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VALUATION AND MANAGEMENT OF TROPICAL FORESTS: IMPLICATIONS OF UNCERTAINTY AND IRREVERSIBILITY

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VALUATION AND MANAGEMENT OF TROPICAL FORESTS: IMPLICATIONS OF UNCERTAINTY AND IRREVERSIBILITY

Abstract. This paper develops a framework for the valuation and management of tropical forests that reflects their ecological and economic characteristics. The analysis demonstrates the importance of modeling the feasible use patterns and the information structure in tropical forest management decisions. The model predicts that cases exist where the foresighted management of forests leads to more preservation than the traditional expected value approach. An application in Thailand 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 in light of uncertainty and information flows.

keywords: tropical forests, irreversibility, uncertainty, Thai parks

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VALUATION AND MANAGEMENT OF TROPICAL FORESTS: IMPLICATIONS OF UNCERTAINTY AND IRREVERSIBILITY

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). 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 not measured correctly 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, Barbier, Burgess, and Markandya, 1991, and Binswanger, 1991). Here, we focus on the issue of measurement, by providing a framework for valuation of tropical forests that accounts appropriately for both uncertainty about future benefits and constraints on reversibility of some patterns of use.

We begin in the next section with a discussion of the major uses of tropical forests, paying particular attention to the relationships among uses. Section 3 provides the elements of a framework for valuation and management, taking account of these 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

2.1. 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 non-human 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. A recent synthesis of ethical positions relevant to differing sustainability paradigms is given in Turner, Pearce, and Bateman (1994).

There is an important point to note in this connection. Often in environmental economics, we speak of intrinsic or 'non-use 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.

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, apart from any human activity affected by them.

2.2. *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 biosphere reserves also falls within this category. We observe in passing that all of these uses are sustainable in the sense that the capacity to enjoy them is not significantly diminished over time; they create low intensity, short duration ecosystem disruption and permit recovery of ecosystem functions (Uhl *et al.*, 1990). For a discussion of alternative definitions of sustainability, see Pearce, Markandya, and Barbier (1989).

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 (for a relatively recent review, see Fankhauser, 1994). 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, 1988, 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—down from about double that amount in 1950. 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.

2.3. Intermediate Uses

Other kinds of human activities can maintain some of the benefits of preserving forest land while providing other economic benefits. These activities might include agroforestry projects where crops are planted among trees, selective harvesting of trees from a forest, or small-scale agricultural plots as employed in shifting cultivation. When carefully practiced, these activities can provide long-term benefits from the income-generating activity and from the standing trees; they create moderate intensity ecosystem disruption (Uhl *et al.*, 1990). In some cases, the ecosystem recovers after such uses while in other cases the disruption is permanent but the ecosystem functions are not completely lost. For example, an agroforestry project may begin with the removal of some trees from a forested area. The new spaces are then planted with crops which provide obvious economic benefits. The removal of trees and the crops themselves disrupts the ecosystem but the remaining trees continue to provide ecosystem services.

Another possible example, shifting cultivation, is sometimes considered a major cause of deforestation. Indeed, 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 such farming allow the land to return to some level of forest cover in the long run. 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 uses in this category disrupt the ecosystem in a moderate way but provide some environmental services and direct economic benefits over a long time frame. Properly managed, these uses work with the ecosystem to provide sustainable benefit streams.

2.4. 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, non-native 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 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).

2.5. 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.

2.6. Other Extractive Activities

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, 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 constraints involving the feasibility of sequences of uses. 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 non-concave function of area if there is some critical minimum habitat size (Albers, 1996). Indeed, the ability to preserve biodiversity or specific species may depend on the size and the shape, including wildlife corridors, of the preserved area (Soulé, 1990). 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 about future benefits of preservation, and irreversibility of the development alternative (Arrow and Fisher, 1974; Henry, 1974; Fisher and Hanemann, 1986; and Hanemann, 1989).

