta-\alpha-1)(\alpha+\beta-1)}} \mathbf{-2}\left[\frac{\alpha^{\beta-\alpha-1}w^n(I\,\mu\big/\rho^{\frac{1}{2}})^{-\alpha}}{p^d(\beta-\alpha)^{\beta-\alpha}}\right]^{\frac{1}{\alpha+\beta-1}}$$

[27]

$$L_c^f* = \left[\frac{\alpha^{\beta-\alpha-1} w^n (I\mu / \rho^{\frac{1}{2}})^{-\alpha}}{p^d (\beta-\alpha)^{\beta-\alpha}} \right]^{\frac{1}{\alpha+\beta-1}} \quad [28]$$

$$L_c^m* = \left[\frac{\alpha^{\beta-\alpha-1} w^n (I\mu / \rho^{\frac{1}{2}})^{-\alpha}}{p^d (\beta-\alpha)^{\beta-\alpha}} \right]^{\frac{1}{\alpha+\beta-1}} \quad [29]$$

$$Y_c* = w^n L_c - 3\left[\frac{\alpha^{\beta-\alpha-1} (I\mu / \rho^{\frac{1}{2}})^{-\alpha} w^{\alpha+\beta}}{p^d (\beta-\alpha)^{\beta-\alpha}} \right]^{\frac{1}{\alpha+\beta-1}} + \left[\frac{\alpha^{(\beta-\alpha-1)(\alpha+\beta)} w^{(\alpha+\beta)} (I\mu / \rho^{\frac{1}{2}})^{-\alpha}}{p^d (\beta-\alpha)^{(\beta-\alpha)(\alpha+\beta)}} \right]^{\frac{1}{\alpha+\beta-1}} \quad [30]$$

Government uses the community's known optimal choice of L_c^d*, L_c^f*, and L_c^m* to solve its own welfare maximization problem:

$$Max\ W_g = AE^{\chi} + BL_g^o \quad [31]$$

$$s.t. \quad E = I[(\mu/\rho^{1/2})L_c^f*L_c^m*/L_c^d*]$$

$$L_g = L_g^o$$

Solution of the first order necessary conditions yields government optimal labor allocations and maximal welfare under community management.

$$L_g^o* = L_g \quad [32]$$

$$W_g* = BL_g + A\left[\frac{\alpha^{\beta-\alpha-1} w^n (I\mu / \rho^{\frac{1}{2}})^{\beta-1}}{p^d (\beta-\alpha)^{\beta-\alpha}} \right]^{\frac{\chi}{\alpha+\beta-1}} \quad [33]$$

Contract Option #3: Co-Management ($L_g^f>0, L_g^m=0, L_c^f=0, L_c^m>0$)

In this final of the three contractual options facing government, the community's problem becomes:

$$Max\ Y_c = w^n L_c^{\,n} + p^d E^{\alpha} L_c^{\,d\beta} \qquad [34]$$

$$s.t. \qquad L_c = L_c^{\,d} + L_c^{\,n} + L_c^{\,m}$$

$$E = I[L_g^f L_c^{\,m} / L_c^{\,d}]$$

Solution of the first order necessary conditions yields community optimal labor allocations and maximal income under co-management.

$$L_c^{\,d}{*} = \left[\frac{w^n(\beta-\alpha)^{\alpha-1}}{p^d \alpha^{\alpha} I^{\alpha} L_g^{f\alpha}}\right]^{\frac{1}{\beta-1}} \qquad [35]$$

$$L_c^{\,n}{*} = L_c - \left[\frac{\beta}{\beta-\alpha}\right]\left[\frac{w^n(\beta-\alpha)^{\alpha-1}}{p^d \alpha^{\alpha} I^{\alpha} L_g^{f\alpha}}\right]^{\frac{1}{\beta-1}} \qquad [36]$$

$$L_c^{\,m}{*} = \left[\frac{\alpha}{\beta-\alpha}\right]\left[\frac{w^n(\beta-\alpha)^{\alpha-1}}{p^d \alpha^{\alpha} I^{\alpha} L_g^{f\alpha}}\right]^{\frac{1}{\beta-1}} \qquad [37]$$

$$Y_c{*} = \ w^n L_c^{n*} + p^d I^{\alpha} L_g^{f\alpha} (\sigma\eta^{\frac{1}{2}})^{\alpha} L_c^{m*\alpha} L_c^{d*\beta-\alpha} \qquad [38]$$

