A Spatial-Intertemporal Model for Tropical Forest Management Applied to Khao Yai National Park, Thailand

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Abstract

This paper discusses the application of a spatial-intertemporal model for tropical forest management to Khao Yai National Park in Thailand. This type of model, especially the spatial components, finds different optimal land allocations than do traditional models at empirically relevant levels of benefits. The spatial analysis here suggests that most of this park can be best used as a preserved area and also provides support for expanding the park into an adjacent unpopulated area. The analysis demonstrates that the park's benefits to regional agriculture and villagers are large enough that preservation can proceed without international support, and that local people, as a group, have incentives to maintain most of the area as preserved land. Although the data cannot support a full case-study, these results underscore the need for empirical assessment of the spatial aspects of protected area management.

Key Words: parks, protected areas, people-park conflict, spatial, biodiversity, option value

JEL Classification Numbers: Q2, Q15, O13

Contents

Summary

This paper links a model of ecological and social constraints on tropical forest management to data describing these constraints. Although not a complete case study of Khao Yai National Park (KYNP), in central Thailand, this paper examines the empirical importance of uncertainty, irreversibility, spatial relationships, and resource dependence by local people in tropical forest management. The modeling of intertemporal characteristics of tropical forest management generates a quasi-option value that does not contribute much to the optimal land use patterns under a variety of descriptions of uncertainty unless the time frame considered expands from 15 years to 30 years. The spatial relationships—habitat size, recreational benefits as a function of size, a positive externality of proximity to preserved land on resorts, and a negative externality of crop damage from proximity to preserved land—appear especially important in determining land use patterns. Analysis of the KYNP dataset raises some questions about management decisions, such as regulations against using any park land for buffer zones, the prohibition on extracting renewable resources from the park's forest, and the decision to manage the area as a homogeneous block. In this paper the KYNP dataset forms the basis for a discussion of the relevance of a spatial-intertemporal modeling perspective for a real-world case, the potential for efficiency losses associated with some management decisions, and the types of research and data required for further policy analysis.

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Heidi J. Albers*

Tropical forests in developing countries challenge traditional forest management approaches because their ecological characteristics and the manner in which people use them place constraints on their efficient management. Tropical forests present ecological constraints on intertemporal management because the future benefits from these forests are highly uncertain, and some forest uses are irreversible (Albers et al. 1996). Tropical forests create ecological constraints on spatial management because externalities, both positive and negative, across adjacent plots may contribute significantly to such benefits as biodiversity (Albers 1996). Tropical forests present social or institutional constraints on management because of the complex policy and property rights setting in most developing countries and because forest benefits accrue to a wide range of people, from neighboring villagers collecting vegetables to the distant populations that enjoy tropical forests' contributions to global climate control.

Governments in developing countries, who typically own and manage the majority of their countries' forest resources, have increasingly employed systems of parks and reserves (Repetto 1988; Ghimire 1994).[i] As discussed in the growing literature on conflicts between people and parks, a government's emphasis on protection of tropical forests often ignores the impact of this management on rural people dependent on the forest resources (West and Brechin 1991; Ghimire 1994; Albers and Grinspoon 1997). Managing tropical forests by restricting access to resources, together with the spatial and intertemporal constraints, raises questions about the efficiency of management choices, such as the size of the protected area, the uses allowed within the protected area, and the degree to which managers should consider the impact of their decisions on rural communities.

Despite the importance of tropical forests, few studies have linked a model of ecological and social constraints on forest management to data describing these constraints. Khao Yai National Park (KYNP) in central Thailand provides an opportunity to demonstrate the empirical importance of spatial, intertemporal, and social constraints on tropical forest management.

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KYNP has been the subject of much research, including both ecological studies and economic valuation studies, which has generated more information than is available for most similar tropical forests. KYNP also presents clear management challenges. The park is not an island of pristine forest surrounded by cropland; rather, it has substantial tourist facilities both at its center and at its entrances, in one area it abuts a mountainous wilderness, and some of its boundaries have been permeable to local villagers taking forest products from a *de facto* buffer zone (Khao Yai Ecosystem Project Final Report 1982; Albers and Grinspoon 1997). Even the relative wealth of information about KYNP does not contain the precise numbers for a full spatial-temporal model. Nor are the current zones of land uses in and around the park the result of conscious management decisions.

Even though those data restrictions and policy decisions preclude a comprehensive case study, the KYNP dataset allows an examination of the empirical relevance of uncertainty, irreversibility, spatial relationships, and resource dependence by local people. Analysis of the dataset raises some questions about management decisions, such as regulations against using any park land for buffer zones, the prohibition on extracting renewable resources from the park's forest, and the decision to manage the area as a homogeneous block. In this paper, the KYNP dataset forms the basis for a discussion of the relevance of the modeling perspective for a real-world case, the potential for efficiency losses associated with some management decisions, and the types of research and data required for further policy analysis.

Ecology, Use, and Management of the Park

Tropical forests such as the forest in KYNP present managers with the challenge of incorporating ecological and social characteristics in decision analysis. From an economic perspective, with a concern for efficiency, the park's tropical ecology requires, at a minimum, management rules that reflect the irreversibility of some uses, the uncertainty about future values, and the spatial considerations for providing biodiversity. From a societal perspective, the social uses and management institutions of KYNP require management rules that reflect the park regulations, the needs of local people, and the impact of the preserved area on neighboring agricultural land and resorts. Given these ecological and institutional requirements, KYNP's management rules rely on assessments of the types of land uses available and the relevant number and size of spatial zones within the area.