The focus of this paper is on laying out a broader framework for valuation and decision making, 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, agroforestry could be M, and large-scale forestry or cattle ranching could be D.

The earlier literature on decisions under uncertainty generally involved two periods. Another way in which we broaden the focus 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 evolution of alternative sequences.

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 → P, P → D, and D → 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

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

where $E[\cdot]$ is the expected present value of the variable in the brackets and the expectation is with respect to the information set available in the first period. Similarly, the maximum expected present values associated with intermediate and development uses in the initial period 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

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

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 *no* difference between the values associated with the two information scenarios: $\hat{V}_D - V_D^* = 0$. For the other two uses, however, there *is* 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 0 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 $(\hat{V}_P - V_P^\circ) - (\hat{V}_M - V_M^\circ) \geq 0$? 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

An application of this framework to a tropical forest in Thailand reveals the differences between the land management plans of a foresighted planner who uses the closed-loop decision rule and a myopic or traditional manager who uses the open-loop decision rule.[1] While the data set contains rough estimates, this example demonstrates the role of sustainability and irreversibility constraints on the development use, D, in determining optimal plans. The example demonstrates that, 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 example uses an area currently designated as a park because of the availability of data, but using such an area also provides a simple setting of a single land owner with well-defined property rights. In much of the world's remaining tropical forests, governments own the land but permit, even encourage, non-preservation land uses (sometimes resulting in title to the land) such as timber operations followed by temporary agriculture. While the following example does not examine these landowner/user issues, the important idea is the same for a government managing park land directly as for a government managing forest land conversion indirectly: the feasibility of land use sequences should play an important role in current decisions. In the non-park cases, this analysis suggests that policies should include incentives for land use decisions that reflect sequences of uses rather than just the first non-forest use.

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[1] This model employs net benefit maximization for the planner's objective function instead of other objectives such as maximizing employment. If these benefits are allocated across the population, then the plan that maximizes net benefits also creates the highest average benefits per household. When such reallocation does not occur, then other objective functions may be desirable.

The manager chooses among three uses, P, M, and D, for the first of three periods in four portions of Khao Yai National Park (KYNP). These uses are defined as described above with D as a trapping state, M as an intermediate use providing long-term benefits, and P as a flexible and sustainable use. The manager employs a 12-year decision period which reflects the investment cycle used to evaluate eucalyptus plantation profitability (Tongpan *et al.*, 1990). The purpose of this example is to demonstrate the role of prospective information in deciding between land use options when some uses are irreversible. To simplify the exposition, the manager faces uncertainty about the future benefits from the P use but not about the future benefits of M or D. The benefits for the M and D uses, however, can be viewed as their expected values where no new information will be forthcoming to aid the decision. This example thus emphasizes the high degree of uncertainty about future preservation values relative to the uncertainty about other values and recognizes that information about preservation values is growing compared to information about other values. The uncertainty description and the sensitivity analysis presented here can be interpreted as including uncertainty about preferences, values, or institutional changes.

4.1. The Data Set

The data required to determine the optimal patterns of land use in KYNP include, among other things, estimates of preservation values, productivity and sustainability of agriculture on the tropical soils, and timber production values. Fortunately, appropriate assumptions about the relative values exist because ecologists and economists have studied KYNP extensively. Still, the data for the valuation of benefits from different uses are somewhat incomplete. These pieces of missing data imply that the following analysis should be viewed as an example that demonstrates the potential impact of the modeling framework rather than a full-fledged empirical study. Table I contains our 'best guess' for the value of each use for each of the four plots in each of the three periods. For example, to determine the present (expected) value of using zone 2 for P followed by M and followed by D, simply add zone 2's first-period P value (row 1, column 4) to zone 2's second period initial M value (row 6, column 4) and add zone 2's third period D value (row 4, column 4).