The government's problem and its optimal choices and maximal welfare conditional on these community best-responses are:

$$Max\ W_g = AE^{\chi} + BL_g^{\,o} \qquad [39]$$

$$s.t. \qquad E = I[L_g^{\,f} L_c^{\,m}* / L_c^{\,d}*]$$

$$L_g = L_g^{\,o} + L_g^{\,f}$$

$$L_g^{\,f}* = \left[\frac{(\beta-\alpha)^{\chi} B}{\alpha^{\chi} \chi I^{\chi} A} \right]^{\frac{1}{\chi-1}} \qquad [40]$$

$$L_g^{\,o}* = L_g - \left[\frac{(\beta-\alpha)^{\chi} B}{\alpha^{\chi} \chi I^{\chi} A} \right]^{\frac{1}{\chi-1}} \qquad [41]$$

$$W_g* = BL_g + \left[\frac{(\beta-\alpha)^{\chi} B^{\chi}}{\alpha^{\chi} \chi^{\chi} I^{\chi} A} \right]^{\frac{1}{\chi-1}} - \left[\frac{(\beta-\alpha)^{\chi} B^{\chi}}{\alpha^{\chi} \chi I^{\chi} A} \right]^{\frac{1}{\chi-1}} \qquad [42]$$

REFERENCES

Agrawal, A. 2001. "Common Property Institutions and Sustainable Governance of Resources." *World Development* 29(10): 1649-72.

Baland, J.-M., and J. P. Platteau. 1996. *Halting Degradation of Natural Resources: Is There a Role for Rural Communities?* Oxford, England: Food and Agriculture Organization of the United Nations, Clarendon Press.

Barrett, C. B., K. Brandon, C. Gibson, and H. Gjertsen. 2001. "Locating Tropical Biodiversity Conservation Amid Weak Institutions." *Bioscience* 51(6): 497-502.

Bell, C. 1989. "A Comparison of Principal-Agent and Bargaining Solutions: The Case of Tenancy Contracts." In *The Economic Theory of Agrarian Institutions*, ed. P. Bardhan. New York: Oxford University Press.

Berkes, F., and C. Folke. 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience.* Great Britain: Cambridge University Press.

Brandon, K., K. Redford, and S. Sanderson. 1998. *Parks in Peril: People, Politics, and Protected Areas*. Washington: Island Press.

Brown, D. N., and R. S. Pomeroy. 1999. "Co-management of Caribbean Community (CARICOM) Fisheries." *Marine Policy* 23(6): 549-570.

Chakraborty, R. N., I. Freier, F. Kegel, and M. Mascher. 1997. *Community Forestry in the Terai Region of Nepal: Policy Issues, Experience, and Potential*. Berlin: German Development Institute.

Dove, M. 1993. “A Revisionist View of Tropical Deforestation and Development.” *Environmental Conservation* 20(1): 17-24.

Eswaran, M., and A. Kotwal. 1985. “A Theory of Contractual Structure in Agriculture.” *American Economic Review* 75(3): 352-367.

Getz, W. M., L. Fortmann, D. Cumming, J. du Toit, J. Hilty, R. Martin, M. Murphree, N. Owen-Smith, A. M. Starfield, and M. I. Westphal. 1999. “Sustaining Natural and Human Capital: Villagers and Scientists.” *Science* 283: 1855-6.

Hardin, G. 1968. “The Tragedy of the Commons.” *Science* 162: 1243-8.

Hobley, M. 1996. *Participatory Forestry: The Process of Change in India and Nepal*. London: Overseas Development Institute.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. United Kingdom: Cambridge University Press.

Ostrom, E., J. Burger, C. B. Field, R. B. Norgaard, and D. Policansky. 1999. “Revisiting the Commons: Local Lessons, Global Challenges.” *Science* 284: 278-282.

Pomeroy, R.S. 1999. “Devolution and Fisheries Co-management.” unpublished manuscript.

Rasmussen, L., and R. Meinzen-Dick. 1995. "Local Organizations for Natural Resource Management: Lessons from Theoretical and Empirical Literature." *EPTD Discussion Paper* 11, IFPRI Environment and Production Technology Division.

Ribot, J. C. 2002. “Democratic Decentralization of Natural Resources: Institutionalizing Popular Participation.” World Resources Institute: Washington, D.C.

