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1. Introduction

Tropical forests provide a wide variety of services to humankind (Repetto, 1988; Peters, Gentry, and Mendelsohn, 1989; and Reid and Miller, 1989). Yet, as documented in these and other sources, the forests are under threat. Repetto observes that, since World War II, deforestation has shifted from temperate to tropical forests and that, in most developing countries today, deforestation is accelerating (pp. 2-15). Table 1 shows that, at 1981-1985 annual rates of deforestation, there are a number of countries where forests will disappear within 30 years. Others, having larger reserves, are losing vast areas every year. A question that naturally arises is, given the value of the tropical forest resource, why is it being destroyed? The answer, it seems to us, is that a very substantial part of the value simply does not get counted, either because it is hard to measure or because it is not captured by those who make the decisions on deforestation. The latter reason has been discussed at length elsewhere (see, for example, Binswanger 1991). Here, we focus on the issue of measurement, by providing a framework for a more complete valuation of tropical forests.

We begin in the next section with a discussion of the major uses of tropical forests, paying particular attention to the relationships among uses. For example, are they compatible with forest preservation? Are they sustainable? Section 3 provides the elements of a framework for valuation and management, taking account of the varied uses. The time dimension will be important here. One issue is, of course, sustainability. Another is feasibility of a sequential pattern of use; livestock ranching may follow the clearing of land for a timber harvest but not vice versa. Finally, as we shall show, the present value of a tract of land will depend on how uncertainty about

future values is treated. In fact, it is the interaction between the feasibility of alternative patterns of forest use and uncertainty about their benefits that generates the main theoretical results, given in Propositions 1 and 2 in section 3. Section 4 contains an empirical application to the valuation and management of a forested area in Thailand.

2. The Uses of Tropical Forests

Uses and Utilitarianism: A Caveat

When we talk about uses of the forest, we have in mind human uses. This is an important distinction, since some would argue that human uses and the values to which they give rise are not deserving of any special consideration when it comes to a decision on whether to preserve a tropical forest. According to one interpretation of this view, nature has rights; to exploit nature is just as wrong as to exploit people (Nash, 1989). Another interpretation is that nonhuman species are intrinsically valuable, independent of any use they may be to humans (Callicott, 1986). We would prefer not to take issue directly with this view. Rather, we would observe that economics is about the human use and valuation of resources. As such, it is embedded in utilitarianism. In the larger philosophical universe, utilitarianism is, of course, only one of many possible approaches to questions of ethics and choice. Advocates of preservation for its own sake are presumably appealing to an alternative to philosophical utilitarianism. In this paper, we confine our focus to what we understand to be the subject matter of economics—the uses and values of resources to humans. At the same time, we recognize that decisions, especially public decisions, affecting tropical forests may be made on the basis of a variety of other considerations as well—including, perhaps, inherent rights or intrinsic values.

There is an important point to note in this connection. Often in environmental economics, we speak of intrinsic or 'nonuse values,' referring to the benefits some

people derive from the mere existence of a natural environment (such as, for example, the Amazon rain forest) even though they make no use of it. In our judgment these benefits are likely to be quite significant for many environmental resources and are legitimately included in our notion of economic value. However, as Batie (1989) points out, this is still a utilitarian view in that the resources, although not used, have value in relation to human welfare. Taking into account this extension of the notion of economic value, a better title for this section of the paper might be: 'The Goods and Services Provided by Tropical Forests,' with the understanding that among these services is the existence of the forests, apart from any use to which they may be put by humans.

There is a further, and equally important, point to be made here. We shall very shortly be talking about local and global environmental services provided by standing tropical forests. These environmental services are, as we shall see, quite tangible and, indeed, impinge quite directly on human activities. Existence value, as just defined, does not. It is derived from the knowledge that the forests or other environmental resources are alive and well, again, apart from any human activity affected by them.

Uses Compatible With Preservation

Several kinds of human activities in and around the forests appear to be reasonably compatible with preservation: hunting and fishing; gathering of food such as nuts and fruits; gathering of forest products such as rubber, oils and medicines; and trekking/camping or ecotourism. By definition, the creation of preserves also falls within this category. We observe in passing that all of these uses are sustainable; they create low intensity, short duration ecosystem disruption and permit recovery of ecosystem functions (Uhl *et al.*, 1990).

Standing tropical forests are also associated with the provision of environmental services, as distinguished from the uses just noted. There are, no doubt, a number of ways in which these services can be classified, but one that in our judgment will be helpful in discussing valuation issues is as local and global. What we are calling local environmental services are, perhaps, best understood by considering some of the consequences of deforestation. For example, the loss of forest cover leads to soil erosion which, in turn, aggravates flooding and contributes to premature silting of reservoirs for irrigation and electric power production. Though local, these impacts are not trivial. It is estimated that revenue losses from sedimentation behind just one dam in Costa Rica have reached a level of $133-$274 million (Postel and Heise, 1988, p. 92).

At a global level, tropical deforestation appears to be related to what may well be the gravest environmental issues of our time: the 'greenhouse effect' and the wholesale extinction of species. As is well known, the buildup of several trace gases in the atmosphere (most importantly, carbon dioxide) is expected to lead to a substantial warming over the next several decades with an attendant rise in sea level and change in patterns of precipitation. Potential consequences, to coastal settlements, to agriculture, and to other activities, have been discussed at length in many places (see Nordhaus, 1991, and Cline, 1991). What is important to note here is that deforestation, almost entirely tropical deforestation, is estimated to account currently for a very substantial fraction of global carbon emissions—between one-fifth and one-half as much as the burning of fossil fuels (Postel and Heise, p. 94).