This analysis divides the 2200 km^2 KYNP into four management units or plots (see Figure 2). The 92.4 square kilometers along the outer edges of the park, plot 1, have been encroached and begin in the use M (KYNP Management Plan, 1987). The well-forested 975 km^2 concentric band inside of plot 1 forms plot 2. The center of the forested area contains 1043 km^2 of forest land and makes up plot 3. The inner two plots, 2 and 3, begin in the preservation use P. The fourth plot, 21 km^2 preserved land, 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. The erosion-control benefits derive from a 'cost of replacement' assessment of the nutrient loss on nearby agricultural land from erosion if the mountainous KYNP area is not preserved (Dobias *et al.*, 1988). The hydrologic benefits of preserving KYNP come from the marginal return to irrigated land of controlling water flows to the surrounding important agricultural lands (Dobias *et al.*, 1988). In the absence of valuation studies aimed specifically at preservation/recreation benefits from KYNP, Dobias *et al.* (1988) combine expenditure information with consumer surplus estimates from other parks to estimate the recreation and existence value of KYNP. This study adds Dobias *et al.*'s estimates of trekking values in the park, too. Estimates of the value of extractive goods form the remainder of the values included in the overall preservation values used in this illustrative example (Dixon and Sherman, 1990; Albers, 1992). Although these data are incomplete, the existing information indicates that the values employed here are realistic estimates for an example designed to illustrate the implications of uncertainty and irreversibility for tropical forest valuation.

These preservation values were calculated for the park area as a whole. For this study, these aggregate values were divided into per-plot values based on existing uses, plot area, and geography. For example, the hydrologic benefits and erosion control benefits were divided into per-plot values based on the amount of each watershed catchment contained in each plot (Khao Yai Ecosystem Final Report, 1982; Albers, 1992). The division of recreation/pure preservation benefits into per-plot values was based on values proportional to each plot's fraction of the total area with plot 3 assumed to contain larger than the area-proportional value and plot 2 assumed to provide smaller than area-proportional value because of their road access and shapes (Albers, 1992). The benefits from extractive goods were divided based on areas and on distance costs.

Two states of the world define the uncertainty about future preservation benefits with a high state creating high levels of benefits and the low state creating low levels of benefits. The high state preservation values reflect the additional preservation value that a viable population of Asian elephants creates in the KYNP.[2] The high state benefits grow at two and one-half percent per year. The low state preservation benefits reflect the possibility of a large drop-off in tourism revenue in

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[2] 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 Thailand's wild elephant population and habitat.

the later periods. The high state occurs with a probability of 0.5 in the second period and 0.25 in the third period.[3]

The benefits from M, or intermediate management, include agricultural values based on a stylized swidden agricultural system and extractive good collection on the remaining non-agricultural land.[4] The benefits from the swidden system come from converting 10 percent of the plot's forest land to small scale agricultural plots which are assumed to be farmed for two years and abandoned. Thus, at the end of one 12-year decision period, sixty percent of the land has been farmed for two years and is at various stages of forest recovery. The agricultural values drop off over time as more land is converted away from forest leaving less erosion control and fewer regeneration pathways for the farmland. The extractive good values are also assumed to be

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[3] These probabilities aid in the illustrative application of the model. This application does not represent a definitive empirical investigation and these probabilities are intended to reflect a plausible scenario. The probability of a high event is assumed to decrease over time to reflect intertemporal changes in elephant preservation benefits and tourism benefits. The probability of the elephants' survival declines over time. The tourism benefits could also decline dramatically if the increasing AIDS threat in Thailand depresses international tourism. These factors support the assumption that the probability of a high event declines over time. See Albers (1996) for a discussion of the probability distribution's impact on the option value size.

[4] Such systems of swidden agricultural occur in similarly mountainous regions of Thailand but are not practiced by farmers near KYNP. These systems can provide long periods of agricultural benefits because they are well adapted to the mountainous forest setting. In contrast, the locally predominate farming in the surrounding flatland would not provide such long-term benefits and represents a more intense land use. This type of local agriculture is included as part of the D use in this example.

unsustainable harvest levels and therefore decline over time.[5] For this example, the M use does not provide the same level of benefits in each year but enough land recovery occurs when farmed plots are abandoned that the benefits can continue for a long time.