Skonhoft, A. and J. T. Solstad. 1996. “Wildlife Management, Illegal Hunting and Conflicts. A Bioeconomic Analysis.” *Environment and Development Economics* 1(2): 165-181.

Skonhoft, A. and J. T. Solstad. 1998. “The Political Economy of Wildlife Exploitation.” *Land Economics* 74(1): 16-31.

SMMA (Soufrière Marine Management Area) 2003, Available at http://www.smma.org.lc/TecStuff/TecIndex.html.

Wells, M., and K. Brandon. 1992. *People and Parks: Linking Protected Area Management with Local Communities*. Washington: World Bank, World Wildlife Fund and USAID.

Western D., and R. M. Wright. 1992. *Natural Connections: Perspectives in Community-based Conservation*. Washington: Island Press.

ENDNOTES

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[1] We abstract from other potential community interests, for tractability of the model.

[2] There is obviously an intertemporal allocation problem as well since time spent on L_c^f or L_c^m improves the future state of the ecosystem and, by law of motion [1], potential future income from resource extraction. We ignore the intertemporal issues, however, in order to concentrate attention on the central issues of externalities and differential productivity across complementary conservation activities. Adding dynamics merely refines the basic story we present.

[3] For the sake of simplicity, we abstract from the related public finance problem. One could readily let the government levy a lump sum tax to finance its activities without changing any of the results to follow. A more realistic, *ad valorem* tax merely adjusts the magnitudes by creating a further externality, but does not change the qualitative results of the model.

[4] This specification implies that government values the state of the ecosystem and thus that there is some long-term interest represented by government. Although we do not present these comparative statics below, as one reduces the value government places on the environment, reflected in the parameter χ introduced shortly in equation (8), government becomes less interested in conservation and thus is less frequently the resource manager in equilibrium.

[5] Objections have been raised to the principal-agent framework in agrarian contracts models, in that it assumes the agent has no bargaining power to increase its share of the gains from contracting (Bell 1989). Although our framework could be extended to a bargaining model, here we are simply concerned with the gains from contracting, and not with the distribution of these gains.

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[6] This of course, depends on the mechanism used for eliciting these funds. The Nash equilibrium for a voluntary contributions mechanism is to give nothing, regardless of the size of the benefit one would derive from provision of the public good. However, the simple observation that public television and radio continue to operate, and charities continue to receive contributions, suggests that people do contribute some positive amount. The amount of the contribution is probably some proportion of one's willingness to pay, which will be larger if the total benefits from the public good are larger.

[7] Note that we are not referring to stability in a dynamic sense. The essence of the community stability variable is anything that affects its ability to set and enforce rules or otherwise resolve externalities.

[8] We consider only the interior solution in the optimization problems, such that strictly positive amounts of labor are used in each activity. Since this paper is based on the notion that multiple functions are necessary for conservation, the corner solutions are inherently uninteresting.

[9] In an effort to conserve space, the final expressions for equilibrium community labor allocations, community income, and state of the ecosystem are not presented in the paper. These can be made available to interested parties upon request.

[10] The curves separating optimal contracts in the efficiency parameter space in this and all other figures reflect exact computations based on the declared parameter values.

Table 1: Effect of Parameters on Relative Efficiencies

Parameter	Effect of increase on abilities	Effect of increase on relative efficiencies
Community instability, σ	$\downarrow m_c$	$\uparrow m_g/m_c$ (government relative management efficiency)
Size of ecosystem, η	$\downarrow m_g$, $\Downarrow m_c$	$\uparrow m_g/m_c$
Government undependability, μ	$\downarrow f_g$	$\uparrow f_c/f_g$ (community relative fundraising efficiency)
Scale of externality, ρ	$\Uparrow f_g$, $\uparrow f_c$	$\downarrow f_c/f_g$

Table 2: Effect of “Context” Parameters on Equilibrium Contract

Community relative fundraising efficiency

Government relative management efficiency

	Low σ small, η small	High σ big, η big
Low μ small, ρ big	Co-management	Government Management
High μ big, ρ small	Community Management	?

