



CANADIAN PARKS COUNCIL
CONSEIL CANADIEN DES PARCS

A Benefit-Cost Framework for Optimal Ecosystem Preservation

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Economic Framework Project
Report 556



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- *promotes excellence in parks and protected areas planning and management;*
- *advocates parks and protected areas values and interests;*
- *encourages cooperation and provides support to member agencies on parks and protected areas issues and initiatives.*

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4. SUPPORTING ECOLOGICALLY SUSTAINABLE TOURISM RELATED TO PARKS AND PROTECTED AREAS;
5. FACILITATING EFFECTIVE MANAGEMENT OF PARKS AND PROTECTED AREAS.

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Economic Framework Project

In 1998 the Federal Provincial Parks Council called for the development of a common framework for measuring the economic value of protected areas. The purpose of the framework was to help FPPC members speak with one voice when talking about the economic benefits of protected areas within their jurisdictions. It was proposed that the framework should include not only traditional economic impact measurement (e.g., tourism spending, spending on capital development), but also direct user benefits (e.g., consumer surplus, existence benefits) and societal benefits (e.g., benefits from biodiversity, water production, scientific and educational benefits).

Because knowledge and measurement techniques are not equally developed in each of these areas, it was proposed that the work of developing a framework be done in three separate phases, which could be pursued concurrently or sequentially as resources allowed. The three phases are:

1. A user-friendly computerized model for estimating economic impact at the provincial level.
2. A handbook of user benefits showing how the FPPC members could undertake such studies in their own jurisdictions.
3. A series of up to 10 exploratory pilot studies undertaken with the help of academics, to establish a body of case studies on societal benefits

The work was carried out by a project task force, made up of representatives from Ontario Parks, BC Parks, Quebec Parks, NWT Parks and Parks Saskatchewan, and chaired by Dick Stanley, Director, Strategic Research and Analysis, Department of Canadian Heritage (as representative of Parks Canada. The publications in this series are the results of the work of this task force.

THE PAPERS:

- 315-e Conservation of Ecological Areas: The Economic Bottom Line
- 315-f La Conservation des aires écologiques: les résultats économiques
- 251-e Benefits of Protected Areas
- 251-f Les avantages des aires protégées
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 - Provincial Economic Impact Model: Instruction Manual
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A Benefit-Cost Framework for Optimal Ecosystem Preservation

A Report to the Federal Provincial Parks Council

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A Benefit-Cost Framework for Optimal Ecosystem Preservation

Executive Summary

This report documents the development of a conceptually sound and flexible framework that enables the valuation of existing and proposed habitat conservation projects. In the course of this research, we have assembled a large amount of data from secondary sources pertaining to the value of wilderness preservation, and the existence of substitution effects and decreasing marginal benefits to conservation. The data, which is presented in this report should be useful to park and reserve managers and policy makers alike.

The cost-benefit framework developed during this project is set at the site level. This reflects the practical concerns of Governmental agencies entrusted with the identification and protection of areas of natural significance. The framework illustrates the economic trade-offs between forestry and conservation inherent to forested areas of Canada. A computerized model is developed that could be applied to any forested area. This flexibility is illustrated with an application to the protection of coastal old growth forest in British Columbia.

The unavailability of valuation information from primary data collection sources in British Columbia and more generally in Canada imposes that this application be interpreted as an illustration of how the model can be used rather than as an actual statement on the value of protecting a portion of the remaining old growth. Nonetheless, the application to the coastal areas of British Columbia shows that land-use specialization is a desirable approach to land management. While a significant proportion of the remaining coastal old growth should be legally protected as parks, the results would prescribe that the balance of the land base be put into intensive forestry rotation. Although the analysis was carried out at a generic level of detail, it seems clear that a significant proportion of the remaining coastal old growth of British Columbia temperate rainforest should be preserved indefinitely. The results also demonstrate how (and provide values for) the net value of protected areas can be calculated in a sound welfare economics framework.

We urge the FPPC and its member organisations to engage in the collection of primary data on the value of protected areas. Only with such data could the conclusions of this report be corroborated.

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A Benefit-Cost Framework for Optimal Ecosystem Preservation

1. Introduction

Decisions regarding land-use have important economic consequences. Industrial activities such as mining and forestry provide net economic gains but in most cases preclude the flow of wilderness benefits (e.g., ecosystem services, recreational, nonuse and option values) that wild land would otherwise have provided. In contrast, the designation of protected areas ensures the continued production of benefits from wilderness at the cost of foregone gains for those involved in extractive industries.

Economic arguments to justify additional ecosystem (and species) protection have been promoted by economists and by a growing number of natural scientists (Bowes and Krutilla, 1989). Using contingent valuation and other methods, economists have now produced hundreds of studies of the value of wildlife species and ecosystems, covering the full range of benefits from pharmaceutical and scientific value of species, non-timber forest products, recreational benefits, watershed and ecosystem services, and nonuse values.¹ These studies have played a significant role in exposing the economic significance of wilderness and protected areas, and have been an important tool in the battle to recover foregone benefits resulting from damage to natural resources.

Nonetheless, the merit of site-specific valuation studies has also been questioned on the grounds that they ignore inter-dependence and existing complementarities (in the production of economic benefits) between protected areas, adjacent unprotected wilderness and developed lands.

To illustrate the potential importance of interdependence, consider the situation presented in Box 1:

Box 1: The value of a small wilderness area.

1A) An entire Island (perhaps as large as Vancouver Island) is covered with untouched old-growth forest and naturally functioning ecosystems. All but a tiny fraction of the island is legally set aside as protected area. Species that depend on old-growth forests for their survival are found throughout the island. How much would you be willing to pay to protect the remaining unprotected old-growth?

1B) The same island as in 1A) has been heavily exploited for timber production and mining, and only a tiny fraction of the original old-growth forest remains. Species that depend on old-growth forest can now be found only on this small portion of the island. How much would you be willing to pay to protect the remaining unprotected old-growth?

Empirical evidence suggests that respondents to benefit valuation surveys answer these types of questions quite differently (e.g., Rollins and Lyke, 1998; Majid et al., 1983). Specifically, individuals are typically prepared to pay less to protect an area of land where large wilderness areas are already protected than where little else remains in a natural state.

While leaving a small area unprotected may have negative consequences even when the remaining forest is intact, these consequences are likely to be much smaller than when the area is the last remaining one of its type. The value of the area, from both ecological and economic perspectives, depends on the context in which it is valued. The protection of a small area in a sea of wilderness is far less ecologically critical -- and far less economically valuable -- than the protection of the same area when it is unique.

In general, the empirical evidence suggests that, as the number of parks or total area under protection increases, total nonuse benefits increase but at a diminishing rate. This is what economists call

¹ For instance, Environment Canada's Environmental Valuation Resource Inventory contains references to more than 700 valuation studies, of which nearly 500 contain some analysis of the value of non-extractive or passive uses of the environment. See van Kooten and Bulte (2000) for a technical review.

decreasing marginal returns. Decreasing marginal benefits have important practical implications that are addressed by the valuation framework presented in this report.

A similar point can be made about the recreational value of parks and other accessible wilderness areas. Two situations are presented in Box 2 to help illustrate the point.

Box 2: On the recreational benefits of protected areas.

2A) You are planning a week-end camping trip to one of several wilderness areas within a two hour drive from your home. As you prepare to leave for the week-end, you learn that the park you intended to go to is closed for a few days due to unforeseen circumstances. Do you choose to stay home, go to one of the other parks in your area or do something else?

*2B) You are planning the same camping trip to the **only** wilderness area within reasonable driving distance of your home. The next closest park is a 10-hour drive away. As you prepare to leave, you learn that the park you intended to visit is closed for a few days. Do you choose to stay home, go to the park 10 hours away or do something else?*

The importance of context as a determinant of recreational value is illustrated by questions 2A and 2B. On average, we expect that a park closure would impose a smaller loss on individuals who have several other opportunities nearby than on those who do not. This is not very different from saying that the additional recreational benefits that a new park creates are greatest when little else is protected.

The value of parks and other protected resources is also sensitive to the presence of unprotected wilderness areas. To the extent that they are not immediately threatened, wilderness areas provide shelter to wildlife, plants and insects; maintain biological diversity; and ensure, at least in the short term, the persistence of natural processes. Since unprotected and protected wilderness provide the same ecological services the value to society of a particular natural area is again dependent on the overall wilderness remaining. The relevant context in which a park is valued should therefore include references to the extant unprotected wilderness and the degree of threat to its continued existence.

To be sensitive to such interdependency between parks, wilderness areas and unprotected wilderness implies one last challenge: the incorporation of the time factor. As the use of unprotected land changes (e.g. unprotected forest may be logged in the future) so will the value of the remaining wilderness. A proper accounting of the costs and benefits of wilderness conservation must be mindful of inter-temporal changes in land-use. The time dimension is typically difficult to grasp because of the sheer uncertainty surrounding future economic conditions. Nonetheless, explicitly incorporating time in a valuation framework acknowledges the interest of future generations in natural resource conservation and the effect of current and future land-use decisions on their well being.

The challenge is therefore to construct a valuation approach that accounts for inter-dependence between various areas of protected and unprotected land within a consistent inter-temporal framework. The resulting approach must allow the analyst to compute the total value of a network of protected areas within a particular region, and permit the identification or computation of site-specific benefits.

We are not aware of the existence of such a framework and set out to construct a model that can accomplish this task. In this document, we report our progress in this direction with respect to three core objectives. First, we construct a conceptual framework for appropriately measuring the benefits and costs of wilderness conservation. Our framework can help achieve the greatest possible benefits of land-use at the eco-region or eco-section level in addition to providing a measure of the value of specific sites (existing or proposed). Second, we report the results of an application of the model to a generic portion of the remaining old-growth coastal temperate rainforest of British Columbia. Although we do not describe a specific geographical area for this application, the model is calibrated and this report was written with the wilderness of Vancouver Island in mind. Finally, in our concluding remarks, we note the importance of collecting primary data as a pre-requisite for sound decision making. Without such data, a precise assessment of the value of existing or proposed parks will remain an elusive goal, one that must be

achieved if economic arguments in favor of conservation are to be taken seriously.

The remainder of this report is divided into four sections. After next section's review of the relevant literature on the marginal value of protected areas and resources, the valuation framework is presented in Section 3. In section 4, a computerized model is calibrated and simulated for a portion of British Columbia's remaining coastal old-growth forest and the results are presented. We conclude the report by pointing out some caveats and directions for future work; as well as providing a brief summary of our findings.

2. The Marginal Benefits of Land Protection: a Review of Past Findings

2.1 Nonuse Benefits²

Many studies have been conducted on the use and nonuse benefits of wildlife species, recreation sites, forests and ecosystems. However, the merit of site-specific valuation studies has often been criticized both for ignoring the existence of other protected areas and for neglecting the substitution possibilities they present. As a method to assess the benefits of conservation measures, contingent valuation has also been criticized for what often appeared to be its insensitivity to substantial changes in the quantity of the good being valued (van Kooten and Bulte, 2000).

These criticisms have in turn motivated new research that supports the view that individual preferences for recreational activities and environmental protection follow basic tenets of the economic theory from which valuation methods have emerged: individuals take advantage of substitution possibilities and marginal nonuse benefits decrease as the amount of conservation increases.

For instance, Majid, Sinden and Randall (1983) found that the sum of benefits from a set of proposed parks presented as increments to a system of existing parks were less than half the benefits of the same parks when valued individually. They conclude that "the common empirical focus on visitor values of proposed facilities, without explicit consideration to their incremental nature may be misplaced." "If the policy decision context, and hence, the valuation context is incremental, accurate results require that willingness to pay questions be framed in incremental terms." (p.392).

Recently, Rollins and Lyke (1998) address the sensitivity of contingent valuation to increments in the number of parks in a study of new park creation sponsored by Parks Canada. They found that the existence value of creating new park in the Northwest Territories (NWT) was critically dependent on how many other parks already exist. The economic benefits arising from the creation of a new parks was found to be significantly greater when little or no territory had been previously protected.

The mean willingness to pay (WTP) per household for the creation of one park in the NWT was \$105.45 compared to \$161.85 for two parks, \$191.57 for four parks and \$188.44 for completing the National Park System with ten additional parks. Accordingly, the marginal value of the first park was estimated at \$105.45 per household, while it was \$56.40 for the second park and \$29.72 for the next two parks. Total WTP for the creation of 10 parks was not statistically different from the benefits derived from four parks. This emphasizes the rapidity at which marginal benefits decline.³ These results, presented in Table 1, are

² The nomenclature of benefits used in this report follows current academic standards. The correspondence with the terminology suggested by the IUCN and used in recent reports to Parks Canada (The outspan Group, 1996) is as follows: nonuse values (existence and option benefits), fishing, hunting and non-consumptive recreational benefits are "personal benefits"; the benefits of carbon sequestration are "societal". In this paper, we also consider the "available rents" derived from forestry. The technical term "rent" represents the net available surplus attributable to the productive capacity of the land. It is defined as the value of wood shipments minus harvesting costs and an allowance for the cost of capital, including a risk premium and a normal return on capital. The rents from forestry are the net benefits of logging. Economic rents are not classified in the Outspan's report. In particular, it is important to note that they are NOT "Business Benefits". The Outspan's definition of business benefits covers economic impacts which are transfers between individuals in the course of conducting normal economic activity. In contrast, rents are a consistent welfare measure of the economic surplus accruing as a result of the natural capacity of the land to grow trees for commercial use. Rents are above and beyond (they do not include) the cost of logging and normal economic profits. Since most forestry land is owned by the Provincial Crown, these surpluses ought to accrue to the residents of the province where logging takes place. In fact, the majority of forestry rents in BC is actually captured by the provincial treasury in the form of stumpage fees that forest companies pay to the Crown when an area is logged. See Grafton et al. (1998) for details.

³ The absence of measurable additional benefits from increasing the number of parks from four to ten may be attributable to the fact that respondents did not receive detailed information about the last six park proposals.

consistent with basic economic theory. Diminishing marginal values are observed and respondents are capable of distinguishing between existence goods of different scope. The total WTP function has a concave shape due to decreasing marginal benefits (Figure 1).

Table 1
WTP for Proposed National Parks in Canada

Number of New Parks	Mean Household WTP (\$)
1	105.45
2	161.85
4	191.57
10	189

Source: Rollins and Lyke (1998)

Rollins and Lyke (1998) point out that any (contingent) valuation study must be preformed within a policy-relevant framework, where goods are anchored in a context that explicitly defines the relevant range of scope. This implies that participants involved in the valuation process must be aware of the amount of the good that will exist, regardless of whether the policy action is carried out.