The benefits from the irreversible development option, D, derive from permanent agriculture and medium-sized plots of eucalyptus plantations (Tongpan *et al.*, 1990).[6] The estimates of the agricultural values come from crop production in the surrounding flatlands. Because farming in KYNP would involve upland farming on erodible slopes, these agricultural value estimates decline over time at a rate that corresponds to erosion-induced productivity declines on the slopes of fragile tropical soils (Onchan, 1990; Thailand Development Research Institute, 1986). The eucalyptus values come from Tongpan *et al.*'s description and analysis of existing eucalyptus plantations in Thailand. Following Tongpan *et al.*, the values used here reflect a 12-year investment horizon, based on rotation ages, which defines the length of the planning period here. The values contain the assumption that current prices and cost structures represent the expected value of future prices and cost structures as

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[5] Troy Hansel, a Peace Corp Volunteer in KYNP, describes the existing extraction levels as borderline sustainable in that continued extraction at current rates can continue indefinitely. 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.

[6] The amount of land converted to agriculture and eucalyptus plantation per plot depends on the plot's topography and accessibility. Plot 1's D option includes 25 percent of land in agriculture and 25 percent in eucalyptus. The remote plot 2 contains 40 percent agriculture and 10 percent eucalyptus. Plot 3 converts 10 percent eucalyptus and 30 percent agriculture. Plot 4's D values include 40 percent of the land in agriculture but its slopes and remoteness prohibit eucalyptus production.

described above. In the first example discussed below, the eucalyptus values remain undiminished over the three periods. Changing that assumption by modeling eucalyptus values that decline over time—a potentially realistic case for plantations on such fragile soils—reveals the importance of 'sustainability' of eucalyptus values in determining current land use patterns.

4.2. Solving the Planner's Optimal Land Use Problem

In this empirical application, each manager, the traditional open-loop manager and the foresighted closed-loop manager, views the future M and D benefits with certainty, which simplifies their decision. Each manager 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. For plots 2, 3, and 4, the traditional manager finds the maximum of:

$$
\begin{aligned}
V_P^* &= P_0 + \max\{E[P_1] + \max\{E[P_2], M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\} \\
V_M^* &= M_0 + \max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\} \\
V_D^* &= D_0 + D_1 + D_2.
\end{aligned}
$$

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

$$
\begin{aligned}
\hat{V}_P &= P_0 + E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \\
\hat{V}_M &= M_0 + E[\max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \\
\hat{V}_D &= D_0 + D_1 + D_2.
\end{aligned}
$$

Both the managers look at the M and D income streams for plot 1.

Two PASCAL programs solve the optimization problems from the perspective of each manager for the KYNP example using the benchmark data presented in

Table I.[7] The programs calculate the option value. The benchmark optimization assumes a 10 percent discount rate.

4.3. Results

In the benchmark case, the traditional and foresighted managers preserve markedly different amounts of KYNP (see Figure 3a). Both managers convert the degraded plot 1 to the development option due to its low productivity in agriculture. The managers also agree on the use of plot 4 for intensive extractive goods and small scale agriculture, or use M. While both planners preserve plot 2, they differ in their decision on plot 3. The traditional manager develops this plot and thereby reduces the amount of local parkland by half.[8] The foresighted manager preserves this area and maintains the opportunity to take advantage of future information about future preservation values.

The option value generated in this benchmark 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 shows the potential significance of our theoretical framework, especially in cases where the preservation and development benefits appear close in expected value.

The example generates a small option value because of the relatively small value of future periods when compared to the current period value and because of the small range of possible outcomes (Albers, 1996). Option value will be larger in cases of uncertainty in near periods and in cases of large divergences in possible outcomes.

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[7] See Albers, 1992 for the computer code to solve these optimization problems.