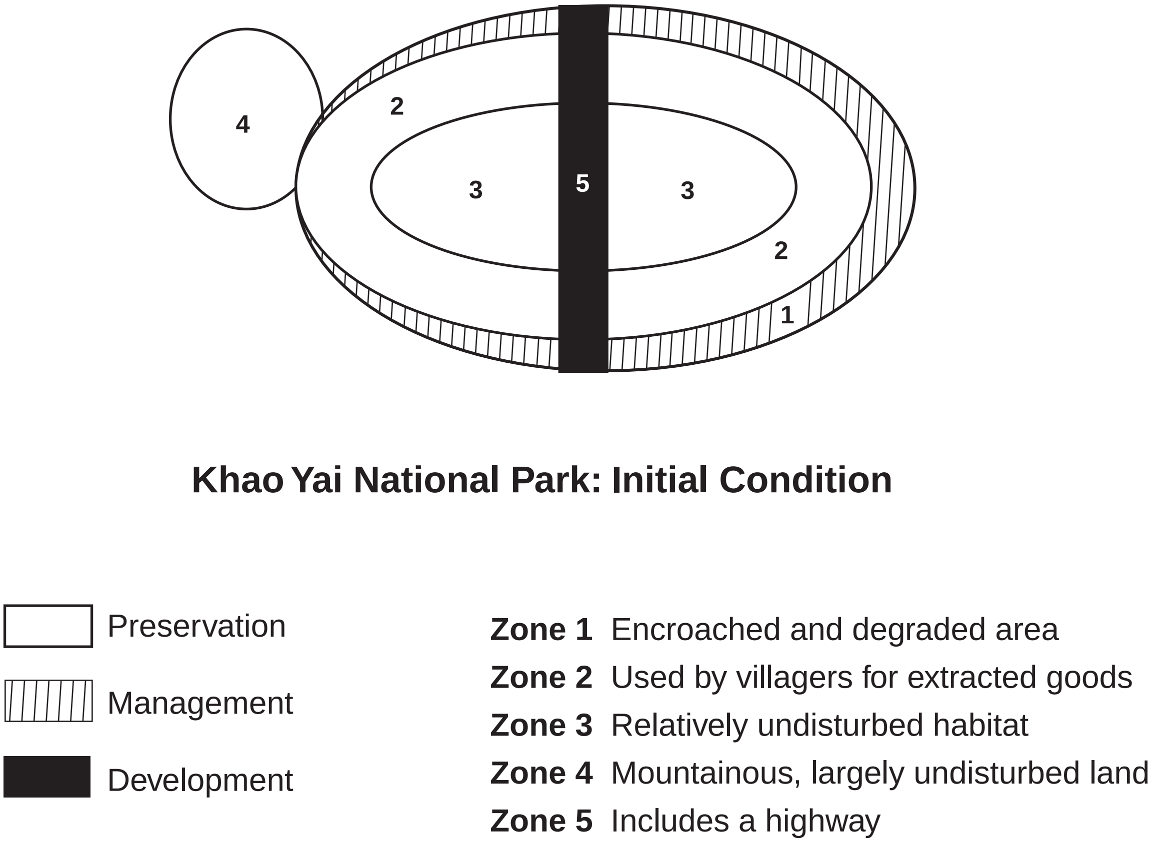
Background

The Royal Forestry Department (RFD) has managed KYNP since it became Thailand's first national park in 1962. The agency aims to preserve the diversity of flora and fauna that led to the park's selection as an ASEAN Heritage Park and Reserve and continues to attract domestic and international tourists, especially birdwatchers. National regulations for park management prohibit any other uses of park land, such as extractive collection or selective logging. The RFD therefore manages KYNP's 2,200 square kilometers as a preservation area, with tourism and research as the only land use activities. The RFD views the park as one cohesive management unit and focuses on offering tourist information at park headquarters and enforcing the preservation mandate at the encroached park boundaries. Park managers responded to conflicts between their preservation goals and perceived misuse by tourists by eliminating overnight visitation in 1992. Tourists and researchers have continued, however, to take advantage of the vast resources that KYNP offers.

Land Use Zones

Although the park is managed as one unit, the management zones for this analysis reflect current uses and ecological conditions and recognize that areas of the park have been subjected to different levels of human use, which have changed their function and value. Figure 1 depicts the park's management zones and their initial uses. Certainly, management zones based on current ecological conditions represent only one possible division of the park into units; with enough information, management zones could reflect other attributes of the land and changes over time. Finer and more management zones cannot, however, be supported with the available data.

Figure 1: KYNP Zones and Initial Uses



For the purposes of this study, zone 1 consists of 92.4 km^2 of encroached and degraded areas on the outer edges of the park (Khao Yai National Park Management Plan 1987). Zone 2 contains a 975 km^2 band of land beginning at the outer borders of KYNP, which villagers use extensively for extractive goods (Albers 1992). Zone 3's 1,043 km^2 of relatively undisturbed habitat, the core of the park, has easily accessible trails for tourists, birdwatchers, and hikers. Zone 4 is 21 km^2 of mountainous, largely undisturbed land that lies outside the park's borders to the northwest. Zone 5 includes a highway that bisects the park, the park headquarters, tourist accommodations, restaurants, managed grassland, and park employees' lodging. Zone 5 generates value but is not part of the decision framework because the irreversibility of the development option means that this zone will always be developed land.

Land Use Options and Time Periods

As in any intertemporal management decision under uncertainty, the reversibility of decisions on land use allocations plays a potentially important role in the decision framework and, here, in the optimal land use patterns (Arrow and Fisher 1974; Pindyck 1991). In the case of KYNP, an irreversible loss of some forest land is apparent in the long-standing regions of grass, scrub, or low-biomass forest in some heavily disturbed areas. This irreversible loss appears to be the result of popular local land uses, such as large-scale "permanent" agriculture and perhaps eucalyptus plantations. Still, the ecological characteristics of the park's forest include the ability to recover to nearly full forest cover, over time, after less disruptive uses. This ecological characteristic of recovery over time demonstrates itself in the quality of the forest now standing on the many areas that were used for swidden agriculture and nontimber forest products before the park's establishment. These observations about the ecological characteristics of land use in and around the park suggest two categories of land development: one land use modeled as an irreversible decision and another land use modeled as reversible over time.

Given those ecological characteristics, the four land uses considered here depict varying levels of intensity and reversibility (Albers et al. 1996; Uhl et al. 1990). Preservation (P) provides the greatest flexibility because preserved land can be converted to any use in subsequent periods. Intermediate management (M) and development (D) reflect conversion of the land from its natural state. Development prevents the land from functioning as part of an ecosystem and comprises eucalyptus plantations, permanent agriculture, and resort development. Intermediate management does not destroy all the land's contribution to the ecosystem and represents the system of swidden agriculture and extractive collection. Although intermediate-managed land can later support development, reversion to the preserved state requires time in the recovery use (R).[ii]

To reflect the timing of land recovery after the intermediate management use, M, and the length of most policy plans, a period here refers to five years. The decision framework determines the optimal land use for the first five-year period in a series of three periods. With this framework, for example, land can be used for intermediate management for five years in the first period, followed by five years of recovery in the second period, and followed by five years of preservation in the last period. The framework represents the "five-year plan" as a basic decision unit with only one land use permitted within each period.

In addition to this intertemporal characterization of the land use options, uncertainty about future benefits contributes to the management decision framework and to the optimal land use patterns. Although the value of all of these land uses is uncertain, the analysis presented here focuses on uncertainty about the future preservation values. This analysis models the uncertainty about the future values of intermediate management and development as unaffected by forthcoming information; the values for these uses are the traditional expected values. In this analysis, however, the benefits from preservation of KYNP in the first period are known and there is uncertainty about the future benefits, but information arrives to dispel that uncertainty. Following the economic literature on quasi-option value, information arrives exogenously over time with all of the relevant uncertainty dispelled at the beginning of the new period. The preservation benefits may be high or low depending on the state of the world. The probability of each state and the benefits from preservation for each state are known in the first period. This framework focuses on the uncertainty and exogenous information arrival about future preservation benefits to concentrate the analysis on the characteristics of tropical forests.[iii]

Spatial Aspects of Land Use

Still other ecological characteristics, especially when combined with economic factors, suggest that efficient tropical forest management requires a spatial analysis. In general, tropical ecology suggests that biodiversity increases with contiguous area (MacArthur and Wilson 1967). In KYNP, many large animals, such as elephants and guar, need large areas of contiguous forest land (Soulé 1987). In addition, larger ecosystems may attract more recreational visitors because of trekking and wildlife-watching opportunities. These ecological and economic characteristics of KYNP indicate that the spatial configuration of land uses plays an important role in the flow of benefits (Albers 1996).

Rural people living near KYNP and the resorts that border the park receive benefits directly and indirectly from the park, which implies additional spatial aspects to KYNP management issues. Nearby resort owners clearly gain from their proximity to the park, because their guests are there to enjoy the park and the cool and low-humidity climate. The agricultural neighbors of KYNP continue to collect food and fuelwood from the park despite the threat of punishment, and they also gain from the positive externalities it creates, such as watershed and soil protection. In contrast, farmers near parks in many parts of the world report large losses from the wild animals who destroy their crops (Studsrod and Wegge 1995; West and Brechin 1991; Kiss 1990; Schultz 1986). The neighbors of the park, then, clearly perceive an impact of the park on their welfare, and that impact should be included in an analysis of land use management from a social, rather than a park-only, perspective.[iv]

Because of those spatial characteristics of the benefits from KYNP, decisions about the appropriate land use for one zone cannot be decoupled from the land use decisions for other plots. An efficient manager considers the impact of the land use decision for zone 1, for example, on the land use decision for zone 2. The management zones defined above provide a structure through which to determine the impact of spatial characteristics on optimal land use and to determine the losses associated with managing KYNP as a homogeneous unit. With additional information, the division of KYNP into management zones could be part of the optimization procedure itself as a dynamic choice. More detailed zonation is impossible, however, because even in the data-rich setting of KYNP, valuation information reflecting spatial characteristics is insufficient to inform more detailed divisions, let alone dynamically optimal divisions.[v] If the management zones employed here, and the spatial relationships among zones, demonstrate a significant role in optimal land allocation, that result should be interpreted as an indication of the need to generate more accurate information about spatial aspects of preservation and other benefits.