Loomis and Gonzalez-Cabin (1998) implemented a contingent valuation survey with the objective of estimating the benefits of protecting ancient forests of Oregon and California from destruction by fire. They estimated that residents of Western States have a WTP for fire prevention programs ranging in scope from the protection of 700 to 5,000 acres of old-growth forest per year. Table 2 and Figure 2 illustrate their results and the declining marginal value of additional preservation.

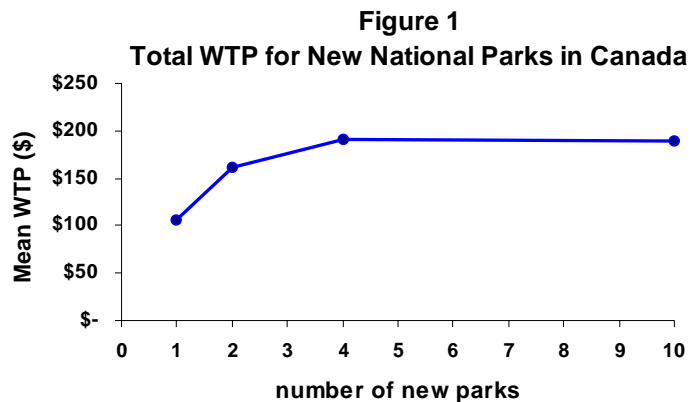


Table 2

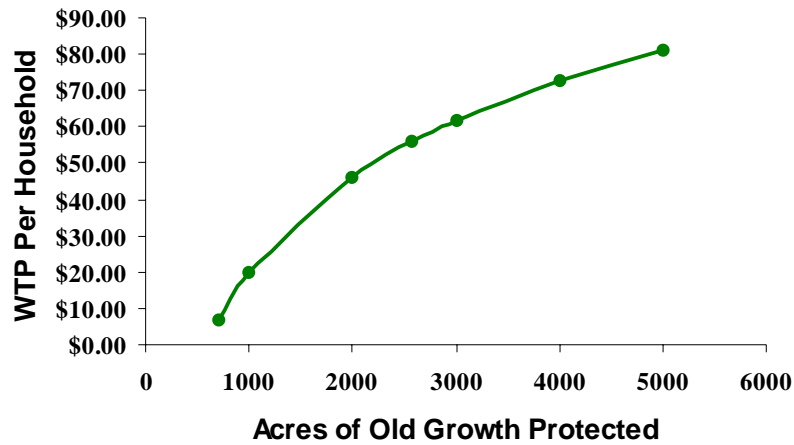
WTP for Ancient Forest Fire Prevention

Acres saved from fire	WTP Per Household (US\$)
700	6.64
1000	20.12
2000	46.3
2569	55.75
3000	61.61
4000	72.48
5000	80.91

Source: Loomis and Gonzales-Caban (1998)

One observes from Table 2 that after the first 1000 acres are protected, subsequent increases in the magnitude of the program yield increasingly smaller increases in WTP. Households are prepared to pay an extra \$26.18 for the second thousand acres of forest, but only \$15.31 for the third thousand acres, \$10.87 for the fourth and \$8.43 for the fifth.

Figure 2
Total WTP Per Household for Fire Prevention



Such results are consistent with evidence provided in separate studies by Walsh, Loomis, and Gillman (1984) and Pope and Jones (1990). Walsh and his co-authors conducted a survey of Colorado residents to estimate the value of preserving four separate levels of the wilderness remaining in the state. At the time of the survey, the state of Colorado already had 13 designated wilderness areas encompassing 1.2 million acres of land.

The area under study was largely composed of land at elevations between 9,000 to 14,000 feet, partly treed and partly above the tree line. Forested areas contained spruce, fir and aspen as well as a variety of wildlife. Participants were asked to estimate their maximum WTP for different increments of land and to allocate their consumer surplus value for recreation, option, existence and bequest values. The four increments considered were the status quo (1.2 million acres), 2.6 million acres slated for protection in 1981, five million acres (7.5% of the state) and 10 million acres (or 15% of the state).

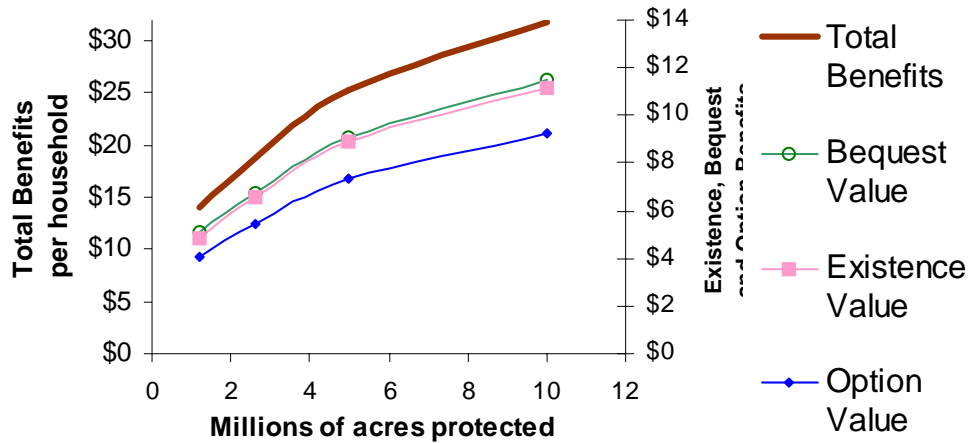
Table 3 illustrates the authors' findings. Again, we observe that, as the amount of proposed wilderness increases, annual household preservation values increase but at a decreasing rate. The increment in consumer surplus that Colorado households derive from non-use values for successive increments in wilderness designation become increasingly smaller. Total benefits per household for each category of non-use value are graphed in Figure 3.

Table 3
Annual WTP per Household Colorado Wilderness
Protected Area (million acres)

	1.2	2.6	5	10
Option Value	\$4.04	\$5.44	\$7.34	\$9.23
Existence	\$4.87	\$6.56	\$8.86	\$11.14
Bequest Value	\$5.01	\$6.75	\$9.1	\$11.46
Total Value	\$13.92	\$18.75	\$25.3	\$31.83

Source: Walsh et al. (1984)

Figure 3
Value of Colorado Wilderness Preservation



In a similar study, Pope and Jones (1990) measured the WTP of Utah residents for increasing the amount of designated wilderness within the state, ranging from 2.7 to 16.2 million acres. The corresponding WTP ranged from US\$53 to US\$92. Although the marginal effect observed in Utah is weaker than reported in previous studies, the authors did note the decreasing value of additional preservation. Table 4 and Figure 4 summarize the findings.

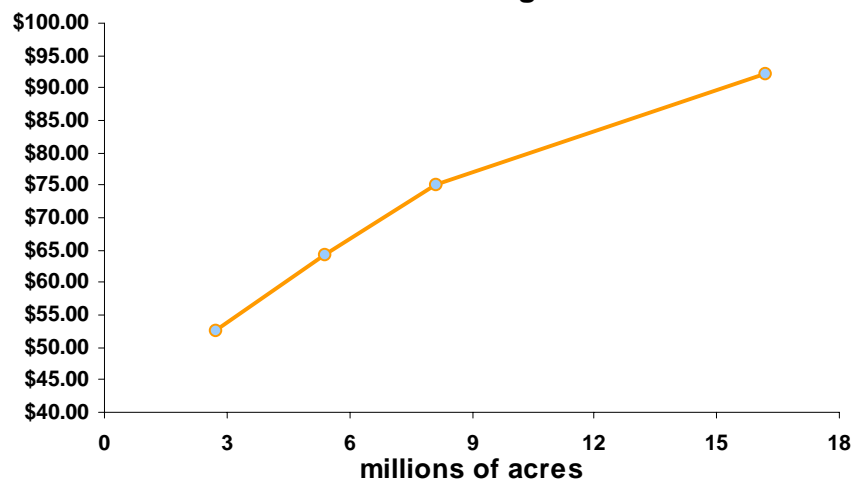
Table 4
WTP for Increasing Wilderness Designation in Utah

Millions of Acres	Average WTP (\$)
2.7	52.72
5.4	64.3
8.1	75.15
16.2	92.21

Source: Pope and Jones (1990)

Other studies provide indirect evidence of decreasing marginal benefits from both land and wildlife

Figure 4
WTP for Wilderness Designation in Utah



conservation. Loomis, Lockwood and DeLacy (1993) found that the total benefits stemming from the protection of Australian forest land increases to a maximum level after which the incremental WTP for additional protection falls. As the total size of the aggregate area slated for protection increases, there is also a greater likelihood of substitution effects between areas. Loomis and Larson (1994) report that Californians were willing to pay \$25 on average for a 50% increase in the population of Gray Whales compared to \$29.73 for a 100% increase of the population. Layton, Brown and Plummer (1999) found high WTP for initial improvements in salmon habitat in Washington state, but few additional benefits arose from more substantial improvements.

2.2 Recreation Benefits

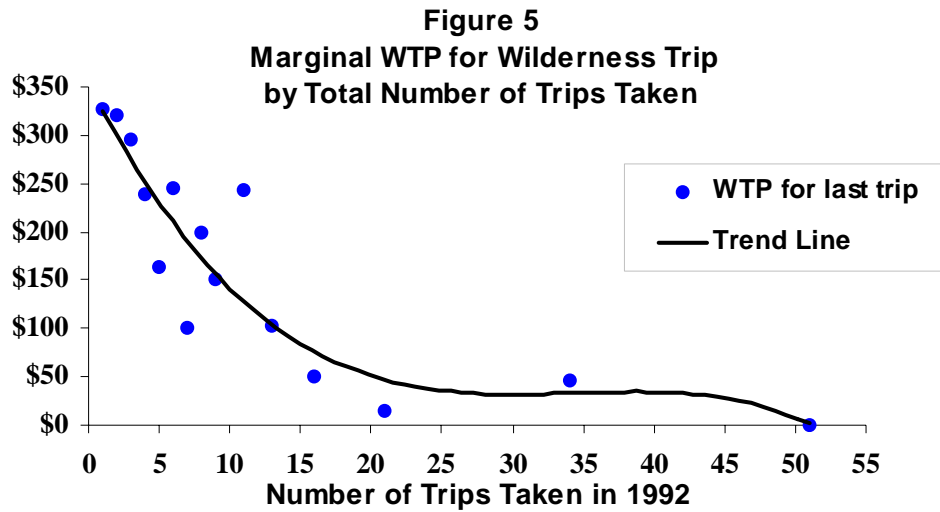
Similar phenomena are observed when studying the value of recreational experiences. Reid et al. (1995) found that residents of BC took nearly 1.4 million wilderness trips within the province of BC in 1992 for a total of 5.1 million recreation days. A sample of these recreationists were asked to indicate how they would be willing to pay for the last wilderness trip they actually took in 1992. Table 5 records the average response conditioned by the total number of trips taken during the year. For example, the average WTP for the last trip of the year by all respondents who took a total of two trips was \$319. By comparison, the average WTP for the last of 13 trips is only \$103 dollars.

Table 5
WTP of Bc Residents for the Last Wilderness Trip Taken in 1992
By Total Number of Trips Taken

Number of trips taken in 1992	Average WTP ^a (\$)
1	326.55
2	319.94
3	296.22
4	239.38
5	163.63
6	245.08
7	100.00
8	200.00
9	150.00
11	242.86
13	103.50
16	50.00
21	15.00
34	46.00
51	0.00

Source: Reid et al. (1995)

While this data is not smoothly decreasing in the number of trips taken, plotting it (Figure 5) reveals an overall declining trend suggesting generally decreasing marginal benefits of additional trips.



Similar results are reported by Rollins (1997) in her study of backcountry canoeing in selected Ontario provincial parks. In this case, respondents were asked to provide their willingness to pay to increase the length of their trip by one day. When reported by trip length, the data shown in Table 6 is again consistent with decreasing marginal value of recreation. The trend line added to Figure 6 emphasizes this result.

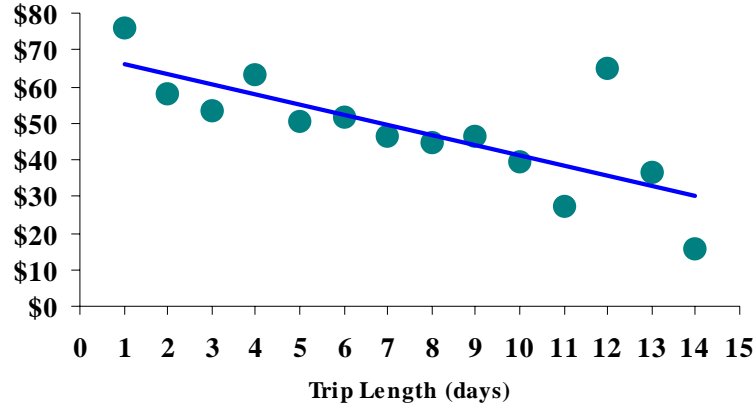
Rollins (1997) cautions (and this applies to the earlier Reid results as well) that because these estimates were obtained from different individuals they do not include the reasons motivating the chosen provincial park or trip length, and thus the variance of WTP estimates cannot be attributed exclusively to the principle of diminishing marginal valuation. However, Rollins (1997) found that “the difference in average WTP per day between trips of different lengths, was statistically significant. Thus, one can infer from this that average WTP is falling and this is not inconsistent with a decreasing marginal WTP” (pg.14).

Table 6
WTP Per Trip-Day by Trip Length

Trip Length (days)	Mean WTP ^a (\$)
3	75.99
4	57.90
5	53.40
6	63.42
7	50.18
8	51.66
9	46.64
10	44.59
11	46.32
12	39.56
13	27.12
14	64.76
15-19	36.55
>20	15.42

Source: Rollins (1997)

Figure 6
WTP for an additional day by trip length



Substitution effects can also have an important impact on attributed values. Rosenthal (1987) empirically demonstrates how the omission of substitutes can overstate the value of recreation sites. The 1982 study pooled data from 60,000 day users at eleven popular water reservoir in Kansas and Missouri. These sites provided opportunities for swimming, fishing, tanning, boating etc. Estimates of consumer surplus per person-day of activity were on average 2.6 times larger when all sites were considered than when benefits were estimated for each site independently. The empirical results also indicated that the demand for recreational use of a reservoir is much less responsive to changes in the cost of accessing the site when the costs of visiting alternative sites are omitted.

Taken as a whole, the evidence is very strong that use and nonuse benefits are subjects to substitution effects and decrease at the margin. This is central to the cost-benefit and valuation framework developed in the next section.