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

Large option values may be expected in the valuation of tropical forests at the global level because of the wide range of estimates from the scientific community about the role of tropical forests in global climate control and the future benefits from preserving biodiversity in tropical forests. Because our example ignores those global values in its concentration on Thailand's management, it understates both the uncertainty about, and the average value of, the tropical forests from a global perspective.

At the 10 percent discount rate in the benchmark example, the optimal land use patterns of the two managers diverge. Both managers remain sensitive, however, to assumptions about that discount rate. For example, the myopic and traditional manager preserves more land—indeed she manages the land in the same way as the foresighted manager—when she employs a zero discount rate (Figure 3b). In this 'no-discount' scenario, the traditional manager finds the sustainability constraint on the agricultural portions of the D values sufficiently costly that she employs the D use only on plot 1. In other words, with no discounting, the traditional manager sees that the future preservation values carry enough weight to overcome the shorter run development values on the large plot 3. In the case of a 20 percent discount rate, both managers convert all of the land away from preservation (Figure 3c). In the closed-loop framework developed here, the manager remains sensitive to the discount rate but preserves land at higher discount rates (10 percent in the example) than the traditional manager.

The manager's choice of optimal patterns responds to the assumption of sustainability of the eucalyptus plantation. For example, relaxing that assumption by making the eucalyptus plantations fail after two investment periods encourages the traditional manager to preserve plot 3 (Figure 3d). Furthermore, removing the sustainability constraint completely by having no income after the first period of D induces both managers to place plot 1 in the M use instead of the D use (Figure 3e). The managers' optimal patterns, therefore, reflect sensitivity to sustainability assumptions. If a manager makes an erroneous assumption about the long-run sustainability of eucalyptus, the resulting land use pattern is strikingly different from the true optimal pattern and the mistake is irreversible.

The discussion to this point has followed the assumption of section 3 that uncertainty about benefits in a period is resolved at the beginning of the period. The resolution of uncertainty in one period does not effect the uncertainty of future. An interesting, and perhaps more realistic, assumption might be that the state revealed in one period changes the priors about the probability distribution for the next period. Using this assumption 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. As above, the traditional manager makes decisions based on the best information available in the current period and ignores the possibility of future information but the foresighted manager recognizes the added information. The probabilities in the benchmark case were:

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

The following example of probabilities maintains the same first-period conditional probabilities, those used by the traditional manager, but models an increase in information from the revelation of the state in time 1:

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

Because the traditional manager uses only the first-period probability information, this change in probability structure does not change the optimal land allocation. Using the benchmark data with this new probability-information description, the foresighted manager's optimal plan also remains unaltered (Figure 3f). The extra information contained in the new probability structure, however, does increase the option value by 8 percent. While the optimal pattern doesn't change, the added option value increases the number of cases where the foresighted manager preserves more land than a traditional manager.

Overall, this KYNP example demonstrates the feasibility and relevance of applying the framework of stochastic dynamic programming to tropical forest valuation and management decisions. The example demonstrates that, over relevant ranges of values, the foresighted manager preserves more land than the traditional manager at the margin. The example also shows that the foresighted manager preserves land at higher discount rates than the traditional manager. The example reveals the ease of expanding the framework to incorporate realistic models of sustainability and information arrival. In addition, this empirical example provides an economic rationale for Thailand's preservation of KYNP—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 than the traditional expected value approach. The KYNP 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

Lemma

The maximum function is convex.

Proof

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

where the X_i are the elements of the vector X.

Consider $g(qX' + (1 - q)X'')$ $\quad 0 < q < 1$,

where X' and X" are two different vectors.

$$\begin{aligned} g(\theta X' + (1-\theta)X'') &= \max\{\theta X' + (1-\theta)X''\} \\ &= \max\{\theta X_1' + (1-\theta)X_1'', \theta X_2' + (1-\theta)X_2'', ...\} \\ &\leq \max\{\theta(X_1', X_2', ...)\} + \max\{(1-\theta)(X_1'', X_2'', ...)\} \\ &= \theta \max\{X_{11}', X_2', ...\} + (1-\theta)\max\{(X_1'', X_2'', ...)\} \\ &= \theta \max\{X'\} + (1-\theta)\max\{X''\} \\ &= \theta\, g(X') + (1-\theta)\, g(X''). \end{aligned}$$

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

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

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

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

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

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,

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

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Table I. Data for benchmark KYNP example.