The second global environmental issue we noted is the threatened loss of species. Although this is the popular perception of the issue, it would be more accurate to speak of the threatened loss of biodiversity. The point of the distinction is that biodiversity, as well as being the source of potentially valuable individual species, is an input to such ecological processes as nutrient and water cycling, soil generation,

erosion control, pest control, and climate regulation—all essential to human survival (Reid and Miller, 1989, p. 88). With respect to individual species, wild relatives of economically important crops, trees, and livestock often carry unique genes that can be used to improve the characteristics of the domesticated stocks or just help them survive changes in the environment. Plants, animals, and micro-organisms found in the wild are also major sources of medicines and industrial substances. Reid and Miller note that tropical species have been particularly important sources of medicines because many active medical compounds are derived from the toxins that they have evolved to combat predation. More generally, tropical forests are important to the conservation of biodiversity because it is believed that they contain more than half of the world's species, though only 7 percent of the land surface. About half of all vertebrates and vascular plant species occur in tropical forests, and recent discoveries of great insect species richness there suggest tropical forests may account for as much as 90 percent of all of the world's species (Erwin, 1982). Although one cannot predict with a high degree of confidence that a particular tract of tropical forestland will be the source of a cure for cancer, or a liquid hydrocarbon, or a desirable crop characteristic, the chances of finding any or all of these are surely greater, the greater is the preservation of tropical forests generally.

Traditional Agriculture and Land Recuperation

Swidden agriculture, or shifting cultivation is sometimes considered a major cause of deforestation. A study by the National Academy of Sciences (1982, p. 13), for example, concludes that at least half of current deforestation results from shifting cultivation. But by traditional shifting agriculture, we have in mind the kind of activity that involves little disturbance to the forest cover and root systems outside the small plot under cultivation, and that allows the plot to regenerate for 20-30 years before a new round of cutting and burning. The small area, short duration and moderate

intensity of the farming allow the land to recuperate in the long run. Swidden agriculture cannot be considered compatible with short run preservation goals but the forest recovery makes this use compatible with long run preservation goals.[1] As noted by Gradwohl and Greenberg (1988, p. 102), many forested areas once considered 'virgin' are now believed to have been occupied for centuries by people practicing shifting agriculture. The difficulty arises when population pressures—and perverse incentives as, for example, the linking of ownership rights to the clearing of land—result in the cutting of what had been protective buffer zones and a shortening or even elimination of the fallow period. It is this 'nontraditional' agriculture that is implicated in deforestation.

Commercial Forestry

Particularly in Africa and Southeast Asia, the first step in the conversion of tropical forests is typically opening an area to logging. Commercial forestry covers a variety of activities—including selective culling of highly valued woods; clear-cutting for timber or pulp production; and plantation harvesting of an introduced, nonnative species. Of course, there is also cutting for fuel, but this is more prevalent in relatively arid areas as opposed to tropical moist forests (Gradwohl and Greenberg, p. 37).

Plantation forestry faces sustainability and irreversibility constraints. The chief problem is the loss of nutrients once the trees are cut since, in tropical forests, the soil is relatively poor, with most of the nutrients stored in the vegetation (Gradwohl and Greenberg, p. 31). This poor soil prohibits long term timber rotations and discourages the natural reforestation of these large areas. The relative irreversibility of the conversion away from natural forest is underscored by the

[1]Tropical forest recovery on these small plots occurs only where regeneration mechanisms exist and where the soil satisfies growth requirements (Uhl, *et al.*, p. 33). These conditions appear to be met in many tropical settings because the fire-enriched soils are not completely degraded during the farming period and the small plot size permits seed dispersal across the plots.

invasion of hardy grasses that out-compete many early successional tree species. Furthermore, some tree crops, such as eucalyptus, leave remnants that further discourage natural regeneration or crop production. In addition, during the period when the soils and management support timber crop rotations the monocultures provide little of the original forest's ecosystem functions (Tongpan *et al.*, 1990).

Commercial Agriculture

Commercial agriculture includes both plantation farming (of such crops as bananas, sugarcane, rubber, and pineapple) and livestock production, especially (in the Amazon and other tropical American forests) beef cattle ranching. To these activities, one might add intensive subsistence agriculture, involving both shifting and continuous cultivation (the latter, primarily irrigated paddy rice).

Like commercial forestry, large-scale or intensive agriculture may not be sustainable. Long-term, continuous cultivation or grazing leads to soil erosion and loss of nutrients and, at least in the case of cultivation, tends also to involve heavy application of fertilizers and pesticides. The buildup and dispersal of these substances, in turn, interferes with the provision of local environmental services. As with forestry, (costly) management inputs can make an agricultural operation relatively sustainable. Mulching, the use of careful cultivating techniques, long fallow periods, and avoidance of poorer soils can all contribute to this objective (Gradwohl and Greenberg, p. 32). The intensity and duration of the land use, however, may prohibit tropical forest regeneration after farm abandonment.

Other Extractive Activities: Mining, Water Resource Development, and Transportation

To some extent, extractive activities are just an extension of the hunting and gathering that is consistent with forest preservation. For example, medicinal substances, meat, skins, plumage, and even live animals may be taken for export

rather than subsistence. Additionally, however, fairly large areas may be affected by mining, water resource, and transportation projects. Of all of the uses discussed thus far, these are probably the most disruptive of the forest ecosystem and their consequences almost certainly the most difficult to reverse. By definition, a mining project cannot be sustainable, though it can, of course, produce great wealth over the life of the mine. Water impoundments (the construction of large dams for irrigation or hydroelectric power) will also have finite lives as reservoirs silt up over several decades. Moreover, as we have seen, the silting process is accelerated by deforestation and resulting soil erosion.

3. A Framework for Valuation

We start by making a distinction between valuing the specific services provided by a forest and valuing the forest itself, viewed as an asset generating a stream of services over time. Mapping from the valuation of service flows to the valuation of the asset raises the issue of allocation of forestland among alternative uses. As indicated in the preceding discussion, a great many different kinds of goods and services are provided by the forest, not all of them compatible with each other. In the circumstances, a choice among them is required, and this choice will dictate the value of the forest. In effect, the forest can be regarded not as a single asset but rather as a portfolio of assets, whose composition can be varied over time (subject to some constraints). Thus, the forest cannot be valued without regard to future choices about how it will be managed: Valuation cannot be divorced from decision making. The issue of choice is particularly relevant in the tropical forest setting, given the wide range of uses and activities relative to those supported by temperate forests in developed countries.