3. A Cost-benefit and Valuation Framework

3.1 The Need for a Comprehensive Cost-Benefit Approach

Because of decreasing marginal benefits and implied substitution effects, the correct economic value of a park or unprotected old-growth set-aside forest can only be assessed in light of existing or anticipated usage of other comparable land.

The decision to log or to create a park cannot be taken without due consideration for existing and anticipated land-use patterns. Natural scientists have long advocated a more global approach to resource management and we make the same argument for policy and economic reasons. A broad approach is required because it is the relevant context for the valuation of resource benefits. Factual observations and basic tenets of economic theory tell us that individuals take advantage of substitution possibilities, and that they are willing to pay higher prices for rare goods (including environmental goods) than for abundant ones. These aspects of human preferences are integral to the cognitive frame of reference from which individuals determine the value of nature.

In order to value conservation measures properly, it is necessary to have an understanding of future land-use decisions. In the context of old-growth forest, this means knowing if and when the stock of existing old-growth will be reduced, and when forests will be allowed to regenerate to a sufficiently mature age to provide some nonuse and recreation benefits. In short, valuing the protection of forested areas requires having a good grasp of forestry and how it affects land-use over time.

This calls for a dynamic cost-benefit framework. Land-use decisions affect human welfare far into the future. Retaining old-growth maintains wildlife habitat and other ecosystem services, and satisfies the preferences of individuals who care about a healthy environment. It allows future generations to enjoy these services as well. On the other hand, logged timber provides immediate financial benefits but slowly releases carbon into the atmosphere, contributing to the greenhouse effect and potential warming of the planet. Forest regeneration (after harvest) provides different types of recreational opportunities and results in higher rates of carbon uptake than is the case for mature forests. These effects call for a valuation framework that consistently reflects and accounts for the various flows of benefits and costs through time.

The need to predict or model forestry decisions substantially complicates the task of valuing the protection of forested areas. The overall modeling strategy is to build a forestry sector along with the benefits and costs of conservation directly into the model. The analysis proceeds by asking the model to make economically optimal land allocation decisions over time. Land can be allocated between protected old-growth, unprotected old-growth, logging or regenerated areas 80 years after logging. An acceptable program must be complete and feasible. By complete, we mean that all sites included in the analysis must be assigned a particular land-use for the entire time horizon. The program is feasible if it respects a number of constraints. For instance, an area cannot be covered with old-growth if it has previously been logged. The criterion guiding the selection of a particular land-use pattern is simply the maximization of net discounted benefits to society. Under this criterion, the pattern of land-use selected is the one that generates the greatest possible level of benefits to society.

Introducing a forestry model is necessary but admittedly cumbersome. It is perhaps even unpopular with natural scientists and park managers who may not feel they have the expertise required to conduct valuation work in this setting. These caveats notwithstanding, the approach we develop confers one substantial strategic advantage to the conservationist. Because the land-use decisions prescribed by the valuation framework are objectively optimal and account for the opportunity costs of forestry, little or no doubt should remain that the most desirable use of the land is indeed to preserve it in its original state.

3.2 Previous Work

Previous research on the optimal management of old-growth over time can be categorized into two separate streams. The first attempts to answer the question “How much of this type of forest should be preserved? By virtue of the research question posed, ANY portion of the area under study can be dedicated to forestry or left intact as old-growth. Reed (1993) analyses uncertain timber and amenity values, while Conrad and Ludwig (1994) and Conrad (1997) provide empirical applications with uncertain amenity values. Conrad and Ludwig (1994), for example, show that a deterministic model would lead one to protect 24% (16%) of remaining old-growth if the discount rate is 4% (6%). Introducing uncertainty into the model would increase the proportion of remaining old-growth to protect to as much as 36% (21%). In these models, amenity values are left unspecified, except as a proportion of commercial timber value.

Van Kooten and Bulte (1999) balance conflicting demands on forestlands in the coastal region of British Columbia by computing socially optimal stocks of old-growth forests (see also van Kooten 1995b). They consider a variety of non-timber values and explicitly include carbon storage and uptake benefits, which have been ignored in earlier studies. They conclude that up to 50% of British Columbia Coastal forest should remain untouched.

These studies have shortcomings, the most important of which is the homogeneity of the forest and the impossibility of identifying which parts of the greater eco-region should be logged and which should be protected.

The second stream of research that has inspired our work addresses this issue by asking the question “How should a designated number of forested areas that are interdependent in the production of non-timber benefits be managed over time?” In his pioneering work on multiple use forestry within a single stand, Hartman (1976) recognized the need to, and advocated the use of, a system approach to forestry management. He states that when there are “many plots of forest land which could reasonably be taken as units for making cutting decisions, what happens on one plot will clearly affect the value of a standing forest on other units.”

Bowes and Krutilla (1985, 1989) were the first to take up Hartman’s challenge. They devise a method that incorporates stand interdependence at the forest level. Bowes and Krutilla (1985) consider the multiple use management of a small forested area that provides timber, water flow and recreational benefits. They simulate a situation where the forest is divided into three stands, each of which is fully stocked initially by trees older than 120 years. They employ a thirty-year interval between harvests with the maximum age of the stand occurring at 120 years. Recognizing complementarities and substitutes, non-timber values (recreation and water flow benefits) are dependent on the age mix of all three stands.

The authors investigate the tradeoffs between timber and non-timber values at the forest level. They do this by generating optimal harvesting decisions under a variety of price levels for recreation and water flow benefits, finding that harvesting decisions are quite sensitive to multiple-use demands as well as the parameters affecting timber and non-timber benefits. For instance, when recreation values are at the base level and water flow amenities have no value, two-thirds of the area should be preserved as old-growth, while the remaining stand should be harvested under a 90-year rotation. On the other hand, they find that no harvesting should take place when recreational benefits are more than 50% above the base level. In contrast, when recreational benefits are low, long run optimal management calls for staggered 120-year rotations on each of the three stands. Importantly, they often observe stand specialization. Some stands are kept as old-growth, providing high amenity value, while others are put on harvesting rotation to maximize timber values.

Bowes and Krutilla (1989) consider harvesting decisions on a forest composed of eight stands of equal size and productivity. As in all work described here, the objective is to maximize the discounted sum of net timber and non-timber benefits. Non timber values are determined by the combination of stand ages and total area of stands of different ages. The ideal stand and age mix consists of a small amount of land available for wildlife to forage, a larger amount of land reserved for old-growth, and the remainder composed of a balanced mix of different ages. Multiple use and timber management regimes are compared at two different interest rates, and over three different net stumpage prices.

Once again, the authors find that the optimal management plan is extremely sensitive to the magnitude of recreational values and to the initial diversity of age classes within the forest. As previously recognized, specialization may occur with certain stands dedicated to maintaining old-growth, while other stands are regenerated thereby providing forage to wildlife.

Swallow and Wear (1992) study a situation where two landowners separately manage neighboring forest stands of equal size. The neighboring landowner manages his stand for timber benefits only, while the focal landowner's welfare depends on both timber revenues and the amount of wildlife on his stand. In this study, the interdependence between stands is made explicit by the fact that returns in the form of wildlife depend on the total forage produced on both stands.

This analysis reveals that the optimal program generally consists of a sequence of nonconstant rotations covering a wide variety of possible harvesting schedules. The exact form of the rotations depends primarily on the initial conditions (the stands' initial ages) and the magnitude of benefits that can be obtained from different mixes of forage and forest cover. The substitutability of alternative stands in providing forage areas for wildlife is an important factor in the analysis.

Swallow et al. (1997) extend Swallow and Wear (1992) by allowing a single land manager to control the entire two-stand ecosystem. The manager seeks to maximize the net stream of timber and non-timber values where non-timber values for either stand depend on the stand's own age and the age of the neighboring stand. Since wildlife migrates, non-timber benefits are based on the condition of the forest overall.

The model considers stand ages in increments of one year (with 80 years being the maximum age) and a discount rate of 4%. The base case simulation involves two cleared (age 0) stands that have identical productivity for both timber and non-timber production. The base case is then compared to nine alternative scenarios that vary the productivity of each stand in the production of timber and non-timber benefits.

The authors find that optimal harvest patterns are sensitive to key parameters representing timber and non-timber productivity. Even with identical production of timber and forage, harvesting rotations can be quite different for each stand. A longer rotation age in one stand can compensate for lack of wildlife habitat when the other stand is younger.

In the long run, specialization arises as a result of timber and non-timber benefits responding differently to management actions. Specialization across stands can lower the age of harvest of one stand while the other stand is allocated for longer rotations to capture profits from timber sales. Swallow et al. (1997) remark that the optimal harvesting schedule at the forest level may deviate wildly from the "rules of thumb" commonly used in traditional forest management as a result of the importance of stand interactions.

Finally, Rose and Chapman (2000) construct simulations for two adjacent stands where each stand is one hectare in size and initially 100 years old. While the first stand is highly productive for timber and hunting, the second stand has a low productivity for each. Four management objectives (and their combinations) are considered: timber benefits, hunting benefits, use (recreation) and non-use benefits, and endangered species protection. Because management decisions that concentrate on only one of these values can reduce the benefits from the other functions, the authors strongly emphasize in their conclusion that economic efficiency requires that all social values be included in the decision-making process.

In all previous research, the conservation of natural areas was defined simply as the absence of, or delays in, logging certain areas. While this achieves de facto preservation of old-growth forests, it does not allow the legal designation of protected areas, a historically successful policy instrument.⁴ In the model developed in the next section, we rectify this problem by allowing explicit conservation decisions. We also combine elements from both streams of research and recognize preservation and recreation benefits more

⁴ By Act of Congress on March 1, 1872, Yellowstone National Park was "dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of the people" and "for the preservation, from injury or spoliation, of all timber, mineral deposits, natural curiosities, or wonders. . . and their retention in their natural condition." Yellowstone is the first and oldest national park in the world. Banff was established in 1885 as the first of Canada's National Parks under similar terms.

explicitly than most previous work. The outcome is a more realistic model of land-use management decisions that can be used to establish the value of existing or planned park areas in a conceptually sound benefit-cost framework.

3.3 A Model with Explicit Conservation Decisions

In this section, we develop a model for analysing the optimal allocation of BC coastal old-growth and determine the value of protected areas in this region. The model is described in non-mathematical terms, but it is essentially a constrained optimization model with integer decision variables. The GAMS program code is provided in Appendix 1.

The model structure closely resembles that of Bowes and Krutilla (1989), but with the important extension that conservation is made an explicit decision that provides benefits that were not considered in previous work.

Several distinct sites must be managed over time by a “planner”.⁵ At the beginning of the analysis, sites are typically considered to be old-growth, but the analyst can choose other “initial conditions”. In each subsequent period and for each site, the planner must decide whether to log the site for timber, create a park or maintain it as unprotected old-growth forest if it has not yet been logged. Once old-growth forest has been logged, the land is allowed to regenerate naturally and logging can reoccur at any time before or after timber volume reaches maturity at 80 years of age. In this model, the creation of a park does not preclude logging at a later date, but logging prevents the creation of a park for the next 80 years.⁶

The planner can choose to create parks or to log any or all sites at any time. However, it is charged with the task of choosing the management plan that maximizes society’s net benefits from land-use over a long planning horizon (typically 240 years in the computerized version of the model implemented here). Benefits from land-use include the nonuse value of both protected and unprotected old-growth; the option value of protected old-growth; the recreation benefits of activities consistent with park designation; the value of hunting and fishing on regenerated forest land; non-timber benefits from unprotected old-growth (e.g. mushroom collection, Christmas ornaments); the rent from timber harvesting; and the benefits and costs associated with trapping and releasing carbon, an important contributor to global warming. Also accounted for are the costs of creating and operating each park, and the political or transactions costs of removing an area from the list of protected sites. Table 7 summarizes the benefits and costs accounted for by the model and the state or action that give rise to these benefits or costs.

⁵ The “planner” introduced here is used to designate any and all levels of governments collectively responsible for land-use management. In practice, this certainly involves the provincial governments who have immediate jurisdiction over most of the land in Canada, but it can also include the federal and municipal governments and, potentially, aboriginal councils where authority to manage land has been recognized.

⁶ This is consistent with the reality that acts of legislatures can be repealed, and with the history of conservation decisions in British Columbia where, in the past, several previously protected areas have been released from the provincial park system (Sinclair 2000).

Table 7
Benefits, Costs and Their Source

Category	Source
Nonuse Benefits (Excl. Option Value)	<ul style="list-style-type: none"> Protected old-growth Unprotected old-growth
Option Value	<ul style="list-style-type: none"> Old-growth
Non-consumptive recreation benefits	<ul style="list-style-type: none"> Protected old-growth
Consumptive recreation benefits	<ul style="list-style-type: none"> Regenerated forests (80 years or more)
Non-Timber Forest Benefits	<ul style="list-style-type: none"> All old-growth Regenerated forests
Rent from Logging	<ul style="list-style-type: none"> Volume logged during the period
Carbon uptake (benefits of logging)	<ul style="list-style-type: none"> Volume of regenerating forest
Carbon release (cost of logging)	<ul style="list-style-type: none"> Volume logged during the period
Cost of creating parks	<ul style="list-style-type: none"> Initial protection of old-growth
Park Operation and Maintenance	<ul style="list-style-type: none"> Protected areas
Cost of logging protected areas	<ul style="list-style-type: none"> Decision to log a protected old-growth area

There are two types of costs and benefits: those associated with an action (e.g., the cost of creating a park, the net benefits of logging an area) and those associated with the status or “state” of an area (e.g., a protected area provides option value. “State” benefits and costs are dependent on the overall area covered with each type of land. For this reason, each site (indexed i1 to i6 in the current implementation) is given a size (in square kilometres), categorized according to its dominant tree species, and accompanied by a table of timber volume at different ages. In what follows, the six forest sites consist of different species and site qualities. The corresponding volumes of merchantable timber at different ages are reported in Table 8.

Table 8
Site Characteristics and Timber Volume

Site	Species	Growing Condition	Volume of Merchantable Timber (m³/ha)^a				
			20 Years	40 years	60 years	80 Years	Old-growth
i1	Hemlock	medium	0	144	288	417	756
i2	Hemlock	poor	0	39	108	187	507
i3	Cedar	poor	0	16	65	140	405
i4	Cedar	medium	0	49	161	317	765
i5	Hemlock	good	0	360	567	723	998
i6	Balsam Fir	poor	0	10	98	190	630

^a The volume data represents actual average yield per hectare on the BC Coast. Source: van Kooten and Bulte (1999)

With the exception of site i5, the choice of tree species and growing condition reflects the rank of each type in terms of total area of remaining coastal old-growth in British Columbia. Few areas with good (fast growing/high volume) Hemlock remain on the BC coast, but site i5 was assigned these characteristics in order to ensure the presence of one site with good growing potential. Together, these six pairs of dominant species and growing conditions represent 80.1% of all of the remaining coastal old-growth of British Columbia.