Period	**Use**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
time 1	P	29.04	777.42	653.54	14.35
time 2	P (low event)	8.33	228.11	154.59	4.36
	P (high event)	8.33	278.85	290.11	4.36
time 3	P (low event)	2.64	72.37	49.05	1.38
	P (high event)	2.64	94.63	108.49	1.38
time 1	a[a]	41.67	439.75	416.32	33.8
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[a]	8.16	86.15	74.92	1.13
time 3	b	2.6	27.45	23.87	0.36
time 3	c[a]	1.46	15.36	10.96	0.1
time 1	D	50.91	840.31	828.44	9.36
time 2	D	16.41	269.07	265.34	2.98
time 3	D	5.42	86.73	84.86	0.95

Note: All values are present discounted values (interest rate of 10 percent) of benefits received in the time period indicated in column one.

[a] 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 Captions

Fig. 1. Feasible sequences.

Fig. 2. KYNP plots and initial uses.

Fig. 3. KYNP first-period optimal patterns.

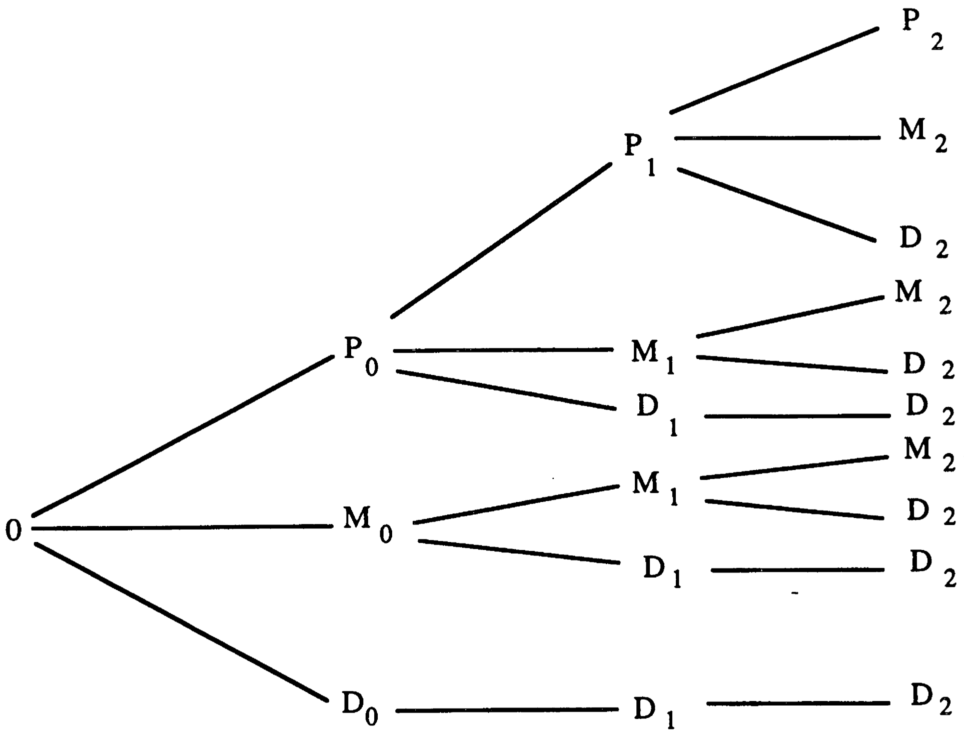

Fig. 1. Feasible sequences.