In this section we lay out a framework for valuing a tract of tropical forestland, allowing for different choices about the uses of the forest and taking into account constraints on the sequencing of uses. We are deliberately vague about the size of

the tract: It may be anything from the one hectare sample of Amazon rain forest studied by Peters, Gentry, and Mendelsohn (1989) to some much larger area. About the only restriction is that it not be so large that choice among uses is not meaningful because, on a large enough tract, one might reasonably expect to find a little of everything. Our framework, in contrast, is designed to exhibit the consequences, for the value of the tract, of a particular set of choices (for example, indigenous gathering, followed by logging, followed, in turn, by beef cattle ranching). Of course, in applying this framework to an appropriately delimited tract, the analyst would need to know (or assume) something about what is going on elsewhere in the forest, as well. Spatial relationships may be important here. For example, the benefits of preservation will be a nonconcave function of area if there is some critical minimum habitat size (Albers, 1993a). Also, as noted earlier in the discussion of shifting cultivation, preservation benefits will be affected by the intensity of activities in adjacent tracts and by the configuration of the tracts. In what follows, we assume that information of this sort can be developed in an empirical case study or policy analysis and indicate how it might be fit into a larger framework—one that is readily adapted to show the consequences of different choices and sequences of uses and assumptions about such things as time discounting, sustainability, and the benefits of particular uses in particular periods.

Our point of departure is the work on choices between just two alternative uses of a natural environment, development, and preservation, as originally set out in Fisher, Krutilla, and Cicchetti (1972). The focus there was on methods of estimating time profiles of benefits of the alternative uses and on strategies for choosing between uses. Greater realism was introduced in theoretical analyses of the preservation versus development decision under uncertainty, especially about future benefits of preservation, and irreversibility of the development alternative. (See Arrow and Fisher, 1974; Henry, 1974; Fisher and Hanemann, 1986; and Hanemann, 1989. Also,

see Pindyck, 1991, for a review of the financial literature dealing with formally similar problems.)

The focus of this paper is on laying out a broader framework for valuation and decision, drawing on results in the earlier literature where relevant. One important way in which the current framework is broadened is by consideration of more than two alternative uses of the land. In the preceding section, we distinguished uses compatible with preservation, small scale agriculture, commercial forestry, commercial agriculture, and other extractive activities. To make the conceptual transition from just two uses (one irreversible) to several, it will be sufficient to specify three generic uses with appropriate constraints on feasible sequences. Thus, we consider preservation, P; development, D; and an intermediate use, M. We assume that it is possible to go from P to P, M, or D; from M to M or D; and that D is a trapping state. The relationship of the generic uses to those discussed in the preceding section would need to be specified in a particular empirical setting. For example, indigenous gathering (a use compatible with preservation) could be P, swidden agriculture could be M, and large-scale forestry or cattle ranching could be D.

Another way in which we broaden the focus of the earlier work on decisions under uncertainty is by considering more than two periods. It will be essential to model the choices over at least three periods, in order to accommodate the recovery dynamics and learning behavior that we feel are relevant to managing the tropical forest environment.

The decision problem is then one of allocating a tropical forest tract among three competing uses, P, M, and D, over three periods, to maximize the expected benefits of use. The pattern of feasible sequences is displayed in Figure 1. Note the much greater complexity than in the two-use, two-period model, which involves just three feasible sequences: $P \rightarrow P$, $P \rightarrow D$, and $D \rightarrow D$.

In the standard approach to benefit/cost analysis, uncertain future benefits are replaced by their expected values. We shall model the choice of forest use under this assumption and contrast it with the choice that results when the analyst takes into account the prospect of new information about uncertain future benefits. The former information structure is known as open loop, and the latter as closed loop, in the language of stochastic control (Rausser and Hochman, 1979, and Walters, 1986). Open loop is, in fact, not rational if information is changing over time, but that has not prevented generations of applied benefit/cost analysts, including the present authors, from employing it. In the open-loop formulation, the maximum expected present value associated with putting the forest tract to the preservation use in the first period is

$$V_P^* = P_0 + \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\}, \tag{1a}$$

where the expectation is with respect to the information set available in the first period. Similarly, the discounted present value associated with intermediate and development uses are

$$V_M^* = M_0 + \max\{E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} \tag{1b}$$

$$V_D^* = D_0 + E[D_1] + E[D_2]. \tag{1c}$$

In these formulas, while it is recognized that the discounted present value associated with a current use depends partly on decisions about future uses, the current anticipation of those decisions is based entirely on current information about future benefits and costs.

However, this overlooks the possibility that better information about future benefits and costs will be forthcoming in such a way as to influence the future decisions about the uses of the forest tract. Let us now assume that such information is forthcoming. Specifically, we assume that, at the start of each period, the decision maker learns what the benefits of each of the alternative uses of the tract will be in that period (though not in future periods) and then chooses the highest-yielding alternative. In this closed-loop formulation, the maximum expected present value associated with preservation in the first period is

$$\hat{V}_P = P_0 + E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\}]. \tag{2a}$$

Similarly, the present values associated with the intermediate and development uses are

$$\hat{V}_M = M_0 + E[\max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \tag{2b}$$

$$\hat{V}_D = D_0 + E[D_1 + D_2]. \tag{2c}$$

Observe that, in the case of the development use, there is <u>no</u> difference between the values associated with the two information scenarios: $\hat{V}_D - V_D^* = 0$. For the other two uses, however, there <u>is</u> a difference, given by

$$\begin{aligned}\hat{V}_P - V_P^* = {} & E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2] \\ & - \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] \\ & + \max\{E[M_2], E[D_2], E[D_1] + E[D_2]\}\end{aligned} \tag{3}$$

and

$$\hat{V}_M - V_M^* = E[\max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] - \max\{E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\}. \tag{4}$$

We shall prove

Proposition 1

$$\hat{V}_P - V_P^* \geq 0; \qquad \hat{V}_M - V_M^* \geq 0. \tag{5}$$

Proof. See Appendix

The interpretation is that the present value associated with the preservation or intermediate uses is larger when one recognizes the prospect of being able to use better information in making future decisions than when one disregards this prospect. The difference is what is known in decision theory as the expected value of information; that is, $\hat{V}_P - V_P^*$ measures the expected value of future information conditional on allocating the forest tract to a preservation use in period zero. Similarly, $\hat{V}_M - V_M^*$ is the expected value of information conditional on intermediate use. With regard to development, the conditional expected value of information, $\hat{V}_D - V_D^*$, is zero because allocating the tract to development at time zero eliminates all options with respect to alternative future uses of the forest and thus deprives the decision maker of the freedom to take advantage of any future information. That is why the information has no economic value.