A Spatial and Intertemporal Modeling Framework

The economic management model discussed here takes the spatial and intertemporal model in Albers (1996) and adjusts the spatial characteristics and land use categories to address the KYNP case. As discussed above, the economic management model formed to address the issues of land allocation in KYNP must have several characteristics: a variety of land use options; spatial dimensions; and intertemporal aspects. This model considers four land use categories to distinguish among degrees of irreversibility. The model forms a spatial framework to examine management of the area as one unit versus multiple units and to recognize the externalities associated with different land uses. The model's intertemporal framework allows characteristics of tropical ecosystems and uncertainties about future relative values to be incorporated in current decisions.

As in many models of irreversible decisions under uncertainty, the model for KYNP gives a flexible manager an incentive to remain flexible by postponing irreversible choices—here, the development land use—until information clarifies the value of the choices. The model's closed-loop solution for the flexible manager creates an expected value of preserving land in the first period calculated with future information that is as large as or larger than the expected value with no information forthcoming, as in the open-loop solution of the inflexible manager (Albers et al. 1996; Fisher and Hanemann 1986a, 1986b; Arrow and Fisher 1974). The flexible manager's model contains an added value, called quasi-option value, which reflects the expected value of future information if the manager is in a position to take advantage of it.

In the model presented here, patterns of land uses within a period arise because the division of KYNP into management zones creates a cellular structure for the spatial analysis. The patterns of use on those zones and the flow of intertemporal benefits among them determine the value of the entire park area. The pattern of use creates additional value when, because of the proximity of two particular uses, a use in one zone creates an externality. To maximize the total value of the land, the pattern's impact on total benefits should be considered.

The model here attempts to capture three spatial characteristics of the benefits from land use in and around KYNP. To characterize the added benefits of creating large habitats, the model adds a value, named P-annex, to the total benefits for every instance of adjacency between two preserved zones (see Appendix 1 for notation). To capture the increase in the value of resort development due to proximity to preserved land, the model adds a site externality value (S) for every instance of a border between a developed and a preserved zone.[vi] To represent the potential for crop loss on agricultural land bordering preserved land, the model subtracts a crop-loss cost (C) when a zone of intermediate-managed land shares at least one border with a zone of preserved land.

The spatial and intertemporal models combine to create a model of some of the ecological characteristics and use characteristics of tropical forests and their impact on the benefits from land use patterns. The differences between the optimal patterns of the flexible and inflexible managers demonstrate the role of forthcoming information in determining the patterns. In similar fashion, the differences between patterns formed by a manager who incorporates the spatial interdependencies in her decisions—that is, the spatial manager—and a manager who does not recognize these interdependencies—that is, the nonspatial manager—demonstrate the role of the spatial modeling in determining the patterns. A manager who uses the complete model and incorporates future information and the spatial interdependencies is a spatial and flexible manager. The traditional manager who ignores forthcoming information and spatial interdependencies is a nonspatial and inflexible manager. Falling in between these two managers are the spatial, inflexible manager and the nonspatial, flexible manager. A PASCAL computer program solves the optimization problem for this four-zone, three-period, four-use case.

The economic management model developed here reflects the management perspective of a planner seeking to maximize total benefits generated by the land and land uses. The model therefore includes all benefits rather than just the benefits that accrue to park managers. In this sense, then, the model is different from a model that would be employed by KYNP managers, who do not consider the impact of the park on rural people, for example.

Values

The model permits an examination of management issues for KYNP through the use of an extensive dataset that describes the characteristics of the park, the value of alternative land uses, and the interaction of the values across management units. This dataset brings together information from several studies, including ecological information from the Khao Yai Ecosystem Project Reports, planning ideas from the KYNP Management Plan (1987), and economic valuation from Dobias et al. (1988) and Dixon and Sherman (1990). To fit the spatial and intertemporal model, the data from these sources are divided into per-zone values and combined with a description of uncertainty and of cross-zone interactions to form the relevant dataset in Table 1. The resulting dataset contains assumptions about uncertainty, per-zone values, and spatial values that limit this analysis to an example rather than a full-fledged case study.

The preservation values sum benefits from three categories: hydrology and erosion control benefits; recreation values; and sustainable extractive incomes (Albers 1992). The park protects watersheds and provides water for irrigation to the surrounding agricultural lands, services valued at 31.7 million Baht, or approximately US$1.27 million, per year (Dobias et al. 1988). The park's forest controls soil erosion, which Dobias et al. (1988), using a nutrient-loss cost-of-replacement method, value at 75.3 mB/year.[vii] The park generates recreation benefits and consumer surplus of approximately 35 mB/year, although this estimate may be low because it is based on a portion of visitor expenditures and studies of other parks' consumer surplus (Dixon and Sherman 1990; Dobias et al. 1988). Trekking and camping opportunities generate an additional 2.6 mB/year of recreation benefits (Brockelman and Dearden 1990). The park also generates extractive values of approximately 100 B/day during the six-month nongrowing season from the vegetables, medicines, herbs, and meats extracted by the 3,000 local families (Albers 1992). The park's preservation values, for this study, include this extractive income despite the illegality of this collection activity.

To value preservation benefits, existing studies have viewed KYNP as a unit. For the spatial analysis in this paper, the values for the entire park must be divided into values generated by each zone and values generated by patterns of uses on those zones. For the purposes of this study, the total park values from hydrology and erosion control are divided on a per unit area basis. The recreation benefits are assumed to come largely from the inner core area, zone 3, and from zone 2. Of the total recreation benefits for the park, zone 2 is assumed to generate 25% of its area-proportional value because of its small size and awkward shape without a preserved zone 3. The remainder of the recreation benefits from zones 2 and 3 are included as the P-annex term—that is, the additional value of having both zones 2 and 3 preserved or the value of generating contiguous habitat and recreation area. This valuation assumption reflects the fact that if only zone 3 or only zone 2 were preserved, hiking opportunities and biodiversity would be diminished. The preservation values for zone 4 and the P-annex value for preserving zones 2 and 4 come from the value of trekking from local villages into the park. The per-zone extractive values reflect actual use in zone 2, use without enforcement of the ban on collection for zone 3, and values proportional to area for the other zones (Albers 1992; Dixon and Sherman 1990). Again, no existing studies divide the total preservation values by zone, and this study can only approximate the divisions. Still, these divisions appear reasonable and allow a determination of the role of spatial aspects in allocating tropical forest land.

For the intertemporal analysis in this study, the preservation values must include a description of uncertainty about future values. The preservation values may increase over time if ecotourism continues to grow but could also decrease if the wildlife within the park declines or other factors prevent tourism. The preservation values here reflect only a small portion of the possible range of values because information about the probability of different events is extremely limited. The preservation values will clearly be higher if elephants survive in KYNP, lower if they do not (Dobias, 1985). The values employed here, then, reflect the benefits associated with the preservation of a viable population of elephants in Thailand weighted by the fraction of those benefits that KYNP provides (Albers 1992; Dixon and Sherman 1990). That contribution to preservation value, 122.5 mB/year, added to the other preservation values, forms the high end of the range of preservation values used in the following analysis, corresponding to the case of elephant survival. This value is not added to the low-state values for preservation and thus forms the distribution of uncertainty for the benchmark case. The probability assigned to the high and low states is 0.5 for lack of specific information about the probability of elephant survival and about trends in the value of elephant preservation over time. Each zone has a high- and a low-state preservation value, although there is no difference between the high and the low for zone 1, which does not generate elephant habitat benefits.[viii] Again, assessment of preservation values rarely includes a range that describes the uncertainty. This attempt, while clearly insufficient for detailed analysis, demonstrates the potential role of such uncertainty and the need for further study to depict such probability distributions.