In the initial simulation of the model, each site is assumed to cover an area of 100 km². This is purely an assumption that we use to explore the models and the driving factors behind the solution it provides. We relax this assumption later on.

After land allocations are made in each period, the costs and benefits of these decisions are computed, the state of each site is adjusted to reflect the latest land allocations (or the unchanged state, or the ageing of timber), and the benefits associated with the resulting state are added up. Performing these computations requires that the total area of land under several different states be known at all points in time. Thus, at the beginning of each period, the model calculates the total amount of land in protected old-growth, unprotected old-growth, total old-growth, and in fully regenerated forest. The result is then used to determine the value of each category of benefits during the period. The overall benefits and costs of the program are discounted at a real rate of 3% to provide the net present value.

It is important to realize the extent of the computational challenge required to find the land allocation program that maximizes benefits to society. To do so, it is useful to think about the following analogy. Imagine six hikers at a trail head. They start walking and, after one hour, come to a fork in the trail. The fork has three branches and each hiker individually decides which of the branches to take. They may all take the same branch, separate into smaller groups, or individually go their own way. Given six hikers, each having to choose one of three branches, this results in $3^6=729$ different possible configurations of where the hikers could be after they encountered the first fork.

Suppose that our hikers plan on walking for a total of 12 hours and that after each hour of walking each hiker encounters a new fork in the trail with three new alternatives. Then, there are $729^{12}=2.252839 \times 10^{34}$ different combinations of routes that our hikers can collectively take. To carry the analogy further, if there are costs and benefits (different to each of the hikers) associated with reaching each fork, and from choosing each new branch of the trail, the task of the planner in our problem is akin to asking a mountain guide to choose the walking plan (among the 2.25×10^{34} possible routes) that maximizes the sum of benefits to the group.

The problem of choosing between logging, protection or inaction in each period is analogous to the mountain guide's problem. It is only slightly simplified by the fact that certain choices cannot be made. For instance, creating a park the year after (or even 20 years) after a site has been logged does not make sense and is therefore not allowed. In the hiker's analogy, this means that some hikers may come to a fork that only offer two instead of three alternative branches. This reduces the complexity of the problem, but still leaves an enormous number of possible path configurations to choose from.

Problems of this type can rapidly become so large as to exceed the computing capacity of modern computers. This is a problem known as the "curse of dimensionality" and is due to the fact that the number of possible decisions explodes exponentially as the number of time periods increases.

The curse of dimensionality is especially common in forestry models because the slow growth and long lifespan of trees require long planning horizons. While it is desirable to solve our land allocation problem over a time horizon exceeding 200 years, no modern desktop computer has enough memory and computing speed to do so. For this reason, we simplify the problem by employing a 20-year time step so the planner can make changes to the allocation of land only once every 20 years. Solving the model for 12 periods representing 20 years each keeps the computational problem to a manageable size while maintaining a sufficiently long time horizon of 240 years.⁷

⁷ Even with this simplifying assumption, a typical run of the model can take up to 5 hours to return a solution.

The computerized model was implemented as a Mixed Integer Programming problem (MIP) using a proprietary software called GAMS (Generalized Algebraic Modelling System) and the CPLEX solver module. The problem is a special case of MIP in which all decision variables are binary (0 or 1). For instance, the decision to create a park on site i at time t is represented by the variable $\text{park}(i,t)=1$. If no park is created, $\text{park}(i,t)=0$. Similarly, the decision to cut site i at time t is represented by $\text{cut}(i,t)=1$ while $\text{cut}(i,t)=0$ represents the decision not to log this site at t . The CPLEX solver module is recognized as the most powerful and accurate algorithm for these kinds of problems.

4. Model Calibration and Implementation

The paucity of available data on the value of natural amenities in Canada remains a severe impediment to credible research. For this reason, our analysis is applied to a generic area of the British Columbia coast. Even in this generic context, the principal challenge remains that of realistically quantifying the various benefits and costs in the model. We now turn to this task.

4.1 Forest Functions: the Benefits and Costs of Coastal Old-growth⁸

In this section, we provide measures of timber and non-timber benefits grouped in five categories: (i) non-timber (or minor) forest products (NTFPs), (ii) nonuse values, (iii) recreation, hunting and wildlife viewing, (iv) the benefits and costs of carbon sequestration and release; and (v) the net rents to timber harvesting.⁹ The presentation highlights both useful references and data from secondary sources on the value of British Columbia old-growth forests. We also note the assumptions and calculations made to obtain the final formulation of the model introduced in section three.

4.1.1 Non-Timber Forest Products

Minor forest products mainly include wild edible mushrooms, floral greenery, medicinal plant products, fruits and berries, herbs and edible plants. These products are obtained primarily from unprotected old-growth and regenerated forests. The most important activity, for which the most information is available in BC, is the picking of wild edible mushrooms. Other activities appear to be less important, although little is known about them. While the BC Ministry of Forests attempts to regulate (parts of) the non-timber forest products sector, it does not collect royalties—indeed, income taxes are generally not collected either. Thomas and Schumann (1993) provide a broad overview of NTFPs and their market potential.

At present, between 2,000 and 5,000 people harvest a total of 33 species of wild edible mushrooms across BC. The most important varieties are pine mushrooms, marketed primarily in Japan (where it is known as white matsutake), chanterelles, morels and boletes, with the latter three sold mainly in Europe (France, Germany and Italy).

Pine mushrooms are found "... along the coast and interior mountain ranges of western North America from northern California to Alaska, ... the eastern Maritimes and as far south as Tennessee, ... and throughout the northern forested regions of Saskatchewan and Manitoba" (BC Ministry of Forests 1995, p.10). Clearly, Pine mushrooms are associated with many forest types, although forests must be older than 50 years. About two-thirds of those engaged in mushroom picking are local residents who supplement their incomes, the remainder are professional or nomadic harvesters, who also travel to the Yukon, NWT, Saskatchewan, Washington, Oregon and California to pick mushrooms. The vast majority of mushrooms are marketed in Europe and Japan, but no annual crop statistics are available. A 1994 survey of mushroom companies in BC found that, in 1993, almost C\$3.9 million was paid to pine mushroom pickers for 125.3 tonnes of mushrooms (about \$31 per kg).¹⁰ In 1992, some 32,000 kg of morel mushrooms were harvested in BC. Interestingly, 1993 was considered a poor year for pine mushrooms due to drought, while 1992 was considered a poor year for morels. However, given that there is no other information on mushroom harvest and values, it is impossible to determine whether these years were truly good or bad.

Compared to data for the US Pacific Northwest (PNW), the value of mushrooms to BC is either understated or BC forests are not as rich as those to the south. In 1992, mushroom companies in the US paid US\$20.3 million to 10,400 pickers and the gross value of the industry as a whole (including processing) was estimated at US\$41.1 million, with a net benefit of US\$2.9 million. Using the ratio of

⁸ This section is based on van Kooten and Bulte (1999).

⁹ This research focuses on net economic benefits. Net benefits are defined by appropriate welfare measures as the excess of benefits over the cost of obtaining such benefits. Accordingly, economic impacts and other transfer measures are ignored. since these measures do not capture any net surplus to society.

¹⁰ Of this amount, 110 tonnes was harvested in the Terrace–Nass Valley area and not on the Coast (BC Ministry of Forests 1995).

gross sales for BC to gross sales for the PNW, and taking into account the exchange rate, one obtains an estimate of net benefits for BC of approximately C\$0.6 million.¹¹ Dividing by a total area of mature timber for BC of 26.7 million hectares (see Table 9 below) gives an average net benefit of \$0.02 per ha.¹² Even if the industry is five times larger than this, the average net benefit is only \$0.10 per ha. Lacking data on marginal benefits, we assume they are equal to average benefits and thus constant.

Knowledge about other NTFPs is even sparser. Floral and greenery products are important, particularly at Christmas time. The government does exercise some control by requiring those cutting white pine boughs on Crown land, for example, to obtain a letter of authorisation. Permission prescribes harvesting procedures, schedules and designated area, but says nothing about quantity. Again no attempt is made to collect royalties. A US study estimated that floral and greenery products generated about US\$128.5 million in sales at the wholesale level in 1989 (Schlosser, Blatner and Chapman 1991; BC Ministry of Forests 1995). The study encompassed the US PNW and BC, but most of the industry appears to be located in the State of Washington. Salal (including salal tips) was the most valuable crop, accounting for 10.2% of total sales, with bear grass second at nearly 9.0%.

Schlosser, Blatner and Chapman (1991) indicate that there were 2,670 full-time and 2,750 part-time harvesters, and that plant material cost the floral and greenery industry US\$47.7 million. Using these authors' cost of labour and assuming that part-time workers spent only one-tenth as much time on this activity as full-time workers, the cost of labour amounts to US\$44.2 million. This leaves a net surplus or economic rent of \$US3.5 million spread across two states and one province. If BC generates one-third of these benefits, then, upon adjusting for exchange rates, the benefits from harvest of floral and greenery amount to \$1.65 million in BC. Since the focus of the above study was on areas west of the Cascade Mountains, dividing by 3.4 million ha of mature forest on the Coast gives a value of almost \$0.50 per ha.

There is no information about the value of BC forest-dependent plant and animal species as a potential source of medicinal and pharmaceutical products. Estimates by Simpson, Sedjo and Reid (1996) suggest that the value of BC forests is likely much less than US\$1 per hectare in biodiversity prospecting. Even in a hotspot such as western Ecuador, these authors estimate that the potential biological value of forests is less than \$25 per ha, while it is only \$0.20 for a floristic province in California.

Finally, there are many other NTFPs available from BC forests, ranging from wild berries and fruit to products used to make crafts. Again, there is no information about harvest levels, the types of ecosystems that these products are found in, their occurrence in other jurisdictions, and the value of the products. Based on the above information, it is unlikely that the value of these products exceeds \$0.10 ha⁻¹.

Many of the (modest) values associated with NTFPs are related to timber growth and, thus, are not incompatible with normal timber production. It is true that the capability of a site to grow (some types of) mushrooms might disappear for a period of up to 50 years after harvest, but mushrooms continue to be available on other sites and will return in the future.

Haener and Adamowicz (1999) estimate that the value of aboriginal subsistence use of forests in Alberta could be as high as \$26.8 million. If a similar value applies for BC, and dividing by the area of mature forest, this provides a value of \$1 per ha. If subsistence use is half again as great in BC as Alberta, then each ha of mature forest yields about \$1.50 in such benefits.

Based on this information, we assign a value of \$3.20 per hectare of old-growth or regenerated forest. Table 9 summarizes the data.

Table 9

¹¹ This is determined as $[(3.9 \times 0.7) \div 20.3] \times 2.9 \div 0.7$, where C\$=US\$0.70. Unless otherwise indicated, values are in Canadian currency.

¹² Mature forest refers to trees at or above the age of culmination of mean annual increment (about 100 years). Old-growth refers to forests older than 120 years.

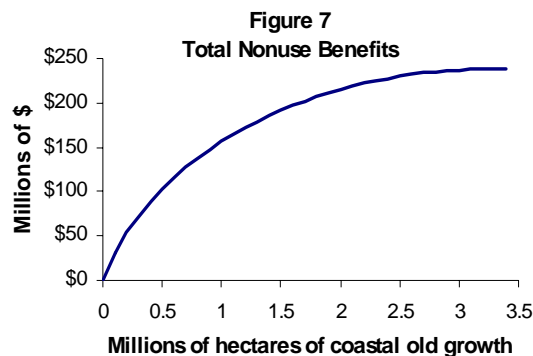
Estimated Value of Non-Timber Forest Products on the BC Coast
(\$ per ha of Mature Forest)

Item	Annual Benefits per Hectare (\$)
* Mushrooms	\$0.10
* Floral and greenery	\$0.50
* Biodiversity prospecting	<\$1.00
* Other	\$0.10
* Aboriginal subsistence use	\$1.50
TOTAL	\$3.20

4.1.2 Nonuse Benefits

It is likely that the greatest opportunity cost associated with commercial timber operations on the BC Coast is the potential loss in nonuse benefits including existence and option values. Using contingent valuation methods (CVM), US researchers calculated that households were willing to pay between C\$50 (Rubin, Helfand and Loomis, 1991) and C\$275 (Hagen, Vincent and Welle 1992) annually to preserve wilderness for northern spotted owl. For BC, Vold et al. (1994) found that households were, on average, willing to pay \$136 per year to double the amount of wilderness in the province from 5% to 10%, and that they would be willing to pay \$168 per year to triple the amount of wilderness to 15%. In order to err on the side of the environment, we assume households value wilderness at \$300 annually (i.e., more than the highest value found in US studies). If households consist of 1.4 adults on average, it is possible to calculate total nonuse benefits per household at \$455.5 million for all of BC and \$339.2 million for the BC coast forest region.

It is still necessary to determine the marginal nonuse benefits associated with retaining land in old-growth. Given the evidence presented in section 2 about the shape of the total nonuse benefit function, we assume that these benefits can be adequately represented mathematically by a Gompertz function of the form $B(X)=aX\text{Log}(b/X)$ where a and b are positive constants and X is the amount of old-growth forest remaining. Under this formulation, we know that the value of protecting all remaining coastal old-growth is equal to \$339.2 million annually (i.e. $B(3.4)=339.2$) and that the marginal value of additional protection reaches zero once all is protected.¹³ Given these assumptions, we evaluate the parameters as $a=70.2941$ and $b=9.2422$. The total benefit function is illustrated in Figure 7. Note that its curvature resembles the shape of functions produced by Walsh et al. (1984) and Rollins and Lyke (1998).



Consistent with the allocation of value reported by Colorado residents (Walsh et al., 1984), it is further assumed that 29% of nonuse benefits consist of option values that can only arise when formal protection is extended to old-growth areas. Therefore, total annual nonuse benefits from old-growth consist of the sum of 71% of the nonuse benefits illustrated by the function for the total amount of remaining old-growth

¹³ Marginal benefits are given by the first derivative. Setting it to zero when $x=3.4$ yields the condition $a[\text{Log}(b/3.4) - 1] = 0$

and 29% corresponding to the area of legally protected land. It is also assumed that a small amount of nonuse benefits (but no option value) is generated by mature regenerated forest stands since they provide wildlife habitat and other ecosystem services. Table 10 summarizes the hypothesized forests values.