In the terminology of the literature on environmental valuation, the quantities $\hat{V}_P - V_P^*$ and $\hat{V}_M - V_M^*$ represent the option value, in the tradition of Arrow and Fisher (1974) and Henry (1974), associated with preservation and intermediate uses in period zero. They measure the value of these uses' flexibility with respect to exploiting new information in later decisions. There is another related, but distinct, element of flexibility: Part of the benefit associated with preservation or intermediate uses arises from the breadth of choice that these uses permit in future decisions.

Intuitively, preservation affords more flexibility than intermediate uses—the reason being that it bequeaths a larger choice set to decision makers in periods 1 and 2. This is true under both the open- and closed-loop controls; from (1a, b, c) and (2a, b, c), we have

Proposition 2

$$(\hat{V}_P - P_0) \geq (\hat{V}_M - M_0) \geq (\hat{V}_D - D_0) \tag{6a}$$

and

$$(V_P^* - P_0) \geq (V_M^* - M_0) \geq (V_D^* - D_0). \tag{6b}$$

Proof

The first inequality in (6a) yields

$$\begin{aligned}(\hat{V}_P - P_0) - (\hat{V}_M - M_0) = {} & E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\} \\ & - \max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \geq 0\end{aligned} \tag{7a}$$

while the first inequality in (6b) yields

$$\begin{aligned}(V_P^* - P_0) - (V_M^* - M_0) = {} & \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] \\ & + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} - \max\{E[M_1] \\ & + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} \geq 0.\end{aligned} \tag{7b}$$

The result follows because the right-hand side of (7a) takes the form $E[\max\{X, Y, Z\} - \max\{Y, Z\}] \geq 0$, while (7b) takes the form $\max\{E[X], E[Y], E[Z]\} - \max\{E[Y], E[Z]\} \geq 0$, where X, Y, and Z are random variables.

Thus, in terms of impact on the breadth of future choices, preservation in period zero outranks intermediate use (and development). Does the same ranking apply to the value of information associated with these two uses? In other words, what is the

relationship between the two kinds of flexibility; does the prospect of a larger choice set make information more valuable so that $(\hat{V}_P - V_P^*)$ - $(\hat{V}_M - V_M^*) \geq 0$? Perhaps contrary to intuition, a simple counter-example shows that this is not true in general. Consider, first, two alternatives (Y and Z) and two states of nature (S_1 and S_2), each with a probability of occurring of one-half. Suppose that the benefits of Y and Z are distributed over the states as follows: Y = 5 in S_1 and 15 in S_2, and Z = 10 in S_1 and 12 in S_2. Then max{E[Y], E[Z]} and E[max{Y, Z}] are readily computed as

$$\max\{E[Y], E[Z]\} = \max\left\{\frac{1}{2}(5)+\frac{1}{2}(15), \frac{1}{2}(10)+\frac{1}{2}(12)\right\} = 11$$

and

$$E[\max\{Y,Z\}] = \frac{1}{2}(10)+\frac{1}{2}(15) = 12.5,$$

respectively. Now add a third alternative, X, where the benefit of X is 9 in S_1 and 14 in S_2. Clearly, E[max{X, Y, Z}] = E[max{Y, Z}], since the maximum benefit obtainable in S_1 and S_2 is unchanged. However, max{E[X], E[Y], E[Z]} > max{E[Y], E[Z]}, since E[X] = 11.5. In this example, having a larger choice set raises V* more than it raises $\hat{V}$ so that the conditional value of information is lowered.

Of course, in a particular empirical application, it may turn out that the use which bequeaths the larger future choice set does have the larger option value. We have simply shown that this need not be so (see also Hilton, 1981). Also, we do not mean to suggest that the optimal initial choice can never be M or D. We have argued that P and M both provide more flexibility than D with regard to both the breadth of future choice sets and the value of future information and that P outranks M by at least

the first of these criteria. But M or D might still be the optimal action in period zero, depending on the relative magnitudes of P_0, M_0, and D_0.

4. Empirical Application in Khao Yai National Park, Thailand

The differences between the framework developed here and a more traditional approach appear in the following application to a tropical forest in Thailand. The sustainability and irreversibility constraints on the development use D prove important in the optimal plans. As compared to a traditional planner, the foresighted manager who considers the possibility of forthcoming information preserves more land and preserves at higher discount rates.

The manager chooses among three uses, P, M, and D, for the first of three periods in four portions of Khao Yai National Park in central Thailand. These uses are defined as described above with D as a trapping state and M reversible after one period of recovery. The periods' length, twelve years, reflects the investment cycle used to evaluate eucalyptus plantation profitability (Tongpan *et al.*, 1990). The manager faces uncertainty about the future benefits from the P use.

The Data Set

The data required to determine the optimal land use patterns in Khao Yai National Park include, among other things, preservation valuation estimates, productivity and sustainability of agriculture on the tropical soils, and timber production values. Ecologists and economists have studied Khao Yai National Park (KYNP) in central Thailand extensively and provide appropriate assumptions about the relative values. The ecological information also aids in the modeling of land recuperation (Table 2).

This analysis divides KYNP into four management units or plots (see Figure 2). The outer edge of the park, plot 1, has been encroached and begins in the use M. The inner two plots, 2 and 3, begin in the preservation use P. The fourth zone,

also in use P, is not currently protected by the park system but is under consideration for annexation. The park is bisected by a road and has tourist facilities at its center.