The value of intermediate management depends on the amount of land converted from forest land, estimates of local agricultural productivity and extractive collection, and changes in productivity over time. Assuming that the intermediate management use, small-scale agriculture, involves converting 10% of the forest land to agriculture—an assumption that approximates the prepark use of the land—the benefits include the value of farming rice and corn on that area for two years before abandonment (Khao Yai Ecosystem Project, vol. 5, 1987; Albers 1992). In the third period of intermediate management use on a particular zone, the agricultural value falls by 10% to reflect the need to start farming low-quality or recently farmed land. In addition, the benefits include the value of extractive products collected from the remaining 90% of the zone at a rate that is 25% higher than the extraction rate for preservation land. The value received from extraction falls by 50% in the second period and by another 25% in the final period to reflect the lack of sustainability of this extraction level and the reduction in extractive area as new agricultural zones are cleared. The total value of intermediate management therefore changes as a function of the number of years a given zone has been in that use. In addition, a zone in recovery after the intermediate management use generates a value equal to the fraction of the low-state preservation value that corresponds to the average recovery biomass divided by the biomass in preservation. Recovery, R, also creates a P-annex value at this biomass-proportional rate (R-annex in the tables).[ix]

The crop-loss spatial term described above occurs whenever an intermediate management zone borders a preserved zone. In the benchmark analysis here, that term carries a zero value because interviews with farmers revealed very little concern for this problem. In the spatial sensitivity analysis, though, this term receives a range of values to depict possible outcomes. In a rare quantitative assessment, Studsrod and Wegge (1995) report that the highest losses near Royal Bardia National Park in Nepal are approximately 35% of the maize and rice crops, which are the most important crops in the KYNP example. The crop-loss term (C) can thus be approximated by reducing the agricultural benefits from a zone of intermediate managed land by 35% when that zone borders at least one preserved zone.

The benefits from the development use come from a variety of large, ecosystem-disrupting uses, such as permanent agriculture, eucalyptus plantations, and resort construction. The agricultural values, gleaned from reports describing productivity and prices in neighboring areas, decline over time as erosion occurs (Albers 1992; Onchan 1990; KY Ecosystem Project, vol. 3, 1987; TDRI 1986). These declines in value range from an immediate productivity loss on hill evergreen soils, to one period (five years) of productivity on dry evergreen soil, and to two periods of productivity on moist evergreen soil. The eucalyptus plantation values reflect the social profitability of the medium-scale eucalyptus planter who plants between 100 and 1,000 rai of eucalyptus (Tongpan et al. 1990).[x] These values depend on road accessibility and topography. The total development values contain assumptions about the amount of land converted to agriculture or eucalyptus, ranging from 25% to 40% of the land for agriculture and from zero to 20% of the land for eucalyptus.

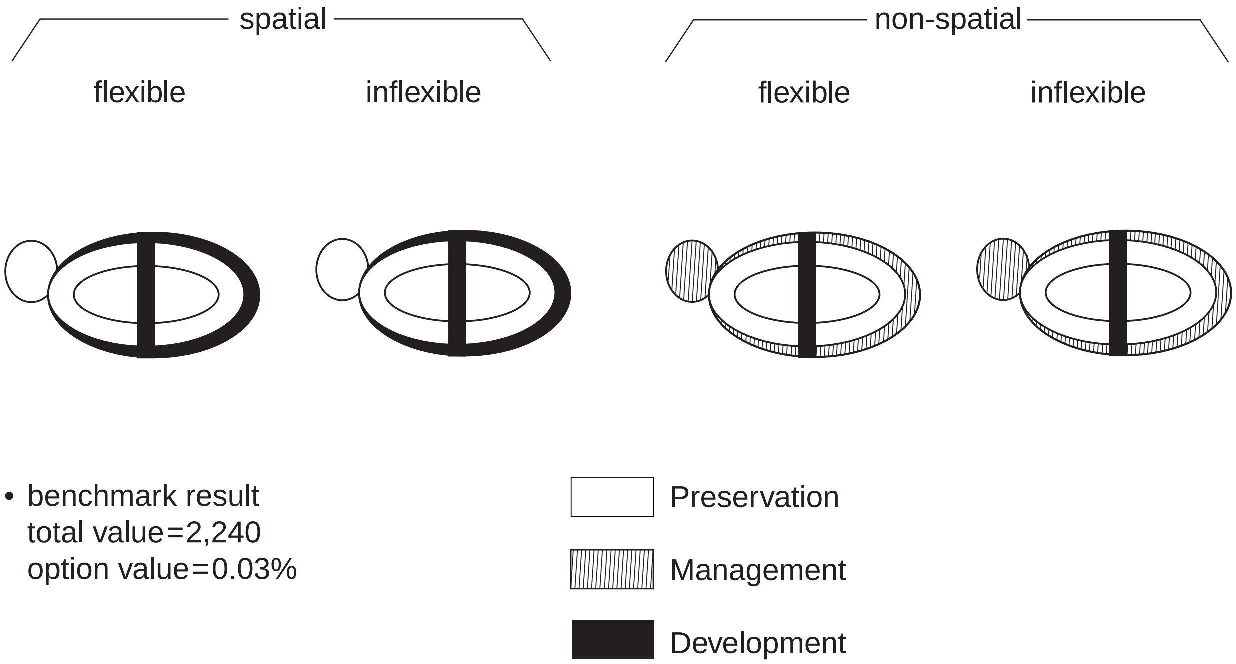
In this empirical application, development in or near KYNP receives a positive externality from proximity to preserved areas if development includes resort ownership. This externality (S) captures the benefits of building a resort near preserved land because most resorts depend on access to the park or preserved land for recreation and for local climate control. The profitability of a resort in the area is approximated by examining the profits generated by Thailand's Association on Tourism at its golf course, restaurants, and lodging within zone 5 of KYNP and correcting for capital outlays and competition (Albers 1992; Dobias et al. 1988).

Table 1 includes the data input into the computer program for the benchmark analysis of KYNP management. The values have been summed over five years for each period at the discount rate shown in the table.

Results

The data produce a set of first-period optimal land use patterns from the four management perspectives: the complete manager with a flexible information structure and spatial terms; the flexible and nonspatial manager; the inflexible and spatial manager; and the traditional manager with the inflexible information structure and nonspatial model. The four managers find the optimal solution but differ in their flexibility with respect to forthcoming information and in their treatment of the spatial relationships. The Thai Royal Forestry Department's management of KYNP does not fall strictly into any one of these management categories, but its decisions can be compared with those generated by each hypothetical manager. Figure 2 presents these results schematically and allows for a visual comparison of the managers' plans. This comparison identifies the role of the elements of the underlying model, both spatial and intertemporal, in determining the outcome. The results and simulations fall into three categories: benchmark and sensitivity analysis; policy issues regarding park management decisions; and consideration of the assumptions and data requirements for spatial analysis.

Figure 2: Benchmark First Period Optimal Patterns



- benchmark result
  total value=2,240
  option value=0.03%

Benchmark Result and Sensitivity Analysis

The KYNP data from Table 1 create the benchmark case whose results form the optimal first-period patterns shown in Figure 2 and Table 2. In the benchmark case, the differences between the managers' patterns come from the flexible and spatial manager's preservation of all but zone 1 versus the inflexible and nonspatial manager's conversion of both zone 1 and zone 4 to intermediate managed land. The differences between the patterns employed by the complete manager (Table 2, row 1, column 1) and the traditional manager (column 5) identify the suboptimality of the traditional approach to park management. The lack of difference between the two spatial patterns, flexible (column 1) and inflexible (column 2), implies that the quasi-option value does not contribute to the optimal patterns at the margin. The differences between the spatial and nonspatial optimal patterns (Table 2, column 1 versus column 4, and column 2 versus column 5) imply that the spatial terms make a significant contribution to the optimal pattern. The added value of large blocks of preserved area, P-annex, between zones 2 and 4 dominates the spatial optima and leads to the preservation of zone 4 in the spatial cases compared with the intermediate management use in the nonspatial cases. The other spatial term, the positive externality of preserved land on resort development (S), dominates the decision on zone 1 as the nearby preserved area in zone 2 creates a large draw for the local resorts. The traditional approach, by disregarding spatial interactions and forthcoming information, ignores the true land use trade-offs and converts too much land to nonpreservation uses.