Table 10
Total Annual Nonuse, Option and Recreation Benefits Coastal British Columbia Forests (\$ millions)
Baseline GAMS model assumptions

	Nonuse Benefits (1)	Nonuse Benefits (2)	Recreation Benefits	Option Value
Land providing these benefits ±	Protected or Unprotected Old-growth Forest	Regenerated Forest (>80 years old)	Protected Old-growth	Protected Old-growth
Hectares (000's)				
0	0	0	0	0
100	22.59	2.53	31.39	22.04
200	38.26	4.81	53.16	37.35
300	51.33	6.87	71.31	50.08
400	62.69	8.72	87.1	61.19
500	72.79	10.35	101.14	71.02
600	81.89	11.79	113.78	79.92
700	90.15	13.03	125.26	87.99
800	97.7	14.09	135.75	95.35
900	104.62	14.97	145.36	102.11
1000	110.99	15.68	154.21	108.32
...
2000	152.78	16.91	212.29	149.11

4.1.3 The Benefits of Recreation

A recent study (Reid 1998) of the benefits of wildlife viewing in BC provides measures of the direct benefits associated with activities whose sole purpose is wildlife viewing and indirect benefits associated with activities where wildlife viewing is secondary. Total benefits for the province amount are estimated at \$985.6 million annually (see Table 11). These values are based on the willingness of respondents to increase actual spending above the expenditures they actually incur to engage in outdoor recreation.

Table 11
WTP by BC Residents for Recreational Activities

Region	Adult Population ('000s)	Indirect Activities		Direct Activities	
		Total (millions)	Annual per Adult	Total (millions)	Annual per Adult
Vancouver Island	549.2	\$27.7	\$50.45	\$221.5	\$403.35
Lower Mainland	1672.8	\$120.3	\$71.92	\$334.0	\$199.66
Thompson–Nicola	123.6	\$7.7	\$62.43	\$38.3	\$310.15
Kootenay	116.5	\$6.3	\$53.66	\$56.1	\$481.78
Cariboo	53.5	\$3.5	\$65.71	\$22.0	\$412.12
Skeena	70.4	\$6.9	\$98.71	\$32.1	\$456.30
Omineca–Peace	132.9	\$9.1	\$68.84	\$29.7	\$223.66
Okanagan	254.4	\$12.0	\$47.14	\$58.1	\$228.54
British Columbia	2973.2	\$193.6	\$65.11	\$792.0	\$266.38

Source: Reid (1998)

Based on total area of mature timber in the province (26.7 million ha), the annual value of wildlife viewing is \$36.92 ha⁻¹. Dividing the sum of wildlife viewing benefits for Vancouver Island and the Lower Mainland by the area of mature forest in the Vancouver forest region yields an annual value of \$206.79 per hectare for the BC Coast. If only the values associated with direct viewing of wildlife are considered, the annual benefits amount to \$163.29 per ha of coastal mature forest.

There is little information about how wildlife viewing conflicts with, or is enhanced by, commercial logging operations. It is likely that commercial timber production and viewing of wildlife are not compatible during logging operations and for a (short) period thereafter, but that logging does enhance this use value by providing access and by providing a greater diversity of landscapes in the longer run (see Budiansky 1995). Further, wildlife viewing is not confined to mature forest areas. Indeed, most wildlife viewing occurs in areas where wildlife are most abundant, such as bird or wildlife sanctuaries, clearings, along rivers (fish going to spawn), ocean settings (whales watching for instance), and so forth. Therefore, the value associated with mature forest areas is likely much smaller than indicated above, particularly on the Coast where opportunities for viewing birds, fish and sea mammals are greatest. Consequently, we arbitrarily assume that the value of wildlife viewing on forested areas of BC's Coast is one-fourth of the above value, or some \$51.70 per hectare of mature forest.

More recent information is also available about the benefits of hunting (Reid 1997). In 1995, BC residents spent \$73.9 million hunting. Expenditures themselves are not a measure of benefit or well being, they are the cost of obtaining hunting benefits. Rather, it is the surplus associated with hunting that is the appropriate measure of benefits, and this turns out to exceed expenditures by more than \$2 million (Table 12). In this case, the economic surplus or benefit is determined as respondents' maximum willingness to incur increased daily hunting costs before they would stop the activity (see Reid 1997).

It is important to note that the economic values per harvested animals are quite high, ranging from \$1,084 for mountain goat to \$7,722 for grizzly bear. As hunting is not incompatible with commercial forest operations in many instances, and indeed logging may increase access for hunters while providing open spaces for the species generally hunted, it is difficult to argue in favour of reduced logging on the basis of this use. Hunting values are spread rather evenly across BC (Reid 1997), so one can allocate values simply by dividing total economic benefit (\$75.9 million) by the total area of mature forest to obtain a value of forestland in hunting of \$2.84 per ha.

Table 12
Annual Economic Benefits of Resident Hunting in BC, 1995

Species Hunted	Benefits to Hunters		Estimated	
	Average Daily	Total (\$ mil)	Number Harvested	Economic Value per Animal Harvested ^b
Cougar	\$89.50	0.788	287	\$2,748.60
Black bear	40.00	3.825	2,940	1,301.10
Grizzly bear	105.30	1.282	166	7,722.40
Mountain sheep	83.20	1.938	335	5,783.60
Mountain goat	60.10	0.684	631	1,084.60
Elk	51.60	8.051	2,237	3,598.90
Caribou	70.70	0.649	190	3,413.80
Moose	49.10	15.823	9,396	1,684.00
Mule deer	45.20	24.918	22,637	1,100.70
White-tailed deer	44.90	13.700	10,698	1,280.60
Small game	7.80	1.067	n.a.	n.a.
Upland birds	7.80	2.814	n.a.	n.a.
Waterfowl	8.00	0.397	n.a.	n.a.
Total^a		75.935		

^a Column total may not add due to rounding.

^b Calculation.

Source: Reid (1997)

In summary, wildlife viewing and hunting together contribute \$54.54 ha⁻¹ to recreation value on the BC Coast. These activities constitute some 25% of total recreation as there are other activities in addition to hunting and wildlife viewing (van Kooten 1995). However, not all recreation is incompatible with logging. Certainly, motoring and boating are not and may even benefit from roads developed as a result of logging.¹⁴ The same is partly true of the activities fishing, camping/swimming, and hiking/skiing. For the latter categories and using data from van Kooten (1995), we attribute one-half of the hiking/skiing values and one-third of fishing and swimming/camping benefits to mature forest. In that case, the total value of mature forest on the BC Coast in recreation turns out to average \$105.51 per hectare, of which \$2.84 comes from hunting and \$10.93 is from fishing. Since hunting is not typically allowed in protected areas, we assign those benefits and approximately half of the fishing benefits strictly to unprotected forests for recreation benefits of \$8.77 per ha per year on regenerated forest land.

In recognition that a great portion of outdoor recreation is attributable to visitors of parks and recreation areas, we assign all other recreation benefits to protected areas. In the simulation model, we again represent the decreasing marginal benefits of recreational activities and its option value by assuming a

¹⁴ There remains controversy about the "benefits" provided by logging roads. While it might be argued that logging roads increase opportunities for recreation, wildlife viewing and hunting, one reviewer argues that increased access reduces wildlife populations due to increased hunting and use of roads by predators, impacts negatively on recreation (due to congestion) and reduces preservation values. Another reviewer points out that there are also positive effects of access on harvest of NTFPs. Support for the view that there may be some positive externalities associated with logging comes from Castle, Berrens and Adams (1994) and Drake (1992).

Gompertz function. The estimated parameters are $a=97.67$ and $b=9.24$.¹⁵ As previously, it is assumed that 29% of recreation benefits consist of option value for future use.¹⁶

Table 10 above summarizes the numerical values used in the baseline simulation of the model for a selected range of areas in protected and unprotected coastal old-growth as well as for mature regenerated forests. Table 10 can be read as follows. Suppose that the following land allocation is made: A total of 500,000 ha remains in old-growth, of which 300,000 ha are protected and 200,000 are not; 100,000 ha are regenerated forest land and 400,000 ha has recently been logged. Such an allocation would yield (for the benefits categories covered thus far) \$72.79 million in nonuse benefits from old-growth, \$2.53 million in nonuse benefits from regenerated forests, as well as \$71.31 million and \$50.08 million in recreation and option benefits from protected areas, respectively. To these values, we would add \$0.88 million in recreation benefits from regenerated areas for total annual benefits of \$197.59 million.

4.1.4 The Benefits of Carbon Sequestration and the Cost of its Release

Forests play an important role as a carbon sink. The release of carbon into the atmosphere after logging and its uptake as trees grow could be a significant determinant of humanity's success in containing the greenhouse effect. According to the mechanisms set forth by the Kyoto Protocol of December 1997, countries are to be debited for carbon released as a result of deforestation, but credited for carbon sequestered as a result of reforestation and afforestation. Carbon cycles can therefore be important determinants of optimal land-use and must be integrated into any cost-benefit analysis of conservation.

It is not clear whether logging and subsequent replanting/natural regeneration (as opposed to land-use change) will reduce the total annual carbon flux. For some primary forests, it may take several hundred years to restore the ecosystem's carbon balance to where it was before logging occurred, but it is not clear that a net amount of carbon is released. This depends on the extent to which carbon gets stored in forest products and assumptions concerning the rate of decay of those products (see van Kooten, Thompson and Vertinsky 1993; van Kooten, Binkley and Delcourt 1995; Sedjo et al., 1995; Sedjo et al. 1997).

Tree species found on BC's coast contain an average 182.4 kg of carbon per m^3 of wood (van Kooten, Thompson and Vertinsky 1993, p.247). Logging releases carbon in the atmosphere that contributes to global warming. Forest regeneration absorbs atmospheric carbon dioxide and relieves some of the effects of global warming. We consider the case in which 40% of the carbon content of trees is released immediately at harvest. The remaining 60% is stored in goods and released into the atmosphere at a rate of 2% of the remaining carbon per year.

The uncertainty regarding the extent of damage caused by carbon to the natural environment and the cost of global warming to humans makes it very difficult to assess the value of carbon sequestration and release. In what follows, we assume that the net discounted cost of a ton of carbon released into the atmosphere is \$50 per ton of carbon.

4.1.5 Timber Benefits

For the 5-year period 1990–1994, Grafton, Lynch and Nelson (1998) estimate that the average annual rent to logging in all of BC was \$1,609.56 million. Given average annual harvests of 70 million m^3 , this implies an average rent of about \$23 per m^3 . Timber on the Coast is generally substantially more valuable than that in the Interior. We simply employ an average rent estimate of \$30 m^{-3} for old-growth timber on the Coast and a value of \$23 m^{-3} for second growth timber.

4.2 Parameters

¹⁵ Note that the parameter b has the same value in both the nonuse and recreational benefit functions. This is a mathematical artifice due to the fact that the parameter b determines the point at which the marginal value of the function equals zero. By assumption, this occurs at 3.4 million hectares in both situations.

¹⁶ The proportion of recreation benefits attributed to option value is purely an accounting designation. By construction of the model, whether these benefits are considered pure recreation benefits or option benefits has no consequence on the total benefits of conservation and therefore does not affect the results of the model.

In setting the model parameters, data already described are employed while other parameter values are simply assumed as they play a minor role or no reliable information can be found to document their value. Parameters are briefly defined in Table 13 along with the values imputed to them in the baseline run of the model. Most of these baseline values are arbitrarily chosen.

Table 13
Model Parameter Definitions and Baseline Values

Parameter	definition	baseline value
rho	real discount rate per year	0.03
beta	real per year discount factor $\beta=1/(1+\rho)$	0.97087
beta2	real compounding factor for 20 year stream	26.87
aofp	capital recovery factor (A/P,0.03,240)	0.031
clp	transaction cost associated with logging a park	\$1 million
size(i)	size of area i (1 km ² =1,000 ha)	100 km ²
c(i)	cost of creating a park at site i (same for all i's)	\$50 million
opc(i)	annual O&M costs at park on site i (same for all i's)	\$10 million
int	length of time interval between decisions	20 years
qog	net timber rent per m ³ of old-growth timber	\$30
q	net timber rent per m ³ of second growth timber	\$23
vrecben	recreation benefits per km ² of regenerated forest	\$8770
ntfp	annual non-timber forest product benefits per ha	\$3.20
vanrho	% of carbon from timber stored in durable goods	60%
vandelta	annual rate of carbon release from durable goods	2%
carbscoef	amount of carbon per m ³ of timber	0.1824 ton
carbshadow	value of damages from 1 ton of carbon released	\$50

4.3 Optimization Results

4.3.1 The Baseline Scenario

In the baseline scenario, each of six sites under consideration covers an area of 100 km², and has identical costs of park creation, maintenance and logging. The optimal result for this simulation calls for the creation of two parks: Sites 2 (poor hemlock) and 3 (poor cedar). Both parks are created immediately and remain protected for the entire period of analysis. This represents protecting one third of the area under consideration, but only 5.8% of the 3.4 million hectares of coastal old-growth remaining in British Columbia. Implicit in the construction of the benefits associated with various levels of old-growth preservation is the assumption that no other old-growth outside of the study area remains. This is clearly not the case and we come back to this issue later.

The other four sites are logged at year zero for the large benefits that cutting large volumes of old-growth timber provide. These forest plots are thereafter put into rotation with Sites 1 (medium hemlock) and 5 (good hemlock) harvested every 40 years and Sites 4 (medium cedar) and 6 (poor balsam fir) harvested only every 60 years.

Summary Sheet 1 provides the basic input and summary of results for the Baseline Scenario. The annualized value of this program is \$353.98 million. Accordingly, the net benefits from this management program are equivalent to receiving roughly \$354 million every year for 240 years.¹⁷ Of this total, 69.9% are obtained from timber harvesting on the four unprotected sites (and include the cost of carbon released into the atmosphere) and 31.1% are from conservation related sources. Conservation benefits are divided between recreational value at \$53.18 million, nonuse values at \$38.27 million and option values in the amount of \$37.35 million annually.

The Summary Sheet includes a convenient pictorial representation of the overall optimal management program. Each of the sites is represented by a bar chart over the planning horizon. The present time period is represented by t=0. Negative values of years simply depict the initial conditions imposed on the model (all sites are unprotected old-growth). Positive values represent time into the future. The fill pattern of the bar identifies the state in which each particular area is in at that time, and black vertical lines (for the forestry state) signify that the area is logged at that particular time.