The preservation benefits, based largely on assessments and valuation studies by Dixon and Sherman (1990) and Dobias *et al.* (1988), include erosion control, hydrologic functions, tourism, and extractive goods.[2] Two states of the world define the uncertainty about future preservation benefits with a high state creating high levels of benefits. The high state preservation values reflect the additional preservation value that a viable population of Asian elephants creates in the KYNP.[3] The high state benefits grow at two and one-half percent per year. The low state preservation benefits reflect the possibility of a large dropoff in tourism revenue in the later periods. The high state occurs with a probability of 0.5 in the second period and 0.25 in the third period.

The M, or intermediate management, use mimics a swidden agricultural system and involves a biannual conversion of 10 percent of the forested land to small scale agriculture with high levels of extractive good production on the remaining land. The agricultural plots are farmed for two years and abandoned. The agricultural values drop off over time as more land is converted away from preservation leaving less erosion control and fewer regeneration pathways for the farmland. The extractive good values are also assumed to be unsustainable harvest levels and therefore decline over time.[4] The abandoned land regenerates according to Suwannapinunt and Siripatanaditok's (1982) biomass regrowth studies. The entire plot can be placed in a

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[2]The preservation value estimates generated by these studies are divided between the plots on the basis of size and geography (Albers, 1993b).

[3]Dixon and Sherman discuss a contingent valuation study that estimates the preservation benefit associated with preserving the Asian elephant in Thailand. This study uses an estimate of KYNP's contribution to that total value as 10 percent. That level reflects KYNP's current support of approximately 10 percent of the wild elephant population in Thailand and 10 percent of the elephant habitat in Thailand.

[4]Troy Hansel, a Peace Corp Volunteer in KYNP, describes the existing extraction levels as borderline sustainable. Those estimates are included in the P values. The M use is assumed to be somewhat more intense than the P use with relatively uncontrolled resource extraction.

recovery use, R, for one period following the M use to allow enough regeneration for the P use in the next period. The R use provides a small fraction of the preservation value with that fraction defined by the amount of biomass on the recovering plot divided by the biomass of that plot in the P use.

The irreversible development option, D, generates income through permanent agriculture and medium-sized plots of eucalyptus plantations (Tongpan *et al.*, 1990).[5] The agricultural values decline over time at a rate that corresponds to erosion induced productivity declines on the fragile tropical soils (Onchan, 1990; TDRI, 1986). Following Tongpan *et al.*, a 12-year investment horizon is used for the eucalyptus plantations. That twelve year plan, a function of rotation age, defines the length of the planning periods used here. In the first example discussed below, the eucalyptus plantations provide undiminished income in all three periods. That sustainability assumption is later removed because it is not known whether these plantations could prove economic over the long run on the fragile soils.

Solving the Planner's Optimal Land Use Problem

The empirical application's certainty over the future M and D benefits simplifies the problem for both the traditional manager and the foresighted manager. Each looks at the four plots individually and determines the optimal first period land use on each plot. They choose between the three uses, P, M, and D, and have the recovery option, R, following the M use. For plots 2, 3, and 4 the traditional manager finds the maximum of:

---

[5]The amount of land converted to agriculture and eucalyptus plantation per plot depends on the plot's topography and accessibility. Plot one's D option includes 25 percent of land in agriculture and 25 percent in eucalyptus. The remote plot two contains 40 percent agriculture and 10 percent eucalyptus. Plot three converts 10 percent eucalyptus and 30 percent agriculture. Plot four's D values include 40 percent of the land in agriculture but its slopes and remoteness prohibit eucalyptus production.

$$V_P^* = P_0 + \max\{E[P_1] + \max\{E[P_2], M_2, D_2\}, M_1 + \max\{R_2, M_2, D_2\}, D_1 + D_2\}$$
$$V_M^* = M_0 + \max\{R_1 + \max\{E[P_2], M_2, D_2\}, M_1 + \max\{R_2, M_2, D_2\}, D_1 + D_2\}$$
$$V_D^* = D_0 + D_1 + D_2$$

The foresighted manager finds the highest valued first period option by examining:

$$\hat{V}_P = P_0 + E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{R_2, M_2, D_2\}, D_1 + D_2\}]$$

$$\hat{V}_M = M_0 + E[\max\{R_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{R_2, M_2, D_2\}, D_1 + D_2\}]$$

$$\hat{V}_D = D_0 + D_1 + D_2$$

The managers look at the M, R, and D income streams for plot 1.

Two PASCAL programs solve the optimization problems for the KYNP plots using the data presented in Table 2. The programs calculate the option value. The benchmark optimization assumes a 10 percent discount rate.

Results

The traditional and foresighted managers preserve markedly different amounts of KYNP (see Figure 3a). Both approaches convert the degraded plot 1 to the development option due to its low productivity in agriculture and relatively small returns to preservation after the recovery period. The planners also agree on the use of plot four for intensive extractive goods and small scale agriculture, or use M. While both planners preserve plot two, they differ in their decision on plot three. The traditional manager develops this plot and thereby reduces the amount of local parkland by half.[6] The foresighted manager preserves this area and maintains the opportunity to take advantage of future information about future preservation values.

[6]The Thai government cannot be considered a "traditional manager" since they preserve this plot.

The option value generated in this example constitutes 1.6 percent of the foresighted manager's value for the KYNP. Despite its small size, this additional value creates a dramatic difference in the optimal land use pattern. This result stresses the need for this framework especially in cases where the preservation and development benefits appear close in expected value. The small option value comes from the relatively small value of future periods when compared to the current period value and from the small range of possible outcomes. Option value will be larger in situations of uncertainty in near periods and in cases of large divergences in possible outcomes. The latter case probably predominates in the global valuation of tropical forests as the scientific community debates the importance of tropical forests for biodiversity and global climate control. This empirical example ignores those global values in its concentration on Thailand's management and, therefore, understates both the uncertainty about, and the average value of, the tropical forests.