The flexible and spatial manager's optimal land use pattern remains remarkably stable across interest rates. This manager makes no changes to her pattern when interest rates fall from 10% in the benchmark to zero. At a 20% interest rate, this manager preserves zones 2 and 3 but converts zone 4 to intermediate management (Table 2, row 2). She sees that at the higher interest rate, the short-term gains from intermediate management overwhelm the possibility of high P-annex values from zone 4 in time 2, and this pattern permits her to capture high P-annex values in time 3. In contrast, the nonspatial managers convert all land to nonpreservation when the interest rate is 20%.

The managers' patterns also demonstrate insensitivity to changes in the probability distribution. At all probabilities of a high state in the third period, all managers maintain their benchmark land allocation despite higher quasi-option values at low probabilities of the high state. The flexible and spatial manager's pattern for zone 4 changes from preservation to intermediate management when the probability of a high state event in both periods 2 and 3 falls below 3% (Table 2, row 3). Similarly, the nonflexible and spatial manager converts zone 4 from preservation to intermediate management when the probability of a high state falls below 6%, demonstrating the decisive role of quasi-option value in the cases between interest rates of 3% and 6% (Table 2, row 4). Even with a lower probability of a high state, increased high state preservation values, and low state preservation values that depict no trekking, no foreign visitation, and 50% fewer domestic visitors, the flexible and spatial manager maintains the same pattern (Table 2, row 5). Although quasi-option value is sensitive to the representation of uncertainty (Albers 1996), the managers in the KYNP case reflect little of this sensitivity because the quasi-option value contributes to the determination of the optimal pattern in only a small range of values.

The flexible and spatial manager's patterns demonstrate more sensitivity to the decision time frame (Table 2, row 6). In a 30-year case (three 10-year periods) with high state preservation values increasing over time and low state preservation values decreasing over time, the flexible and spatial manager preserves less land than in the benchmark case by converting zone 4 to the reversible option of intermediate management. This long-term manager takes advantage of the up-front benefits from intermediate management but can revert through a period of recovery to attain the possibly high preservation values in time 3. Demonstrating extreme sensitivity to the time frame, the traditional manager assigns the heart of KYNP to development.[xi] The flexible and nonspatial manager (Table 2, row 6, column 4) does not convert this land to development, revealing the importance of the quasi-option value in the nonspatial case over a long time frame (Albers et al. 1996). A traditional manager (column 5) who ignores option value and spatial terms naïvely converts more than half of the park to plantations.

Management Policies

The management framework presented here is well suited to examine policy choices that affect the quality of preservation of KYNP and the welfare of local people. The intertemporal and spatial framework permits a comparison of one-zone management with multizone management, an assessment of social losses from ignoring the value of extractive goods, and an analysis of the potential for conflict between local, regional, and international perspectives. Although the incomplete data prevent an assessment of the optimal park management, these analyses help identify potentially superior management practices and priorities for data collection.

KYNP managers view their park as a single unit for management, as do most park managers across the world, despite increasing support for buffer-zone management to address conflicts between local people and park goals (Ghimire 1994; MacKinnon et al. 1986).[xii] By managing the park as a single unit, the managers lose 132 mB, or 5.8% of the park's value, over 15 years from the difference in value between preserving all zones and using the optimal pattern of land use. The managers also lose the opportunity to use zone 1 in a buffer zone plan. If the managers zoned the park for different uses based on current conditions, they could convert zone 1 to managed land to create goodwill between the park and local people, increase the social value of that zone, and provide incentives for local people to cooperate with their broader preservation aims within other zones. With current regulations against buffer-zone management, KYNP managers spend much of their budget on boundary enforcement patrols, which have nevertheless been unsuccessful in eliminating extraction and agricultural encroachment.

KYNP managers consider the park's outer zone 1 as a zone in recovery. None of the managers in our model, however, employ the recovery land use (R) on this zone. The flexible and spatial manager converts zone 1 to the recovery use only when the value of the P-annex term between zones 1 and 2 increases to approximately 10 times the benchmark values (Table 3, row 1). The inflexible spatial manager converts the zone to the recovery use at a slightly higher level. With the benchmark values for P-annex, the flexible and spatial manager converts zone 1 to the recovery use when the preservation values for that zone increase by approximately 16 times the benchmark value; the inflexible and spatial manager requires a 17-fold increase. Both nonspatial managers, who do not value the impact of preserved land on resorts through S, allocate zone 1 to the recovery use when zone 1 preservation values reflect a 5-fold increase over the benchmark values. The decision to allow zone 1 to recover thus appears inefficient over a wide range of preservation values.

The values for preservation used in the benchmark example overstate the values that RFD employs because the Thai government's National Park Act prohibits the collection of extractive goods from parks and the Thai parliament closed KYNP to overnight visitors. The legal but smaller preservation values still lead the flexible and spatial manager to maintain the benchmark land allocation with a lower total value and a dramatic increase in the quasi-option value (Table 3, row 4). The lower preservation values generate a larger quasi-option value because the range of the possible preservation values and the P-annex values are larger percentages of the overall preservation value, increasing the importance of the uncertainty and the quasi-option value (Albers 1996). In contrast, the lower preservation values lead the two nonspatial managers (columns 4 and 5) to convert all the land from preservation to either intermediate management or development. For these nonspatial managers, the pure-preservation values associated with the no-extraction mandate are outweighed by the values from alternative uses.

Park managers attempt to enforce regulations against extraction and encroachment through policing. Statistics on enforcement expenditures in KYNP were unavailable, but managers in other Thai parks spend approximately 8.7 Baht per rai, or approximately US$2.20 per hectare, on enforcement. If managers spend this amount per rai in KYNP, the total expenditure would be 11.96 mB per year. The model's spatial managers maintain their benchmark land allocation when these enforcement costs decrease the net benefits of preservation, whether the preservation values include illegal trekking and extraction or not (Table 3, rows 5 and 6). The nonspatial managers, however, convert the park's inner core, zone 3, to development when they must pay these costs to attain the preservation benefits. Indeed, the nonspatial managers convert both zones 2 and 3 to the development land use when they must pay the enforcement costs to receive the lower, legal pure-preservation values. Managers make some trade-offs between the marginal cost of enforcement and the marginal preservation benefits, but they lack both data for valuing the impact of encroachment or extraction on preservation benefits and information about the impact of enforcement on rural people's activities. Although the spatial managers do not vary their optimal land allocation with enforcement costs, the nonspatial managers' decisions suggest that research on marginal valuation of preservation, both spatially and with respect to quality, and on the impact of enforcement are important areas of future research (Robinson 1996; Albers and Grinspoon 1997).

The local villagers' illegal extraction of products and agricultural encroachment into the park beg the question: How would villagers manage KYNP land? Answering this question helps identify areas of conflict between these resource-dependent people and the park managers. As managers, the local people would not receive benefits from the positive externality on resorts (S) or the P-annex habitat values, but they would continue to receive the hydrologic and erosion control benefits, trekking income, and the extractive goods portion of the preservation values. They would perform the optimization using this different set of values and decide to convert zone 1 and zone 4 to intermediate management. Their conversion of zone 1 to intermediate-managed rather than developed land reflects their inability to capture the S externality benefits that preservation creates for the resorts (Table 2, row 7). Similarly, their conversion of zone 4 to intermediate-managed land reflects their inability to capture the value of large habitats. Most strikingly, the villagers receive large enough benefits from the preservation of zones 2 and 3 that they would preserve them to enjoy sustainable extraction, humidity control, and hydrologic and erosion control benefits.