¹⁷ Note that annualized values are **geometric averages** that take into account the decreasing value of money over time. To transform an annualized value into a total net present value, one must divide the annuity amount by the capital recovery factor (0.031 in the case of 3% and 240 years). Multiplying the annuity by the number of years, as would be done with an **arithmetic average**, is improper.

SUMMARY SHEET 1
Baseline Scenario

Model Parameter and Values

Parameter	Value
<i>rho</i>	0.03
<i>beta</i>	0.97087
<i>beta2</i>	26.87
<i>aofp</i>	0.031
<i>clp</i>	\$1 million
<i>c(i)</i>	\$50 million
<i>opc(i)</i>	\$10 million
<i>int</i>	20 years
<i>qog</i>	\$30
<i>q</i>	\$23
<i>vrecben</i>	\$8770
<i>ntfp</i>	\$3.20
<i>vanrho</i>	60%
<i>vandelta</i>	2%
<i>carbscoef</i>	0.1824 ton
<i>carbshadow</i>	\$50

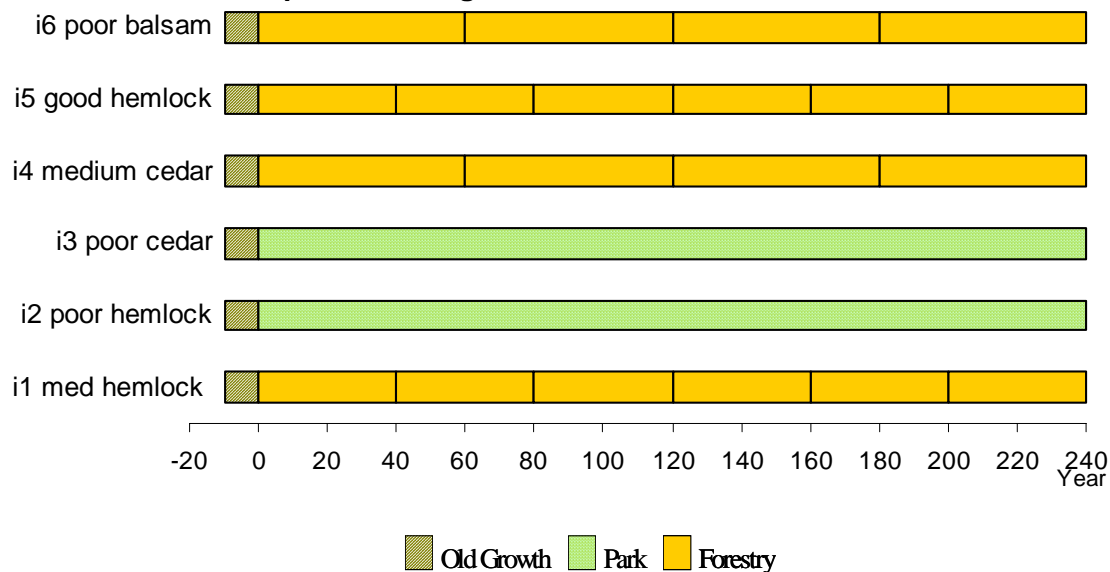
Site Characteristics

Site	Species	Growing Conditions	Size (km ²)
<i>i1</i>	Hemlock	medium	100
<i>i2</i>	Hemlock	poor	100
<i>i3</i>	Cedar	poor	100
<i>i4</i>	Cedar	medium	100
<i>i5</i>	Hemlock	good	100
<i>i6</i>	Balsam Fir	poor	100

Summary Results

Benefit/Cost Category	Annualized Benefits (\$ million)
Nonuse	38.269
Option	37.352
Recreation	53.179
Non-Timber Forest	0.64
Timber	302.741
Carbon Uptake	0
Carbon Released	55.199
Cost of Park Creation	3.002
Park O&M	20
Cost of Logging Park	0
Total Annualized Value	353.979

Optimal Management -- Baseline Scenario



4.3.2 The Value of a Park – Baseline Scenario

While we have just stated the magnitude of benefits from preserving the last two hundred square miles of BC Coastal old-growth, we have NOT stated the NET benefits of this conservation effort. This is because absent the protection afforded to sites 2 and/or 3, society would make the best alternative use of these areas. The benefits granted by the best alternative use is the opportunity cost of conservation and must be subtracted from gross benefits to obtain the net contribution of a park to society.

In the multiple-site context of this model, the net value of a particular park to society is established by imposing on the model that this particular site NOT be made into a park and re-solving the model with this added constraint. The value of benefits to society under the “constrained” solution thus provides the second-best solution resulting from the impossibility to create the park of interest. The difference in total value between the optimal and second best solution constitute the net foregone benefits associated with the no-park constraint and is the net economic value of the park to society.

The model can easily be used to establish the net value of any park or combinations of them. From the baseline scenario, it suffices to add one line of code per park that prohibits the creation of a park at the desired site(s). We ran two separate constrained models to establish the net value of a park at Sites 2 and 3 separately. These results are summarized in Summary Sheets 2 and 3, respectively.

The results indicate that the best alternative to a park at Site 2 is to harvest timber on a 60 year rotation length. The total annualized value of this new plan is \$350.636 million. This is \$3.343 million less than the value of the optimal plan when a park was created at Site 2. Thus, the net annualized economic contribution of the park to society, given the context that a park exists at site 3, is \$3.343 million. Over the 240 year planning horizon and the 3% discount rate adopted for this study, this corresponds to a total net present value of \$111.34 million.

These benefits (\$3.3 million in annualized benefits and the corresponding \$111.34 million in NPV) are the net value of creating a park at Site 2, above and beyond the timber benefits that would be received in the absence of a park. The force of these numbers lie in the fact that the direct and opportunity cost of creating and operating the park are fully accounted for in the framework. The resulting value of the park is the net gain to society from creating it.

When the constraint is imposed that no park be created at Site 3, a slightly different outcome emerges. The old-growth of Site 2 is again protected as a park, providing important conservation related benefits. However, while Site 3's second best use is forestry, the length of the rotation is extended so that, in fact, the forest is allowed to reach the age of 80 years. This provides benefits that by assumption, are not present in younger forests. Unprotected forests of 80 years or older are assumed to provide small nonuse benefits, be suitable for consumptive recreation activities (fishing and hunting) as well as non-timber product harvesting (e.g., mushroom, Christmas ornaments). However, the key factor explaining the postponement of timber harvesting is the benefits of carbon sequestration, which, by assumption, are only obtained when the forest turns 80 years old. The growth in timber volume in a poor hemlock stand is so small that it becomes worthwhile to postpone harvesting in order to capture the benefits of a regenerated forest. However, once the one time gains of carbon uptake have been banked, a new timber harvesting rotation begins.

SUMMARY SHEET 2
 Baseline Scenario
 No Park at site 2

Model Parameter and Values

Parameter	Value
rho	0.03
beta	0.97087
beta2	26.87
aofp	0.031
clp	\$1 million
c(i)	\$50 million
opc(i)	\$10 million
int	20 years
qog	\$30
q	\$23
vrecben	\$8770
ntfp	\$3.20
vanrho	60%
vandelta	2%
carbscoef	0.1824 ton
carbshadow	\$50

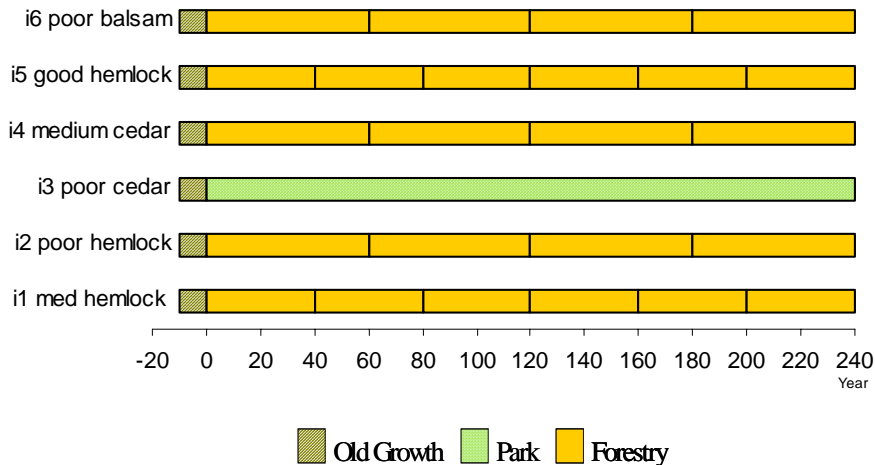
Site Characteristics

Site	Species	Growing Conditions	Size (km ²)
i1	Hemlock	medium	100
i2	Hemlock	poor	100
i3	Cedar	poor	100
i4	Cedar	medium	100
i5	Hemlock	good	100
i6	Balsam Fir	poor	100

Summary Results

Benefit/Cost Category	Annualized Benefits (\$ million)
Nonuse	22.578
Option	22.04
Recreation	31.382
Non-Timber Forest	0.32
Timber	349.894
Carbon Uptake	0
Carbon Released	-64.077
Cost of Park Creation	-1.501
Park O&M	10
Cost of Logging Park	0
Total Annualized Value	350.636

Optimal Management -- Baseline Scenario
 No park at site 2



SUMMARY SHEET 3
Baseline Scenario
No Park at site 3

Model Parameter and Values

Parameter	Value
<i>rho</i>	0.03
<i>beta</i>	0.97087
<i>beta2</i>	26.87
<i>aofp</i>	0.031
<i>clp</i>	\$1 million
<i>c(i)</i>	\$50 million
<i>opc(i)</i>	\$10 million
<i>int</i>	20 years
<i>qog</i>	\$30
<i>q</i>	\$23
<i>vrecben</i>	\$8770
<i>ntfp</i>	\$3.20
<i>vanrho</i>	60%
<i>vandelta</i>	2%
<i>carbscoef</i>	0.1824 ton
<i>carbshadow</i>	\$50

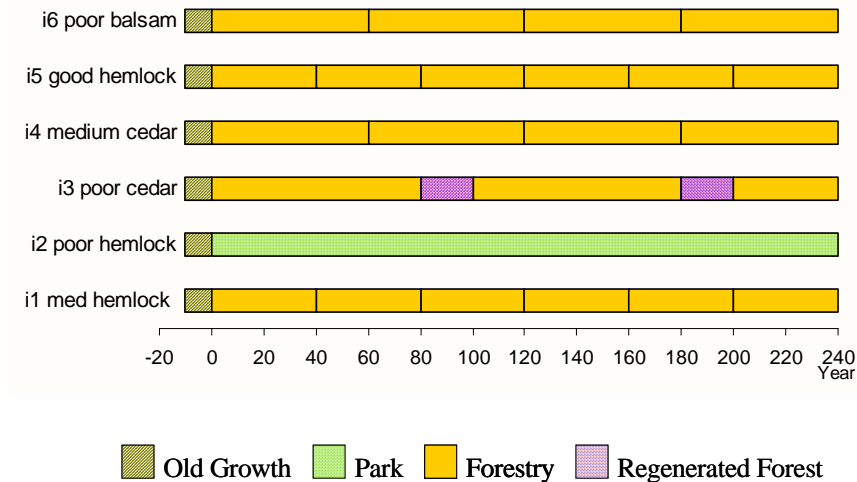
Site Characteristics

Site	Species	Growing Conditions	Size (km²)
<i>i1</i>	Hemlock	medium	100
<i>i2</i>	Hemlock	poor	100
<i>i3</i>	Cedar	poor	100
<i>i4</i>	Cedar	medium	100
<i>i5</i>	Hemlock	good	100
<i>i6</i>	Balsam Fir	poor	100

Summary Results

Benefit/Cost Category	Annualized Benefits (\$ million)
Nonuse	22.688
Option	22.04
Recreation	31.421
Non-Timber Forest	0.334
Timber	339.721
Carbon Uptake	0.379
Carbon Released	-62.425
Park Creation	-1.501
Park O&M	-10
Logging Park	0
Total Annualized Value	342.656

Optimal Management -- Baseline Scenario
No park at site 3



Comparing the constrained results to the baseline scenario, the net annualized value of protecting Site 3 is \$11.32 million for a net present value of \$377.12 million. It follows that protecting 100 km² of old-growth hemlock at Site 3 is more than three times as valuable to society than protecting old-growth cedar on Site 2. This difference is explained entirely by the difference in timber productivity between the two sites. Old-growth cedar growing on a poor site (Site 3) contains less merchantable timber than hemlock growing in similar conditions. As a result, the opportunity cost of creating a park is greater where hemlock grows and this reduces the net value of a park at this location.

4.3.3 The Value of Remaining Old-growth – Baseline Scenario

The model developed here is very flexible. It can be used to answer a number of policy questions. For instance, it can be used to calculate the net loss associated with a no-park policy, or a no old-growth policy. The reader is again reminded that simply taking the results of the baseline scenario and summing the benefits associated with forest conservation does not constitute an appropriate measure of the true value of preservation to society. It is only the “credit” side of the balance sheet and does not account for the opportunity cost of preservation.

The net value of the remaining old-growth forest protected under the optimal solution to the baseline scenario can potentially be obtained from two separate approaches. The first is to impose the requirement that Sites 2 and 3 no longer be protected while allowing parks to be created in other locations. Doing this produces a result in which Site 6 becomes the only park. Because some level of old-growth protection is achieved under this scenario, this approach does not get directly at the value of the remaining old-growth.

A more direct way is simply to impose the requirement that none of the Sites be made into a park. This leaves the possibility that some of the old-growth may still be kept without legal protection, without the option value and extensive recreational opportunity normally associated with park designation. However, in the optimal solution of the problem under this constraint, all Sites are devoted to forestry rotations. The annualized value of the program is \$333.88 million or roughly \$20.1 million less than the optimal scenario. The corresponding present net gain associated with retaining 200 km² of protected and accessible old-growth is therefore estimated at \$669.44 million (above and beyond the benefits of forestry).

4.3.4 The Size of Sites, Other Old-growth and Additional Considerations

a) Size

The preceding section analysed the simplified situation in which all sites were of identical size at 100 km². Furthermore, implicit in the benefits function is the assumption that no other coastal old growth remains outside of the 600 km² considered in the simulations. These simulations obviously do not correspond to reality and we devote this section to a brief exploration of more realistic assumptions about the size distribution and the existence of some protected old-growth outside of the study area. We finally make a few comments on the importance of nonuse, recreation and option values in the determination of optimal conservation strategies.

Together, the six categories of trees and growing conditions used in the course of this research represent approximately 80% of the remaining forest cover on the BC coast. Thus, it is useful to parameterize the model to make it a more accurate representation of species distribution and growth conditions. The resulting distribution of species over a total of 3300 km² is presented in Summary Sheet 4 along with model results.