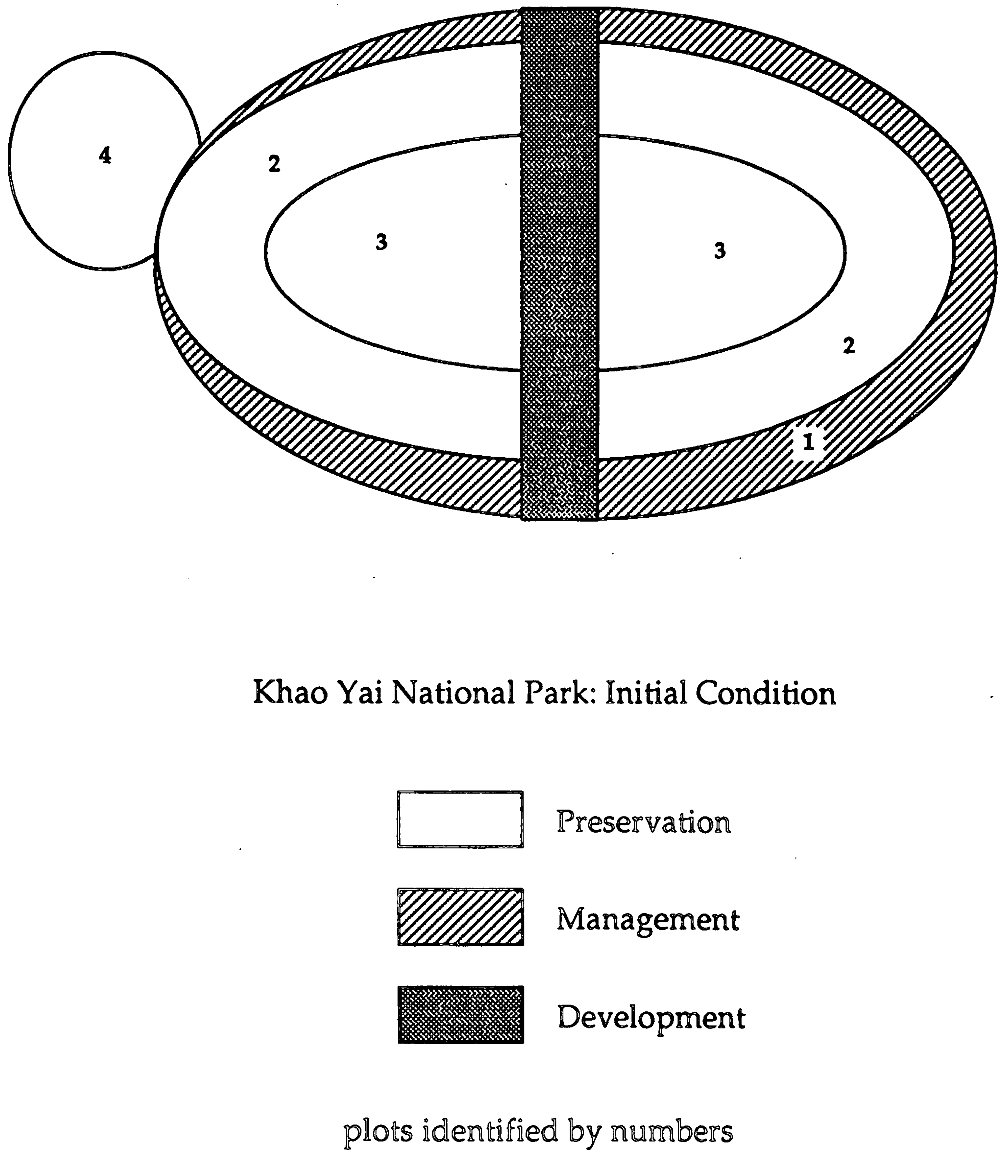

Fig. 2. KYNP plots and initial uses.

foresight **myopic**

a) • benchmark result

option value = 1.6%

b) • r = 0%

option value = 1.8%

c) • r = 20%

option value = 0%

Fig. 3. KYNP first-period optimal patterns.

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%

Fig. 3. Continued.