The next two optimizations reflect the sensitivity of the optimal plans to the choice of discount rate. The two managers arrive at identical land use patterns in the 'no-discounting' scenario (Figure 3b). At a zero discount rate the sustainability constraints on the agricultural portions of the D values limit the use of that option to plot one. The future preservation values carry enough weight to overcome the shorter run development values on the large plot three. A 20 percent discount rate creates the opposite scenario with both managers converting all of the land away from preservation (Figure 3c). The framework developed here does not remove the impact of the discount rate. The benchmark result compared to the zero and 20 percent discount rate examples demonstrates, however, that the framework creates cases where preservation is preferred at higher discount rates than it would be under traditional management.

The assumption of sustainability of the eucalyptus plantation contributes significantly to the optimal patterns. If the eucalyptus plantations fail after two

investment periods then both planners place plot three in preservation (Figure 3d). If the plantations offer no income after the first period then both planners place plot one in the M use instead of the D use (Figure 3e). These results underscore the outcome's sensitivity to sustainability assumptions. It may be the case that the conversion to eucalyptus on some plots results from erroneous assumptions about the capacity of the land to support these monocultures.

The discussion to this point has followed section 3's assumption that uncertainty about benefits in a period is resolved at the beginning of the period. The uncertainty of future benefits is unaffected. A more interesting, and perhaps more realistic, assumption might be improved priors about the probability distribution as a function of the state revealed in the previous period. In the three-period application, the state revealed in the second period provides full information about the second period benefits *and* information about the probability of each state in the third period. The traditional manager makes decisions based on the best information available in the current period and ignores the possibility of future information. The probabilities in the benchmark case were:

		time 2
	time 1	high state pr=0.25
	high state pr=0.5	
		low state pr=0.75
time 0		
		high state pr=0.25
	low state pr =0.5	
		low state pr=0.75

Maintaining the same first period conditional probabilities, those used by the traditional manager, but modeling the increase in information from the revelation of the state in time two produces this example of probabilities:

		time 2
	time 1	high state pr=0.5
	high state pr=0.5	
		low state pr=0.5
time 0		
		high state pr=0
	low state pr =0.5	
		low state pr=1.0

The traditional manager uses only the first period probability information which means that the optimal allocation remains the same. Using the benchmark data with this new probability-information description, the foresight manager's optimal plan also remains unaltered (Figure 3f). This extra information, however, does increase the option value by 8 percent. The added value increases the number of cases in which this intertemporal modeling leads to different optimal allocations than a traditional approach.

This application demonstrates the feasibility and relevance of applying the intertemporal framework to tropical forest valuation and management decisions. The foresighted manager preserves more land than the traditional approach at the margin. The foresighted manager also preserves land at higher discount rates than the expected value rule. The framework easily expands to incorporate realistic models of sustainability and information arrival. In this empirical example, the intertemporal modeling provides economic support for Thailand's preservation of Khao Yai National Park—without relying on global environmental values.

5. Concluding Remarks

The theoretical framework and the empirical illustration presented here demonstrate the importance of modeling both the information structure and the feasible use patterns in tropical forest management decisions. The theoretical model predicts that cases exist where the foresighted management of forests leads to more preservation, or more flexible uses, than the traditional expected value approach. The Khao Yai National Park example provides evidence that such cases occur in relevant ranges of benefit flows. The model focuses tropical forest management on assessments of sustainability and feasible sequences and on analyzing decisions in light of uncertainty and information flows.

Throughout this paper, we have sought to emphasize the link between the valuation of tropical forests and decisions about their uses. We believe that the valuation exercise cannot be designed effectively without reference to the types of decisions that are being made. The framing of the decisions determines the valuation strategy. To this end, we have reviewed alternative uses with a view toward identifying feasible sequences that, in turn, affect the value of some initial choice of use or activity. Further, because of the massive uncertainty about the value of a preserved forest, the decision problem has to be seen as one of stochastic control, in which information acquisition and flexibility rank more highly than nicely determining the allocation of land based solely on current estimates of benefits and costs. The valuation problem becomes one of guessing how the future may be different from the present and identifying blind spots as much as fine-tuning the estimates of what is known.

Appendix

To prove the proposition, we shall need the following

<u>Lemma</u>

The maximum function is convex.

<u>Proof</u>

Let $g(X) = \max\{X_1, X_2, ..., X_n\}$

where the X_i are the elements of the vector X.

Consider $g(\theta X' + (1 - \theta) X'')$ $\quad 0 < \theta < 1$

where X' and X" are two different vectors.

$$
\begin{aligned}
g(\theta X' + (1-\theta) X'') &= \max\{\theta X' + (1-\theta) X''\} \\
&= \max\{\theta X_1' + (1-\theta) X_1'', \theta X_2' + (1-\theta) X_2'', ...\} \\
&\le \max\{\theta(X_1', X_2', ...)\} + \max\{(1-\theta)(X_1'', X_2'', ...)\} \\
&= \theta \max\{X_1', X_2', ...\} + (1-\theta) \max\{(X_1'', X_2'', ...)\} \\
&= \theta \max\{X'\} + (1-\theta) \max\{X''\} \\
&= \theta\, g(X') + (1-\theta)\, g(X'').
\end{aligned}
$$

Thus, $g(E[X]) \le E[g(X)]$.

We now turn to the proof of the proposition. Define $E_{t/t-1}$ as an expectation held in period t, based on observation through period t - 1. We begin by noting that

$$E_{1/0}[\max\{P_2, M_2, D_2\}] \ge \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}$$

from the convexity of the maximum operator and Jensen's Inequality. Thus,

$$E_{1/0}[P_1 + \max\{P_2, M_2, D_2\}] \ge E_{1/0}[P_1] + \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}.$$

Similarly, one can prove that

$$E_{1/0}[M_1+\max\{M_2,D_2\}] \geq E_{1/0}[M_1]+\max\{E_{1/0}M_2,E_{1/0}D_2\}.$$

Let

$$\hat{a} = P_1+\max\{P_2,M_2,D_2\},\ a^* = E_{1/0}[P_1]+\max\{E_{1/0}P_2,E_{1/0}M_2,E_{1/0}P_2\},$$
$$\hat{b} = M_1+\max\{M_2,D_2\},\ \text{ and }\ b^* = E_{1/0}[M_1]+\max\{E_{1/0}M_2,E_{1/0}D_2\}.$$