The optimal solution in this case is to create a park at Site 3, an area of 700 km² of Western Red Cedar. The total annualized value of this program is \$1,620.65 million, of which \$90 million come from nonuse benefits, \$88 million take the form of option value and \$125 accrue to recreationists. The net value of the park is computed as before, providing an annualized value of \$1,538.44 million. Thus, the net annualized economic value of the protected 700,000 hectares area is \$82.21 million. This corresponds to a net present value over the 240 year planning horizon of \$2.74 billion.

Parameter	Value
<i>rho</i>	0.03
<i>beta</i>	0.97087
<i>beta2</i>	26.87
<i>aofp</i>	0.031
<i>clp</i>	\$1 million
<i>c(i)</i>	\$50 million
<i>opc(i)</i>	\$10 million
<i>int</i>	20 years
<i>qog</i>	\$30
<i>q</i>	\$23
<i>vrecben</i>	\$8770
<i>ntfp</i>	\$3.20
<i>vanrho</i>	60%
<i>vandelta</i>	2%
<i>carbscoef</i>	0.1824 ton
<i>carbshadow</i>	\$50

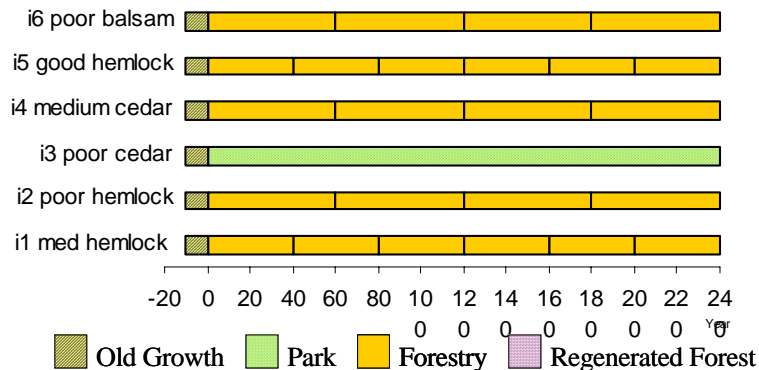
Site Characteristics

Site	Species	Growing Conditions	Size (km ²)
<i>i1</i>	Hemlock	medium	1000
<i>i2</i>	Hemlock	poor	1000
<i>i3</i>	Cedar	poor	700
<i>i4</i>	Cedar	medium	300
<i>i5</i>	Hemlock	good	100
<i>i6</i>	Balsam Fir	poor	200

Summary Results

Benefit/Cost Category	Annualized Benefits (\$ million)
Nonuse	90.17
Option	87.986
Recreation	125.244
Non-Timber Forest	2.24
Timber	1627.685
Carbon Uptake	0
Carbon Released	-301.172
Cost of Park Creation	-1.501
Park O&M	-10
Cost of Logging Park	0
Total Annualized Value	1620.651

Optimal Management -- Full Size Scenario



b) Existing Protected Old-growth

While maintaining the more realistic size distribution, one may ask whether the pre-existence of protected old-growth modifies the outcome of the analysis. Under this new scenario, we assume that 400 km² of old-growth are already protected from logging. This is slightly more than the proportion of BC land currently protected and reflects the fact that some of BC's coastal forests are already protected (e.g. Pacific Rim National Park, Carmanah-Walbran Provincial Park).

Because pre-existing parks provide a base level of conservation, the marginal benefits of additional protection are smaller than in the previous scenario. In fact, they are sufficiently smaller that the optimal decision does not prescribe any new protected areas.

c) Access to Parks and the Importance of Recreation

While the panel on the ecological integrity of Canada's National Parks has been critical of the level of development and public use of our National Parks, it is clear from a final run of the model that, without the benefits of recreation and option value (the willingness of individuals to pay to maintain the option of future use), the opportunity cost of preservation far exceeds its benefits. In other words, the benefits of recreation are essential in making the preservation of old-growth an economically sound decision. "Use it or lose it" comes to mind as an appropriate way of describing the results. Setting recreation benefits to zero to represent pure preservation yields insufficient benefits to justify conservation. The opportunity cost of such preservation without use simply exceed its benefits.

5. Discussion

5.1 Outstanding Issues and Future Work on the Valuation Framework

5.1.1 Area Size and the Optimal amount of Coastal Old-growth Protection

The results of section 4.3.4 call for the protection of more than 20% of the remaining coastal old-growth. However, it is important to realize that the size of the different areas is not endogenous to the decision. This means that the model does not “decide” what the optimal park size ought to be. For instance, it could be more valuable for society to add a second park of, say, 200 km² in an area of poor hemlock growth. However, the current framework can only search for the optimal management program under the condition that the area of poor hemlock is 1,000 km². Either all or none of it can be protected. Devoting some part to conservation and the remainder to forestry may be desirable, but it is not possible to determine this directly in the current state of development of the model.

While the model has the advantage of adhering to the general practice of allowing natural scientists to define environmentally sensitive and representative areas as park candidate, it does not easily provide guidance on “what the economically optimal size of a planned park should be.” Additional development of the model may enable one to answer this more complex question while retaining the essential policy of legally protecting areas. This would likely require transforming the model into a mixed integer-nonlinear problem, a class of programs that tend to be extremely difficult to solve and for which numerical algorithms tend to be far less stable.

5.1.2 Protecting Poor Site Growing Condition

As alluded to earlier, sites with poor growing conditions present the smallest opportunity costs of preservation since creating parks in these areas only prevents low forestry returns. As a result, all parks will always be created on these sites as long as the benefits of preservation are independent of site quality (timber growth potential).

With relatively simple modifications, however, it would be possible to recognize that some sites may have unique natural or landscape features for which no substitutes can be found elsewhere. In the case where unique features are found on more productive grounds, the site-specific amenity benefits may be sufficiently high to warrant their protection. Given the overwhelming evidence from this study demonstrating the high level of substitutability between different natural areas, we expect that only truly exceptional natural features (such as the provision of habitat for highly endangered and desirable species) are likely to lead to a valuation function where no substitute exists. Empirical evidence from valuation studies is required to document such cases adequately.

5.1.3 Site Size and Definition

Another obvious shortcoming of the current version of the model is the implicit limit on the number of possible sites that can be handled. With six sites being managed over twelve decision periods, the model takes a few hours to solve. Increasing the scope of the model in either dimension would increase running time exponentially and make the model increasingly cumbersome. In experimenting with the framework, we have solved problems with six sites for up to twenty decision periods in less than 24 hours. Thus, there remains some flexibility to increase the number of sites and perform a finer analysis of options at the eco-region or eco-province level.

It is also worth mentioning that, while we have associated each site to a particular type of forest, this was largely a simplifying choice. The model can easily be tailored to a policy context in which sites contain a mix of species. All that is required is for the analyst to provide estimates of timber volume and rent for sites of interest. The model is portable and can be applied to any forested area.

5.2 Data Gaps and Collections

By far the most important impediment to obtaining useful and realistic results enabling economically sound land-use decisions is the lack of reliable data on the benefits of environmental conservation in Canada. Collecting valuation data requires a long lead time for the preparation, administration and analysis of surveys; calls for highly specialized technical expertise, and is very expensive. However, until such data

becomes available, researchers, analysts and policy makers will continue to employ values that are unreliable and/or based on untenable assumptions. The uncertainty inherent to the value of non-market goods is compounded by the lack of primary data on the subject. This negatively affects the credibility of the analysis.

The single most important recommendation we can make at this stage is to urge the FPPC and its member organizations to seriously commit themselves to primary data collection to obtain better estimates of the benefits of conservation. Such data collection should be especially sensitive, and carefully designed, to measure the effects of decreasing marginal values of conservation and the substitution effects observed in both nonuse and recreation benefits.

5.3 Closing Comments

The existence of substitution effects and decreasing marginal returns to conservation poses a number of additional challenges. First and foremost, it questions the validity and reliability of single site valuation studies that do not pay sufficient attention to the environmental and policy context in which a park or other natural amenity is valued.

A more profound implication is that the value of a single protected area is no longer an absolute number. The value of a particular park will be greater when no other park exists as opposed to when multiple alternatives are available to visitors, or when other wilderness areas exist to satisfy nonusers' preferences.

As we have shown, these complicating factors do not prevent the valuation of single sites, but make the task more complex. The proper valuation approach requires understanding marginal benefits and the opportunity cost of preservation in order to isolate the net contribution of an existing area to society's welfare.

The model we have developed accomplishes this task by integrating the benefits and costs of forestry and conservation. The method allows the planner to pre-select relevant areas and customize the analysis to a real field situation. In the course of this research, we have assembled a large amount of data from other studies pertaining to the value of wilderness preservation. By itself, we hope that this makes a valuable contribution, but we caution that they are poor substitutes for data obtained from primary collection efforts. As a result, it was necessary to refrain ourselves from being too specific when applying the current benefit-cost model. Consistent with the primary objective of this project, we have focussed on developing a conceptually sound and flexible framework that enables the valuation of existing and proposed habitat conservation projects.

As in previous research, our application to the coastal areas of British Columbia shows that land-use specialization is a desirable approach to land management. While some areas are legally protected as parks, the balance of the land is put into intensive forestry. While the analysis was done at a generic level, it seems clear that a significant proportion of the remaining temperate coastal old-growth of British Columbia should be preserved indefinitely. This conclusion, however, should be revisited when better data from primary sources become available.

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Appendix I
GAMS Program Code – Baseline Scenario

```

$title Base Model

option reslim=100000;
option iterlim=100000;
option optcr=0;

set h  maps total area of regenerated forest-100 sq km (e.g. h2=200 sq km) /h0*h20/;
set j  maps total area of oldgrowth forest-100 sq km (e.g. j2=200 sq km) /j0*j20/;
set k  maps area of oldgrowth protected by parks-100 sq km /k0*k20/;
set m  maps area of regenerated forest protected by parks /m0*m20/;
set t  time period /0*12/;
set i  site index /i1*i6/;
set age age of site at time of logging /age1*age5/;

scalar int  length of interval t (years) /20/;
scalar rho  discount rate /0.03/;
scalar qog  net timber rent from old-growth forests ($ per m3) /30/;
scalar q    net timber rent from regenerated forests ($ per m3) /23/;
scalar conv  conversion from ha to sq kms /1000/;
scalar NTFP  value of non-timber forest products per ha of p and v /3.20/;
scalar vrecben  value of recreation benefits per square km of nonprotected v /8770/;
Scalar clp  transactions cost associated with logging a park /1/;
clp=clp*10**6;

parameter size(i)  area of site i in sq km (must be a multiple of 100 total<1000
/ i1  100
  i2  100
  i3  100
  i4  100
  i5  100
  i6  100
/;

Parameters c(i)  cost of creating a park
/
  i1  50
  i2  50
  i3  50
  i4  50
  i5  50
  i6  50
/;
c(i)=c(i)*10**6;

Parameters opc(i)  annual park operating costs
/
  i1  10
  i2  10
  i3  10
  i4  10
  i5  10
  i6  10
/;
opc(i)=opc(i)*10**6;

```

\$OnText

For logvol, the sites are categorized as follows.

The first 4 are based on total acreage of coastal forest over 80 years old.

i5 is the greatest area on the coast for a good site.

i1 Hemlock (medium sites)

i2 Hemlock (poor sites)

i3 Cedar (poor sites)

i4 Cedar (medium sites)

i5 Hemlock (good site)

i6 Balsam (poor site)

\$Offtext

Table logvol(i, age) timber volumes (merchantable)at site i at age per ha (m3)

	age1	age2	age3	age4	age5
i1	0	144	288	417	756
i2	0	39	108	187	507
i3	0	16	65	140	405
i4	0	49	161	317	765
i5	0	360	567	723	998
i6	0	10	98	190	630 ;

scalar beta2 interval discount factor;

* beta2 calculate the future value of a flow of benefits

* that occur every year in the interval of "int" years.

* These future values are then normally discounted back to period zero

* using beta(t).

$\text{beta2} = (1/\text{rho}) * (-1 + (1 + \text{rho})^{**\text{int}});$

display beta2;

Parameter beta(t) discount factor;

$\text{beta}(t) = (1 / (1 + \text{rho}))^{**(\text{int} * (\text{ord}(t) - 1))};$

Display beta;

* State Variables and Fixed Initial Conditions

Binary Variables p(i,t) state of area i in t is oldgrowth park;

$\text{p.fx}(i, "0") = 0;$

Binary Variables v(i,t) state of area i in t is regenerated (not old-growth);

$\text{v.fx}(i, "0") = 0;$

Binary Variables oldgrowth(i,t) area i is in original old-growth;

$\text{oldgrowth.fx}(i, "0") = 1;$

*Control variables

Binary Variable cut(i,t) area i is logged in period t;

binary variables park(i,t) area i made into a park at t;

* Constraints on the applicability of controls

Equations oldpark(i,t) i cannot become park and logged at t;

$\text{oldpark}(i, t) .. \text{park}(i, t) + \text{cut}(i, t) = L = 1;$

Equations oldpark1(i,t) i cannot become park at t if i logged at t-1;

$\text{oldpark1}(i, t) .. \text{park}(i, t) + \text{cut}(i, t-1) = L = 1;$

Equations oldpark2(i,t) i cannot become park at t if i logged at t-2;

oldpark2(i,t).. park(i,t)+ cut(i,t-2)=L=1;

Equations oldpark3(i,t) i cannot become park at t if i logged at t-3;
oldpark3(i,t).. park(i,t)+ cut(i,t-3)=L=1;

Equations nopp(i,t) existing parks cannot be turned into parks again;
nopp(i,t).. p(i,t)+park(i,t)=L=1;

Equations porv(i,t) area cannot be both park and virgin;
porv(i,t).. p(i,t)+v(i,t)=L=1;

* --- Logical operators for transition equation p

binary variable ptor(i,t) park i got logged;

equation eqptor1(i,t), eqptor2(i,t);

eqptor1(i,t).. p(i,t) + cut(i,t)=l=ptor(i,t)+1;

eqptor2(i,t).. p(i,t) + cut(i,t)=g=ptor(i,t)*2;

binary variable rtop(i,t) area i in rotation becomes park

equation eqrtop1(i,t), eqrtop2(i,t);

eqrtop1(i,t).. (1-p(i,t))+(1-v(i,t))+(1-oldgrowth(i,t))+ park(i,t)=l=rtop(i,t)+3;

eqrtop2(i,t).. (1-p(i,t))+(1-v(i,t))+(1-oldgrowth(i,t))+ park(i,t)=g=rtop(i,t)*4;

binary variable ogtop(i,t) area i in oldgrowth becomes park

equation eqogtop1(i,t), eqogtop2(i,t);

eqogtop1(i,t).. oldgrowth(i,t)+park(i,t)=l=ogtop(i,t)+1;

eqogtop2(i,t).. oldgrowth(i,t)+park(i,t)=g=ogtop(i,t)*2;