Table 3: Comparative Statics: Effect of Change in Parameter Values on Dominant Equilibrium Contract

Parameter	Decrease	Increase
P^d	Government management	Community management
A	Community management	Government management
I	Community management	Government management

LIST OF FIGURES

Figure 1: Optimal Contract in Relative Efficiency Space

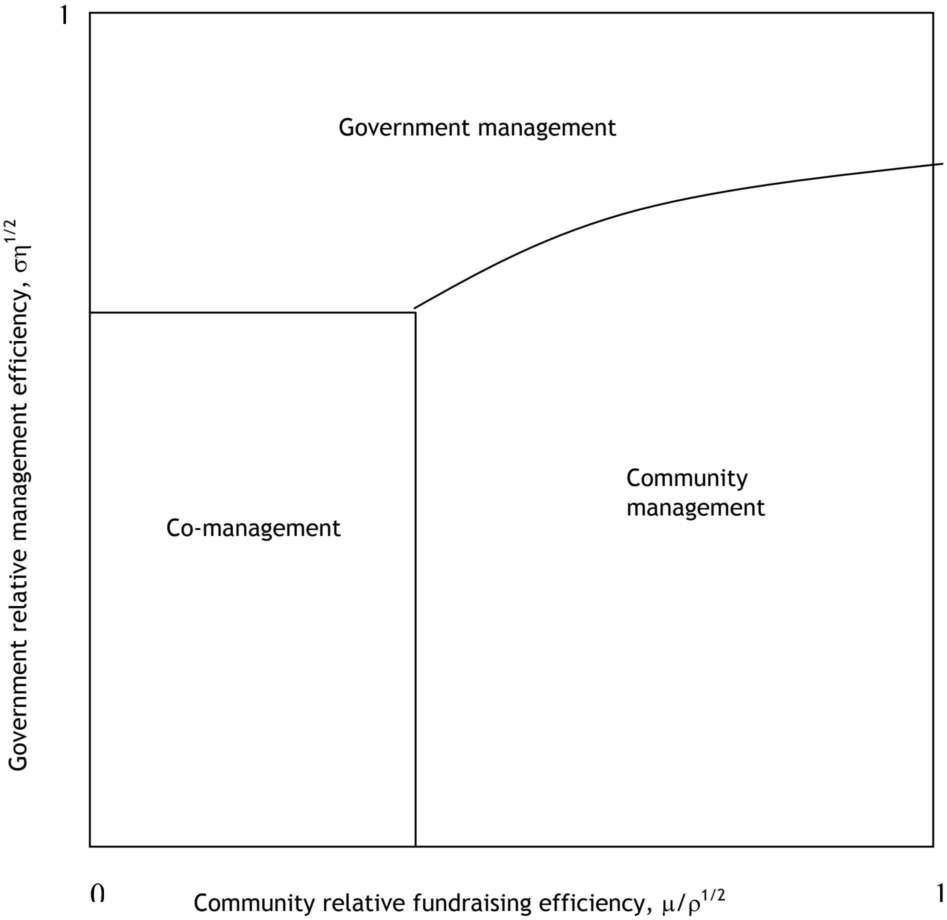

Figure 2: Changing the Market Price of the Exploited Resource

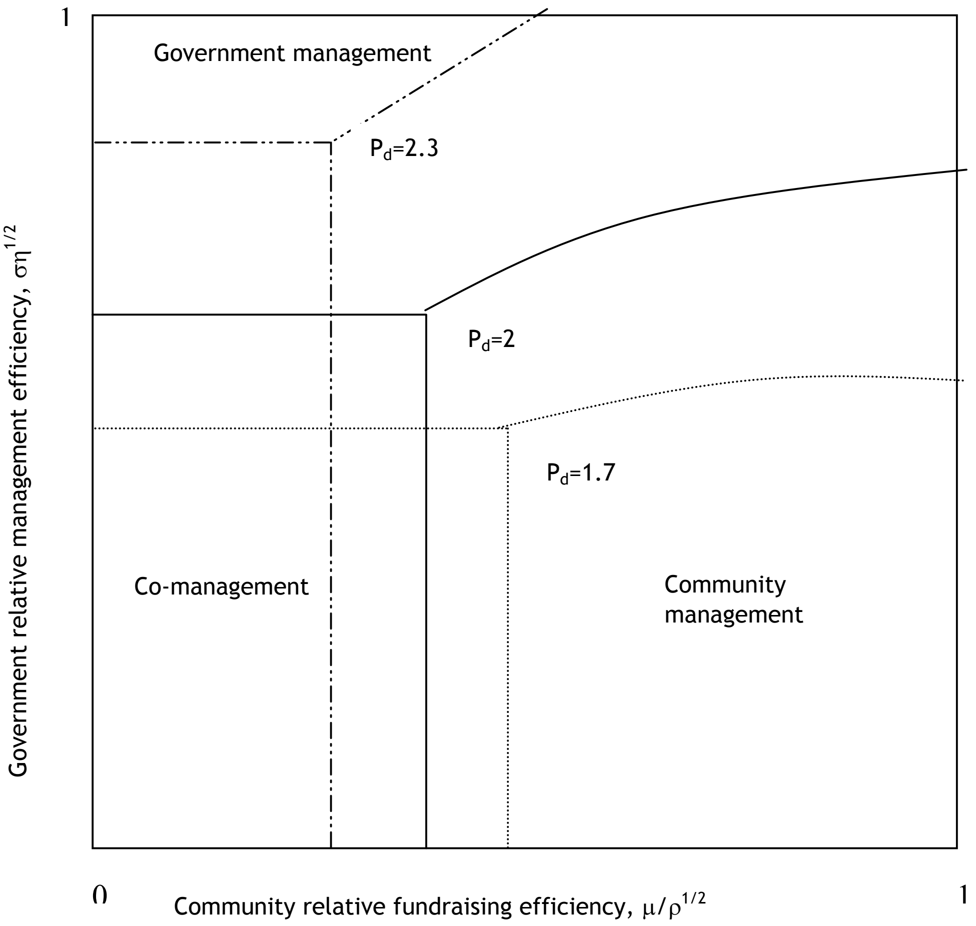

Figure 3: Changing Relative Importance of Ecosystem to Government

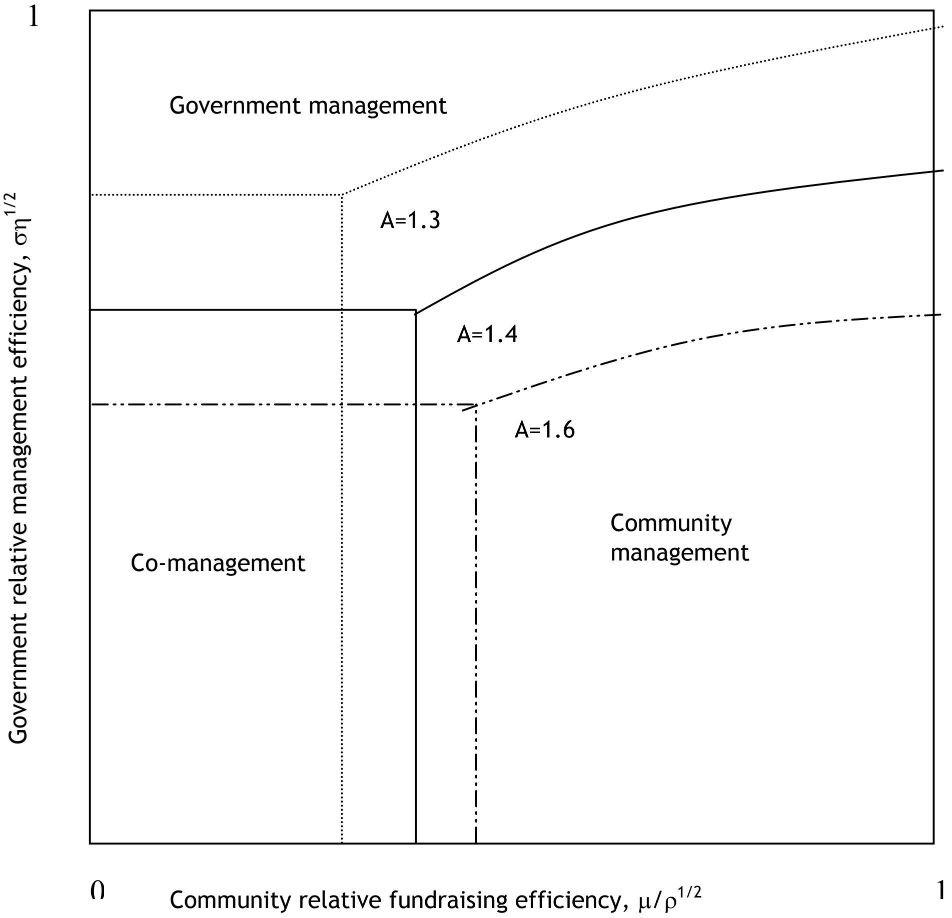

Figure 4: Changing Initial Ecosystem Quality