Since

$$E_{1/0}[\hat{a}] \geq a^* \ \text{ and }\ E_{1/0}[\hat{b}] \geq b^*,$$

it follows that

$$\begin{aligned} E_{1/0}\ \max\{\hat{a},\hat{b},D_1+D_2\} &\geq \max\{E_{1/0}[\hat{a}],E_{1/0}[\hat{b}],E_{1/0}[D_1+D_2]\} \\ &\geq \max\{a^*,b^*,E_{1/0}[D_1+D_2]\}. \end{aligned}$$

Thus,

$$\begin{aligned}
&E_0\,[\max\{P_1+\max\{P_2,M_2,D_2\},M_1+\max\{M_2,D_2\},D_1+D_2\}] = E_0[E_{1/0}\ \max\{\hat{a},\hat{b},D_1+D_2\}] \\
&\quad \geq E_0\ \max\{a^*,b^*,E_{1/0}[D_1+D_2]\} \\
&\quad \geq \max\{E_0[a^*],E_0[b^*],E_0\ E_{1/0}[D_1+D_2]\} \\
&\quad = \max\{E_0\ E_{1/0}[P_1]+E_0\ \max\{E_{1/0}P_2,E_{1/0}M_2,E_{1/0}D_2\}, \\
&\qquad\quad E_0\ E_{1/0}[M_1]+E_0\ \max\{E_{1/0}M_2,E_{1/0}D_2\},E_0\ E_{1/0}[D_1+D_2]\} \\
&\quad = \max\{E_0[P_1]+E_0\ \max\{E_{1/0}P_2,E_{1/0}M_2,E_{1/0}D_2\}, \\
&\qquad\quad E_0[M_1]+E_0\ \max\{E_{1/0}M_2,E_{1/0}D_2\},E_0[D_1+D_2]\} \\
&\quad \geq \max\{E_0[P_1]+\max\{E_0\ E_{1/0}P_2,E_0\ E_{1/0}M_2,E_0\ E_{1/0}D_2\}, \\
&\qquad\quad E_0[M_1]+\max\{E_0\ E_{1/0}M_2,E_0\ E_{1/0}D_2\},E_0[D_1+D_2]\} \\
&\quad = \max\{E_0[P_1]+\max\{E_0P_2,E_0M_2,E_0D_2\}, \\
&\qquad\quad E_0[M_1]+\max\{E_0M_2,E_0D_2\},E_0[D_1+D_2]\}.
\end{aligned}$$

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TABLE 1

Tropical Deforestation

Country	Closed forest area, 1980	Annual rate of deforestation, 1981-1985	Area deforested annually
	thousand hectares	percent	thousand hectares
With high rates of deforestation (≥ 3.0% annually)			
Ivory Coast	4,907	5.9	290
Paraguay	4,100	4.6	190
Nigeria	7,583	4.0	300
Costa Rica	1,664	3.9	65
Nepal	2,128	3.9	84
Haiti	58	3.4	2
El Salvador	155	3.2	5
With large absolute losses (≥ 500,000 hectares annually)			
Brazil	396,030	0.4	1,480
Colombia	47,351	1.7	820
Indonesia	123,235	0.5	600
Mexico	47,840	1.2	595

Source: Repetto (1988, pp. 7-8).

Table 2: Data for Benchmark Khao Yai National Park Example

Period	Use	Zone1	Zone 2	Zone 3	Zone 4
time1	P	29.04	777.42	653.54	14.35
time2	P (low event)	8.33	228.11	154.59	4.36
	P (high event)	8.33	278.85	290.11	4.36
time3	P (low event)	2.64	72.37	49.05	1.38
	P (high event)	2.64	94.63	108.49	1.38
time1	a*	41.67	439.75	416.32	33.80
time 2	a	13.28	140.12	132.65	10.77
time 3	a	4.23	44.65	42.27	3.43
time 2	b*	8.16	86.15	74.92	1.13
time 3	b	2.60	27.45	23.87	0.36
time 3	c*	1.46	15.36	10.96	0.10
time1	R	1.91			
time2	R	0.61	115.01	77.94	2.20
time1	D	50.91	840.31	828.44	9.36
time2	D	16.41	269.07	265.34	2.98
time3	D	5.42	86.73	84.86	0.95

All values are present discounted values (interest rate of ten percent) of benefits received in the time period indicated in column one.
*The uses a, b, and c represent the M use values as they decline over the amount of time in that use. The M values when the plot is converted to M are represented by "a" while the value of a second period of M is denoted with a "b" and a "c" represents a third period of M use.