On the surface, this analysis suggests that preservation of zones 2 and 3 will be possible without government enforcement if local people are given access to a sustainable level of extractive goods; enforcement and/or incentives for preservation are needed only in zone 4. This analysis fails to recognize, however, the difference between a manager optimizing from the local people's perspective and the outcome of open access to these areas. For example, because the hydrology and erosion benefits are externalities created by the forest, an individual may optimally choose to convert land to agriculture, disregarding the impact of the lost benefits on other people. Local people may also exceed the sustainable level of extraction under free access to the area without fear of government reprisal. The villagers' social optimum therefore requires some sort of social resource-access rationing. Nevertheless, this analysis demonstrates that the social goals of local people and park managers are not dramatically different—a finding that should help prioritize enforcement expenditures and encourage communication between park managers and local park users.

Similarly, the global benefits from preservation at KYNP suggest another question: How would the international community manage this land? Because current information about the park does not include the carbon storage and biodiversity values that would be important to an international manager, some approximations must be made. If, for example, the international manager valued preservation in the high state by 50% more than the regional benchmark but faced more uncertainty, which reduced the probability of a high state to 25%, his patterns would be identical to those of the benchmark case for KYNP.[xiii] This international manager sees a larger quasi-option value—2.88%—from the wider distribution describing the P values, but that value does not influence the optimal pattern at the margin. According to this analysis, the international community need not financially support preservation in KYNP other than to continue to send international tourists to the park. The international manager's perspective and compensation will prove important only where the local value of nonpreservation land uses outweighs the government's value of preservation.[xiv]

Spatial Data and Issues

The spatial analyses presented here require assumptions to convert nonspatial information into spatial data—specifically, about how much each zone contributes to total preservations values, how much of the preservation value comes from preserving contiguous blocks, and how the proximity of resorts to the park affects their value. In addition, the spatial analyses above assumed a zero value for any spatial interaction between preserved and intermediate-managed zones. Given the importance of the spatial terms in determining the optimal land allocation in the benchmark, these spatial terms are analyzed in more detail here.

Because the existing valuation data do not value individual zones, the benchmark analysis used the assumption, meant to reflect habitat shape and tourism draws, that 75% of zone 2's and 25% of zone 3's area-proportional tourism and elephant preservation values be allocated to the P-annex term. Yet the optimal land allocations by the spatial managers display no sensitivity to this assumption, because their land allocations do not change from the benchmark allocation regardless of the distribution of zone 2's area-proportional value between zone 2's preservation value and the P-annex term. The optimal land allocations by the nonspatial managers change from preservation to intermediate management on zone 2 when the P-annex values take more than 80% of zone 2's pure-preservation values (Table 4, row 1). The optimal land allocations of the nonspatial managers do not generate the P-annex values, and benefits from development dominate the remaining preservation benefits from zone 2.

The existing valuation data also require dividing the total preservation values into zonal values, as described above, such as the division between zones 2 and 3. When all of the region's tourism and elephant preservation benefits come from zone 3, as opposed to zones 2 and 3 as in the benchmark, the spatial managers demonstrate no sensitivity to the zonation and again preserve both zones 2 and 3. In contrast, the nonspatial managers convert zone 2 to developed land (Table 4, row 2). When zone 2 generates half the benchmark's level of preservation and the other half comes from zone 3, all the managers allocate land according to their benchmark allocation. Moving the distribution of benefits toward zone 2 and away from zone 3, the nonspatial managers convert zone 3 to developed land when more than 75% of its benchmark tourism and elephant preservation benefits accrue to preservation of zone 2 (Table 4, row 3). The nonspatial managers receive too few benefits from preservation without most of the tourism and elephant benefits to forgo the development option and are therefore sensitive to the division of the area's preservation benefits into zones. The spatial managers, in contrast, receive large enough benefits from preserving contiguous plots to make their decisions insensitive to the division of benefits across zones.

The land allocations in the benchmark results above also rely on assumptions about the positive impact of the park on neighboring resorts, the S externality. These results do not change—that is, all the managers allocate land as in the benchmark case—at S values equal to half the benchmark S value (Table 4, row 4). The results for the spatial managers change as that value approaches zero, with both spatial managers allocating zone 1 to intermediate-managed land rather than to development. The land allocations for all managers contain no zones of development for values of S below zero (Table 4, row 5).

Thus far, the data have reflected the information, gathered in interviews, that benefits from zones in the preserved land use and zones in intermediate management do not change with proximity to each other. Although this information represents the KYNP case, reports from neighboring parks of lost agricultural production due to damage by wild animals suggest that the benefits from these two land uses interact in many cases (Studsrod and Wegge 1995; West and Brechin 1991; Schultz 1986). We show no S externality (Table 4, row 5) because the benchmark result has no borders of the intermediate-managed land and preserved land to examine. Using information from Studsrod and Wegge, who find crop damage as high as 35%, and reducing the agricultural values of the intermediate management use do not, however, change the optimal land allocations for the KYNP case, and all managers continue to allocate zone 1 to intermediate management next to zone 2's preserved land (Table 4, row 6). At higher values, however, such as a 50% crop damage rate, the spatial managers convert zone 1 to the developed land use despite the zero-valued site externality (Table 4, row 7).

Similar to the crop damage example but working in the opposite direction, the benefits from intermediate management may increase with proximity to preserved land because the farmers gain access to the extractive products in the preserved zones. When the extractive benefits heretofore contained in the preservation benefits accrue only to people who border the preserved zone rather than to the preserved zone itself, the two externalities between intermediate management and preservation benefits offset each other to some degree. For example, in the case of the preservation values without the value from extraction (as in row 4 of Table 3) and with the crop damage externality set at 35%, both spatial managers employ the intermediate management use on zone 1 only. But including the positive externality of the benefits from extraction in the preserved area induces both spatial managers to create an additional border between intermediate management and preservation by converting both zones 1 and 4 to intermediate management (Table 4, row 8). The example of a trade-off between crop losses and easy access to extractive products appears relevant in many settings.

Discussion and Conclusion

The application of a multizone, intertemporal economic model in Khao Yai National Park, Thailand, demonstrates the empirical importance of intertemporal and spatial modeling of social and ecological factors in tropical forest management. In this real-world example, the intertemporal and spatial model generates some land allocations that are strikingly different from those created by models that focus on one plot or ignore forthcoming information. The direct modeling of the spatial and intertemporal characteristics of the park decreases the sensitivity of the optimal land allocations to assumptions about discount rates. The modeling of the intertemporal characteristics of tropical forest management generates a quasi-option value that does not contribute much to the optimal land use patterns under a variety of descriptions of uncertainty unless the time frame considered expands from 15 years to 30 years. The spatial relationships—habitat size, recreational benefits as a function of size, a positive externality of proximity to preserved land on resorts, and a negative externality of crop damage from proximity to preserved land—appear especially important in determining land use patterns.

The optimal land allocations in the benchmark demonstrate the importance of spatial modeling, but these values contain assumptions because limited information exists to describe the spatial valuation. The optimal land allocations for the spatial managers do not change dramatically even with large changes in the way preservation benefits are divided across zones and the spatial term, P-annex. In a policy setting, the optimal land allocations should reflect preservation valuation aimed at quantifying the per-zone values and the value of spatial interactions across zones rather than preservation valuation that divides the benefits after the collection of valuation data. The optimal land allocations in this example reflect some sensitivity to the size of the spatial term describing the impact of preserved land on resorts and, without this resort site externality, to the amount of crop loss incurred on small agricultural plots near preserved land. Nevertheless, the benchmark land allocations hold over a wide range of assumptions about the size of these spatial values.

Although data limitations preclude a detailed case study for policy, the spatial analysis here suggests that most of the park area is optimally used as a preserved area when the spatial benefits are included in the valuation. In addition, this analysis provides economic support for expanding the park to include a relatively undisturbed and unpopulated area to the northwest of the park. Even though the park provides benefits to the global community, this analysis demonstrates that Thailand captures enough benefits from KYNP to continue its preservation without international support. The park also provides benefits to regional agriculture and villagers that are large enough to indicate that local people, as a group, have incentives to maintain most of the area as preserved land.