Figure 1

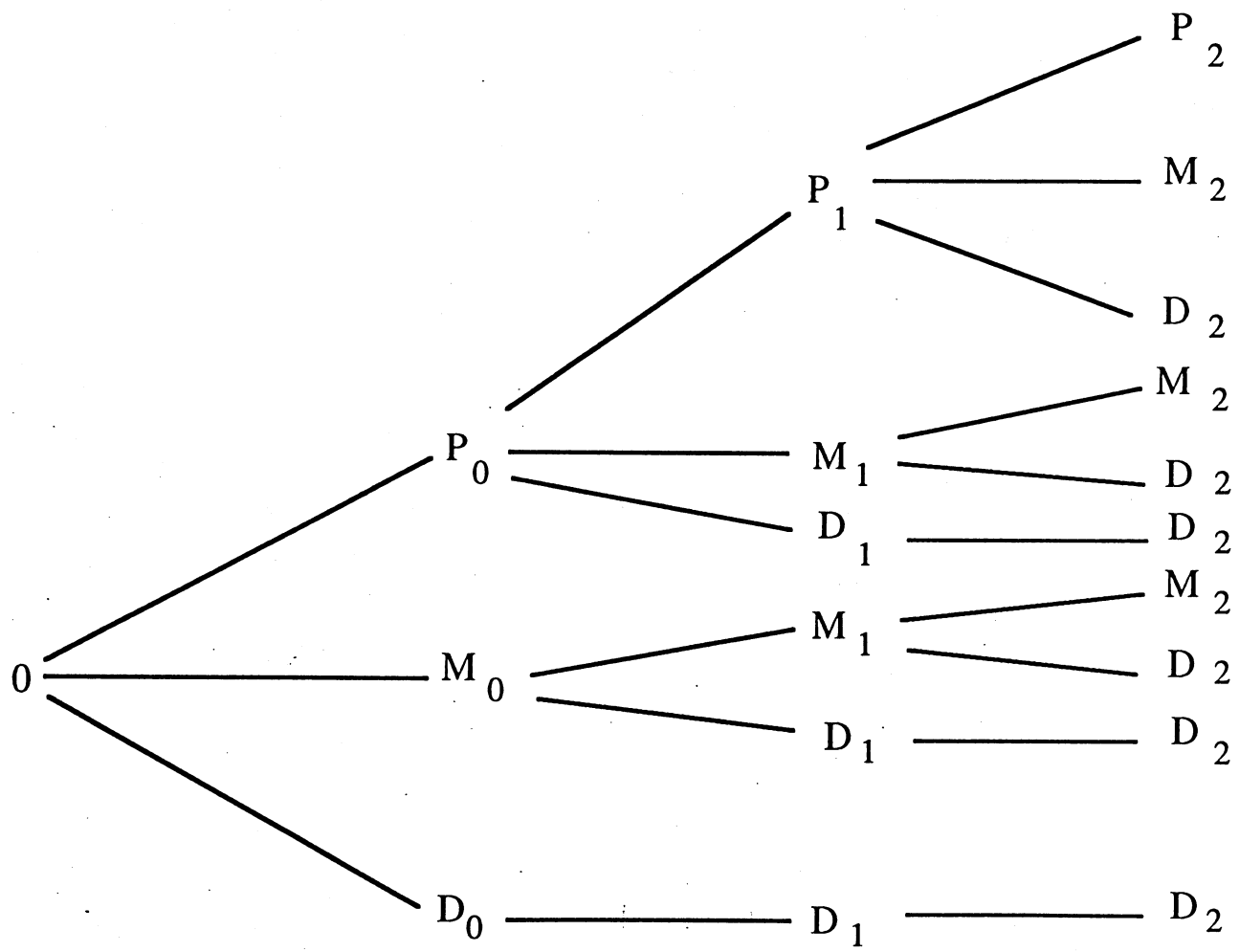
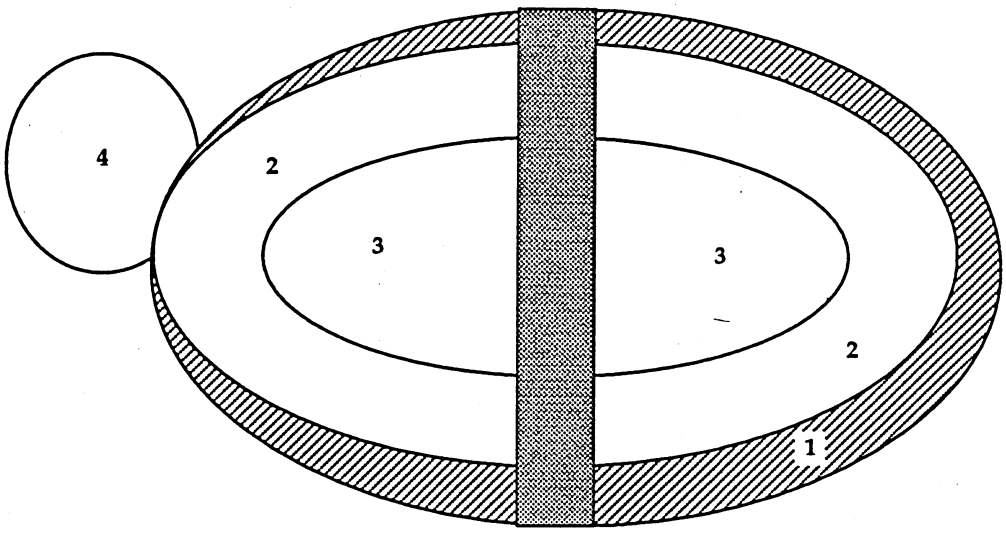


Figure 2: KYNP Plots and Initial Uses



Khao Yai National Park: Initial Condition

Preservation

Management

Development

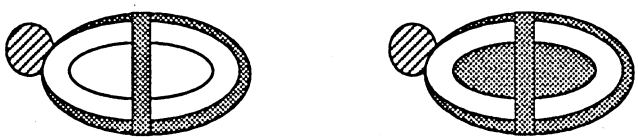
plots identified by numbers

Figure 3: KhaoYai National Park First Period Optimal Patterns

foresight **myopic**

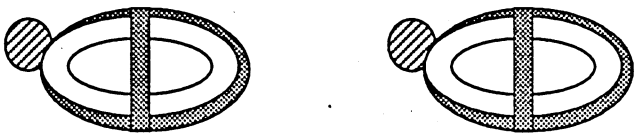
a) • benchmark result

option value = 1.6%



b) • r = 0%

option value = 1.8%



c) • r = 20%

option value = 0%

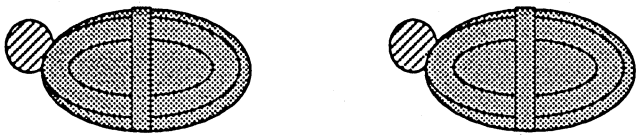


Figure 3: KhaoYai National Park First Period Optimal Patterns, *continued*

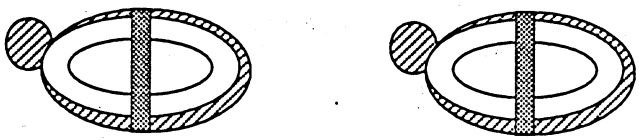
foresight **myopic**

d) • two periods of eucalyptus

option value = 1.6%

e) • one period of eucalyptus

option value = 0.8%



f) • learning

option value = 1.7%