Given the recent literature on the potential contribution of preserved areas toward achieving the dual goal of preservation and local development (Albers and Grinspoon 1997; Studsrod and Wegge 1995; Ghimire 1994; Hough 1988), the spatial and intertemporal analysis of current management practices in KYNP reveals ways to increase the social benefits from the park. First, managing the park as one homogeneous unit with the same level of preservation throughout leads to social losses in the area near the park boundaries because those degraded areas produce a higher value in nonpreservation uses. Second, the restrictive definition of preservation leads to social losses because the goals of generating tourism revenues and preserving species could be met while allowing villagers to extract limited amounts of nonmeat products from the park. The combination of these two factors and the lack of incentives for local people to help preserve the area suggests that developing a buffer-zone policy on the park's degraded outer boundary regions and creating incentives for preservation rather than relying exclusively on enforcement would lead to long-term preservation of the resource and to permanent increases in the welfare of local villagers.

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Appendix 1: The Economic Management Model and Notation

The economic management model employed here contains spatial and intertemporal components. The spatial components allow an examination of externalities and of the decision to manage the park as a single unit. The intertemporal components model irreversible decisions under uncertainty. The land manager optimally allocates one of four land uses on each zone of the park for the first of three periods. Finding that optimal allocation requires solving the model with a PASCAL computer program that computes the value of all possible land use patterns and selects the largest present value from the perspective of four managers: the flexible and spatial manager, the flexible and nonspatial manager, the inflexible and spatial manager, and the inflexible and nonspatial manager (Albers 1996; Albers 1992).

The two spatial managers add externality values whenever the land use pattern meets the requirements that provide those values. When a pattern contains two preserved plots that border one another, the manager adds the P-annex value to the total value of that pattern. When a pattern contains a developed plot bordering a preserved plot, the manager adds the site externality value (S) to the total value of that pattern. When a pattern contains an intermediate managed plot next to a preserved plot, the manager subtracts the crop-loss cost (C) for the total value of that pattern.

The two inflexible managers use an open-loop framework to determine their first-period optimal land allocation and therefore do not incorporate future information into their decisions. The inflexible managers' expected value from preserving a zone in the first period is

$$V_P^* = P_1 + \max\{E_1[P_2] + \max(E_1[P_3], M_3, D_3);\ M_2 + \max(R_3, M_3, D_3);\ D_2 + D_3\}$$

where all expectations are taken using only the first period's level of information and subscripts reflect the time period. (Following Albers et al. 1996, the uncertainty occurs across periods; the uncertainty about benefits from preservation for a particular period is completely resolved at the beginning of that period. The uncertainty could be dispelled in other ways, such as through partial learning over, as in an example in Albers et al. 1996, or through learning by doing, as in Miller and Lad 1984. These types of information arrival do not appear important in the KYNP case because the time frame is relatively short and the benefits from the alternative land uses are well identified by their use in the surrounding region.) The inflexible managers compare the expected value of first-period preservation (V_P^*) with that of management or development and implement in the first period the use that generates the highest expected value over the resulting stream.

The flexible managers recognize that information is forthcoming that will improve their ability to make decisions in future periods and place a value on remaining flexible enough to use that information. Although the flexible managers, like the inflexible managers, form expectations based on information in first period (E_1), the flexible managers' maximum expected value is calculated using the closed-loop control rule:

$$V'_P = P_1 + E_1[\max(P_2 + \max(P_3,M_3,D_3); M_2 + \max(R_3,M_3,D_3); D_2 + D_3)].$$

This framework's control rule allows the flexible manager to recognize the value of the future information in the first-period calculations. The flexible manager compares the possible maximum outcomes in her decision, as shown in the equation by bringing the expectation outside of the max operator, in contrast to the inflexible manager's comparison of the average outcomes.

As discussed in the text, the quasi-option value is the difference: $V^*_P - V'_P \geq 0$.

Two states of the world, high and low, capture the uncertainty about future preservation benefits and future P-annex values. The high state of the world occurs with probability pr(hi) and reflects a period of high preservation benefits. The manager chooses the land use on each of the zones for the first period. The four uses come from a set of possible actions, A_t^j made up of uses a_t^j, where j denotes the quadrant and t denotes time. The value in time t of the five zones is

$$V_t = \sum_j v_t(a_t^j) = v_t(a_t^1) + v_t(a_t^2) + v_t(a_t^3) + v_t(a_t^4)$$

The three period optimization problem is

$$\max_{a_t^j} V = V_1 + E[\max\{V_2 + \max V_3\}]$$

(where a_t^j is an element of $\mathrm{A}_t^j = \{P, M, D, R\}$

and u(a_t^j) is the (incremental) value of that use on plot j while v(a_t^j) contains additional values.)

subject to:

Irreversibility Constraints:

1. if $a_t^j = D$ then $a_{t+1}^j, a_{t+2}^j = D$
2. if $a_t^j = M$ then $a_{t+1}^j \neq P$ and $a_{t+2}^j = P$ iff $a_{t+1}^j = R$

Valuation and Uncertainty :

1 . $u(P_2)$, $u(P\text{ - annex}_2)$, $u(P_3)$, $u(P\text{ - annex}_3)$ depend on the state, high or low, with pr(high state) = hi

Spatial Constraints :

For j = 1 :

1. if $a_t^j = D$ and iff $a_t^{j+1} = P$ then $v(a_t^j) = u(D) + S$
2. if $a_t^j = M$ and iff $a_t^{j+1} = P$ then $v(a_t^j) = u(M) - C$

For j = 2 and k = 1, 3, and 4 :

1. if $a_t^j = D$ and iff $a_t^k = P$ then $v(a_t^j) = u(D) + S$
2. if $a_t^j = M$ and if any $a_t^k = P$ then $v(a_t^j) = u(M) - C$

For j = 3 :

1. if $a_t^j = D$ and iff $a_t^{j-1} = P$ then $v(a_t^j) = u(D) + S$
2. if $a_t^j = M$ and iff $a_t^{j-1} = P$ then $v(a_t^j) = u(M) - C$

For j = 1, 2 :

1. if $a_t^j = P$ and iff $a_t^{j+1} = P$ then $v(a_t^j) = u(P) + P\text{ - annex}$

For j = 4 :

1. if $a_t^j = D$ and iff $a_t^2 = P$ then $v(a_t^j) = u(M) + S$
2. if $a_t^j = P$ and iff $a_t^2 = P$ then $v(a_t^j) = u(P) + P\text{ - annex}$
3. if $a_t^j = M$ and iff $a_t^2 = P$ then $v(a_t^j) = u(M) - C$

(The spatial terms S and P-annex are added for each relevant border while the spatial term C is subtracted when one or more borders with preservation zones occur with a zone in intermediate management. The value of each spatial term depends on the zones involved as seen in Table 1: KYNP Data.)

Table 1: KYNP Data: Benchmark Values*

Zone	*Time*	*State*	*P value*	*M A value***	*M B value*	*M C value*	*R value*	*D value*
1	1	high low	16.73 16.73	28.98			1.22	50.64
	2	high low	10.39 10.39	18.00	14.55		0.76	25.79
	3	high low	6.45 6.45	11.17	9.04	5.71		2.74
2	1	high low	455.04 404.05	305.83				846.13
	2	high low	282.54 250.88	189.90	153.55		181.61	422.22
	3	high low	175.44 155.78	117.91	95.35	66.00		197.67
3	1	high low	424.54 288.37	266.97				820.16
	2	high low	263.61 179.05	165.77	145.58		129.61	466.73
	3	high low	163.68 111.18	102.93	90.39	64.80		156.21
4	1	high low	8.11 8.11	11.18				9.36
	2	high low	5.04 5.04	6.94	4.06		3.65	5.81
	3	high low	3.13 3.13	4.31	2.52	1.42		3.61
5	1	high low	n.a.	n.a.	n.a.	n.a.	n.a.	46.43
	2	high low	n.a.	n.a.	n.a.	n.a.	n.a.	24.32
	3	high low	n.a.	n.a.	n.a.	n.a.	n.a	3.95

n.a.= not applicable because of starting point in irreversible development

*All values are in 1990 million Baht increments (1 Baht = US$0.04). All values are the sum of five years (one period) of benefit flow. All sums are in present value terms, calculated with a discount rate of 10%. Where only one value is entered, the same value is used for the high and low events.

** “A value” is the value of the M option during the first period of its use, “B value” is that value in the second period of use, and “C value is that value during the third period of use.

Table 1: KYNP Data: Benchmark Values, *continued*

Zone	*Time*	*State*	*P-ann*	*R-ann*	*S*	*C*
1 - 2	1	high low	26.42 0.00	2.27 0.00	111.14 111.14	0.00
	2	high low	16.41 0.00	1.04 0.00	69.01 69.01	0.00
	3	high low	10.19 0.00	*	42.85 42.85	0.00
2 - 3	1	high low	414.34 74.23	*	46.24 46.24	0.00
	2	high low	257.27 46.09	6.13 1.09	28.71 28.71	0.00
	3	high low	159.75 28.62	*	17.83 17.83	0.00
2 - 4	1	high low	39.88 0.09	*	*	0.00
	2	high low	24.76 0.06	0.64 0.00	*	0.00
	3	high low	15.38 0.03	*	*	0.00
3 - 5	1	high low	*	*	73.22 73.22	*
	2	high low	*	*	45.47 45.47	*
	3	high low	*	*	28.23 28.23	*

*Value not applicable due to initial zone use.

Table 2: Sensitivity Analysis

	Flexible and spatial	*Inflexible and spatial*	*Quasi-option value as % of total*	*Flexible and nonspatial*	*Inflexible and nonspatial*
Benchmark	DPPP	DPPP	0.03	MPPM	MPPM
i=20%	DPPM	DPPM	0.17	MDDM	MDDM
pr(hi)<3%	DPPM	DPPM	0.43	MPPM	MPPM
3<pr(hi)<6	DPPP	DPPM	0.64	MPPM	MPPM
P spread	DPPP	DPPP	1.35	MPPM	MPPM
30 years	DPPM	DPPM	0.50	MPPM	MDDM

Table 3: Policy Results

	Flexible and spatial	*Inflexible and spatial*	*Quasi-option value as % of total*	*Flexible and nonspatial*	*Inflexible and nonspatial*
10x Bench.	RPPP	DPPP	0.89	MPPM	MPPM
16x Bench.	RPPP	DPPP	0.89	RPPM	RPPM
5x Bench.	DPPP	DPPP	0.03	RPPM	RPPM
legal P value	DPPP	DPPP	2.26	MDDM	MDDM
P - enf.	DPPP	DPPP	1.76	MPDM	MPDM
legal P - enf.	DPPP	DPPP	4.06	MDDM	MDDM
local persp.	MPPM	MPPM	0.00	n.a.	n.a.

Table 4: Spatial Sensitivity Analysis

	Flexible and spatial	*Inflexible and spatial*	*Quasi-option value as % of total*	*Flexible and nonspatial*	*\Iinflexible and nonspatial*
>80% P-ann.	DPPP	DPPP	0.02	MMPM	MMPM
zone 2 P in 3	DPPP	DPPP	0.02	MDPM	MDPM
zone 3 P in 2	DPPP	DPPP	0.31	MPDM	MPDM
S=0.5 *S	DPPP	DPPP	0.23	MPPM	MPPM
S=0	MPPP	MPPP	1.67	MPPM	MPPM
S=0; C=35%	MPPP	MPPP	1.48	MPPM	MPPM
S=0; C=50%	DPPP	DPPP	1.48	MPPM	MPPM
C=35%+EXT	MPPM	MPPM	4.50	MPPM	MPPM

Endnotes

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[i] Although the example developed here considers the management of a tropical forest in a park, many of the results can be generalized to a nonpark setting where efficient land use allocation is the goal.

[ii] The conversion from one land use to another land use always requires some time. This model and application reflect the ecological information that the conversion time to the M or D uses is short compared with the amount of time it takes for forests to recover after the M use.

[iii] The assumption that no new information will arrive before a decision must be made to dispel uncertainty about M and D simplifies the analysis and focuses the framework on the considerable uncertainty about preservation benefits. This assumption does, however, bias the optimal land uses toward the less flexible land uses, M and D, because a model that allowed for forthcoming information about these land uses would contain incentives to wait in the flexible land use until that information ruled out a "bust" in the D or M values (Albers 1997).

[iv] The economic enforcement literature contains some discussion of whether illegal activities, such as the extraction of fuelwood and food from KYNP, create positive benefits from a social perspective and about the weight a planner should assign to these benefits (Cite). In its attempt to demonstrate the empirical importance of spatial and intertemporal aspects of tropical forest management rather than to form policy prescriptions for KYNP managers, this paper takes a planner's perspective by including benefits that accrue outside the park rather than the perspective of a park manager who values preservation alone.

[v] Theoretical analyses, such as Epstein (1980) and Hanemann (1989), indicate that when the spatial trade-off between a reversible and an irreversible land use is continuous, as opposed to the discrete blocks imposed here, no quasi-option value is generated. The information available for making such trade-offs in an empirical setting, however, limits the application of this result.

[vi] Developed land may create a negative externality on neighboring preserved land through edge effects and pollution. This paper assumes that both intermediate-managed land and developed land create the same externality on preserved land and that the per-plot preservation values are net of that externality. The P-annex term can thus be thought of as the added value of avoiding the negative externality created by nonpreservation uses on neighboring plots.

[vii] Unless otherwise stated, all values are 1990 baht. One baht is approximately US$0.04.

[viii] In a fuller analysis that includes other values—such as carbon storage, existence value for other species, local and global climate control, and an assessment of marketable forest products—the probability distribution would reflect the likelihood that each of these values will matter in the future. In this empirical example, however, the values incorporated are values that RFD has at hand. The 50-50 probability distribution is a guess on whether elephants will survive and/or be highly valued in the future. See Albers (1996) for a theoretical examination of the impact of the probability distribution on quasi-option value and land use plans.

[ix] The remaining 90% of the plot provides nearby seed sources and protection from erosion for the deforested plots. The agricultural land can recover from the use through these protection and recuperation mechanisms. With smaller management plots this interaction would occur across plots, and recovery of one area would depend on preservation in nearby areas (Uhl et al. 1990; Albers 1996).

[x] The Thai unit of measurement, the rai, is equal to approximately 1,600 square meters.

[xi] This conversion to developed land does not reflect a large resort-generated S value because this occurs in the nonspatial case.

[xii] Buffer zones that surround a core preservation area are areas in which different levels of land use are permitted. These areas serve the dual purpose of reducing local people's dependence on the core area and of

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mitigating the border and edge effects on the ecosystem of that core area. KYNP managers are constrained by federal regulations that prohibit buffer-zone use of park land. Many conservationists support this position by arguing that only land outside parks should ever be used for buffer zones (MacKinnon et al. 1986) and that no reallocation of parkland toward nonpreservation uses is appropriate. In the KYNP case, the development of a buffer zone outside the park would require removing people from their land.

[xiii] Studies attempting the valuation of these tropical forest benefits have only recently begun to appear in the literature. This study simply demonstrates the impact rather than attempting to realistically value these benefits.

[xiv] This statement assumes that the government is both willing and able to manage the land for the economically efficient land use pattern. In some countries the government may not capture enough of the preservation benefits to generate a budget, or may have other budgetary issues limiting its ability to enforce the optimal management scheme.