Equations transp(i,t) transition for p;

transp(i,t+1).. p(i,t+1) =E= p(i,t)-ptor(i,t)+park(i,t);

* --- Logical operators for transition equation v

binary variable vtor(i,t) virgin area i got logged;

equation eqvtor1(i,t), eqvtor2(i,t);

eqvtor1(i,t).. v(i,t) + cut(i,t)=l=vtor(i,t)+1;

eqvtor2(i,t).. v(i,t) + cut(i,t)=g=vtor(i,t)*2;

binary variable vtop(i,t) virgin i got parked;

equation eqvtop1(i,t), eqvtop2(i,t);

eqvtop1(i,t).. v(i,t) + park(i,t)=l=vtop(i,t)+1;

eqvtop2(i,t).. v(i,t) + park(i,t)=g=vtop(i,t)*2;

binary variable rtov(i,t) previously logged returns to virgin if not cut or parked;

equation eqrtov(i,t), eqrtov1(i,t);

eqrtov(i,t).. 5-(v(i,t) + p(i,t)+ oldgrowth(i,t) + cut(i,t)+ cut(i,t-1)+ cut(i,t-2)+ cut(i,t-3)+
park(i,t))=L=rtov(i,t)+4;

eqrtov1(i,t).. 5-(v(i,t) + p(i,t)+ oldgrowth(i,t) + cut(i,t)+ cut(i,t-1)+ cut(i,t-2)+ cut(i,t-3)+
park(i,t))=g=rtov(i,t)*5;

Equations transv(i,t) transition for v of site i;

transv(i,t+1).. v(i,t+1) =E= v(i,t)-vtor(i,t)-vtop(i,t)+rtov(i,t);

* age proxy of logged site

binary variable a1(i,t) age of logged site is 1;

equation eqa11(i,t), eqa12(i,t);

eqa11(i,t).. cut(i,t) + cut(i,t-1)=l=a1(i,t)+1;

eqa12(i,t).. cut(i,t) + cut(i,t-1)=g=a1(i,t)*2;

binary variable a2(i,t) age of logged site is 2;

equation eqa21(i,t), eqa22(i,t);

eqa21(i,t).. $\text{cut}(i,t) + \text{cut}(i,t-2) + (1-a1(i,t)) = a2(i,t) + 2$;
eqa22(i,t).. $\text{cut}(i,t) + \text{cut}(i,t-2) + (1-a1(i,t)) = g = a2(i,t) * 3$;

binary variable a3(i,t) age of logged site is 3;
equation eqa31(i,t), eqa32(i,t);
eqa31(i,t).. $\text{cut}(i,t) + \text{cut}(i,t-3) + (1-a1(i,t)) + (1-a2(i,t)) = a3(i,t) + 3$;
eqa32(i,t).. $\text{cut}(i,t) + \text{cut}(i,t-3) + (1-a1(i,t)) + (1-a2(i,t)) = g = a3(i,t) * 4$;

binary variable a5(i,t) age of logged site is 5 (old-growth first cut only);
equation eqa51(i,t), eqa52(i,t);
eqa51(i,t).. $\text{cut}(i,t) + \text{oldgrowth}(i,t) = a5(i,t) + 1$;
eqa52(i,t).. $\text{cut}(i,t) + \text{oldgrowth}(i,t) = g = a5(i,t) * 2$;

binary variable a4plus(i,t) other sites logged are age 4;
equation eqa4plus(i,t);
eqa4plus(i,t).. $a4plus(i,t) = E = \text{cut}(i,t) - a1(i,t) - a2(i,t) - a3(i,t) - a5(i,t)$;

*Transition away from original old-growth
equation eoldgrowth(i,t);
eoldgrowth(i,t+1).. $\text{oldgrowth}(i,t+1) = E = \text{oldgrowth}(i,t) - a5(i,t)$;

* States for types of parks (oldgrowth vs virgin);
binary variable ogpark(i,t) area i is old-growth park;
equation eqogp1(i,t), eqogp2(i,t);
eqogp1(i,t).. $p(i,t) + \text{oldgrowth}(i,t) = \text{ogpark}(i,t) + 1$;
eqogp2(i,t).. $p(i,t) + \text{oldgrowth}(i,t) = g = \text{ogpark}(i,t) * 2$;

binary variable newpark(i,t) area i is regenerated park;
equation eqnewp1(i,t), eqnewp2(i,t);
eqnewp1(i,t).. $p(i,t) + (1-\text{ogpark}(i,t)) = \text{newpark}(i,t) + 1$;
eqnewp2(i,t).. $p(i,t) + (1-\text{ogpark}(i,t)) = g = \text{newpark}(i,t) * 2$;

* Measuring the total area category by type of forest
positive variable totogarea(t) total old-growth area (protected and unprotected)(sq km);
equation etotogarea(t);
etotogarea(t).. $\text{totogarea}(t) = E = \sum(i, \text{oldgrowth}(i,t) * \text{size}(i))$;

positive variable ogparea(t) protected oldgrowth area (sq km);
equation eogparea(t);
eogparea(t).. $\text{ogparea}(t) = E = \sum(i, \text{ogpark}(i,t) * \text{size}(i))$;

positive variable ognotarea(t) unprotected oldgrowth area (sq km);
equation eognotarea(t);
eognotarea(t).. $\text{ognotarea}(t) = E = \text{totogarea}(t) - \text{ogparea}(t)$;

positive variable varea(t) unprotected regenerated (virgin) forests area (sq km);
equation evarea(t);
evarea(t).. $\text{varea}(t) = E = \sum(i, v(i,t) * \text{size}(i))$;

positive variable newparea(t) protected regenerated forests area (sq km);
equation enewparea(t);
enewparea(t).. $\text{newparea}(t) = E = \sum(i, (p(i,t) - \text{ogpark}(i,t)) * \text{size}(i))$;

Scalar mul just a utilitarian scalar for logical operations /2000/;

*Matching the area size of oldgrowth to size category

binary variables delta1(j,t);
 equations bigm1(j,t), bigm2(j,t), sumone(t);
 bigm1(j,t).. totogarea(t)/100-(ord(j)-1) =l= (1-delta1(j,t))*mul;
 bigm2(j,t).. totogarea(t)/100-(ord(j)-1) =g= -(1-delta1(j,t))*mul;
 sumone(t).. sum(j,delta1(j,t)) =e= 1;

*Matching the area of oldgrowth parks to size category

binary variables delta2(k,t);
 equations bigm21(k,t), bigm22(k,t), sumone2(t);
 bigm21(k,t).. ogparea(t)/100-(ord(k)-1) =l= (1-delta2(k,t))*mul;
 bigm22(k,t).. ogparea(t)/100-(ord(k)-1) =g= -(1-delta2(k,t))*mul;
 sumone2(t).. sum(k,delta2(k,t)) =e= 1;

*Matching the area size of total regenerated area to size category

binary variables delta3(h,t);
 equations bigm31(h,t), bigm32(h,t), sumone3(t);
 bigm31(h,t).. (varea(t)+newparea(t))/100-(ord(h)-1) =l= (1-delta3(h,t))*mul;
 bigm32(h,t).. (varea(t)+newparea(t))/100-(ord(h)-1) =g= -(1-delta3(h,t))*mul;
 sumone3(t).. sum(h,delta3(h,t)) =e= 1;

parameter nonuse1(j) nonuse benefits from oldgrowth (e.g. j2 = 200 sq miles of oldgrowth)

/
j0 0
j1 31.8
j2 53.9
j3 72.3
j4 88.3
j5 102.5
j6 115.3
j7 127.0
j8 137.6
j9 147.4
j10 156.3
j11 164.6
j12 172.2
j13 179.2
j14 185.7
j15 191.7
j16 197.2
j17 202.3
j18 207.0
j19 211.3
j20 215.2

;

*transforms benefits in million of \$ for total area

$\text{nonuse1}(j) = 0.71 * \text{nonuse1}(j) * 10^{**6}$

parameter nonuse3(h) nonuse benefits from regenerated areas

/ h0 215.2
h1 218.7
h2 222.0
h3 224.9
h4 227.5
h5 229.8
h6 231.8
h7 233.5
h8 235.0
h9 236.3
h10 238.0
h11 238.6
h12 238.9
h13 239.0
h14 239.0
h15 239.0
h16 239.0
h17 239.0
h18 239.0
h19 239.0
h20 239.0

;

*transforms benefits in million of \$ for total area

$\text{nonuse3}(h) = 0.71 * (\text{nonuse3}(h) - 215.2) * 10^{**6}$

parameter precben(k) recreational benefits from area k in oldgrowth parks

```

/
k0 0
k1 44.2
k2 74.9
k3 100.4
k4 122.7
k5 142.4
k6 160.3
k7 176.4
k8 191.2
k9 204.7
k10 217.2
k11 228.7
k12 239.7
k13 249.0
k14 258.1
k15 266.4
k16 274.1
k17 281.1
k18 287.6
k19 293.6
k20 299.0

```

```

/;
*transforms benefits in million of $ for total area
precben(k)=0.71*precben(k)*10**6;

```

```

Parameters optval(k) option value;
optval("k0")=0.29*(nonuse1("j0")+precben("k0"))/0.71;
optval("k1")=0.29*(nonuse1("j1")+precben("k1"))/0.71;
optval("k2")=0.29*(nonuse1("j2")+precben("k2"))/0.71;
optval("k3")=0.29*(nonuse1("j3")+precben("k3"))/0.71;
optval("k4")=0.29*(nonuse1("j4")+precben("k4"))/0.71;
optval("k5")=0.29*(nonuse1("j5")+precben("k5"))/0.71;
optval("k6")=0.29*(nonuse1("j6")+precben("k6"))/0.71;
optval("k7")=0.29*(nonuse1("j7")+precben("k7"))/0.71;
optval("k8")=0.29*(nonuse1("j8")+precben("k8"))/0.71;
optval("k9")=0.29*(nonuse1("j9")+precben("k9"))/0.71;
optval("k10")=0.29*(nonuse1("j10")+precben("k10"))/0.71;
optval("k11")=0.29*(nonuse1("j11")+precben("k11"))/0.71;
optval("k12")=0.29*(nonuse1("j12")+precben("k12"))/0.71;
optval("k13")=0.29*(nonuse1("j13")+precben("k13"))/0.71;
optval("k14")=0.29*(nonuse1("j14")+precben("k14"))/0.71;
optval("k15")=0.29*(nonuse1("j15")+precben("k15"))/0.71;
optval("k16")=0.29*(nonuse1("j16")+precben("k16"))/0.71;
optval("k17")=0.29*(nonuse1("j17")+precben("k17"))/0.71;
optval("k18")=0.29*(nonuse1("j18")+precben("k18"))/0.71;
optval("k19")=0.29*(nonuse1("j19")+precben("k19"))/0.71;
optval("k20")=0.29*(nonuse1("j20")+precben("k20"))/0.71;

```

* Carbon accounts

```

scalar vanrho      proportion of carbon stored in durables (%) /0.6/
scalar vandelta    rate of carbon release from durable (% per year) /0.02/
scalar carbshadow  shadow price of 1 ton of carbon in dollars /50/
scalar carbstcoef  amount (tons) of carbon per m3 of timber /0.1824/
parameter carbrel(i,age) amount of carbon released when site i is harvested (tons);
carbrel(i,age)=logvol(i,age)*conv*size(i)*carbstcoef*((1-vanrho)+(vandelta*vanrho)/
(rho+vandelta));

```

Positive Variables carbus(i,t) carbon uptake at site i in tons (when rotation becomes v or p);
Equation ecarbus(i,t);
ecarbus(i,t).. carbus(i,t)=E=(rtov(i,t)+rtop(i,t))*logvol(i,"age4")*carbcoef*conv*size(i);

Variables tntfb non-timber forest benefits
tnonuse nonuse benefits other than option value
toption option value
tlogben timber benefits
tcarbus carbon uptake benefits
tcarbrel cost of carbon released
trecben recreational benefits
tcofparc cost of creating a park
tclp transactions cost of logging a park
topc total park operating costs
NPV Net Present Value;

Equations etntfb, etnonuse, etoption, etlogben, etcarbus, etcarbrel, etrecben, etcofparc, etclp,
etopc, obj;

etntfb.. tntfb =E=(1/10**6)*(sum((i,t), beta(t)*beta2*NTPF*
(oldgrowth(i,t)+newpark(i,t)+v(i,t))*size(i)*conv)) -
(1/10**6)*(sum(i,beta("0")*beta2*NTPF*(oldgrowth(i,"0")+newpark(i,"0")+v(i,"0"))*size(i)*
conv));

etnonuse.. tnonuse =E=(1/10**6)*(sum((j,t), beta(t)*beta2*nonuse1(j)*delta1(j,t))+
sum((h,t), beta(t)*beta2*nonuse3(h)*delta3(h,t))) -
(1/10**6)*(sum(j, beta("0")*beta2*nonuse1(j)*delta1(j,"0")) +
sum(h, beta("0")*beta2*nonuse3(h)*delta3(h,"0")));

etoption.. toption =E=(1/10**6)*(sum((k,t), beta(t)*beta2*optval(k)*delta2(k,t))) -
(1/10**6)*(sum(k, beta("0")*beta2*optval(k)*delta2(k,"0")));

etlogben.. tlogben =E=(1/10**6)*(sum((i,t), beta(t)*conv*size(i)*(q*a1(i,t)*logvol(i,"age1")+
q*a2(i,t)*logvol(i,"age2")+q*a3(i,t)*logvol(i,"age3")+qog*a5(i,t)*logvol(i,"age5") +
q*a4plus(i,t)*logvol(i,"age4"))));

etcarbus.. tcarbus =E=(1/10**6)*(sum((i,t), beta(t)*carbus(i,t)*carbshadow));

etcarbrel.. tcarbrel =E=(1/10**6)*(sum((i,t),beta(t)*carbshadow*(a5(i,t)*carbrel(i,"age5")+
a4plus(i,t)*carbrel(i,"age4"))));

etrecben.. trecben =E=(1/10**6)*(sum((k,t), beta(t)*beta2*precben(k)*delta2(k,t))+
sum(t,vrecben*beta(t)*beta2*(varea(t)+newparea(t)))-
(1/10**6)*(sum(k, beta("0")*beta2*precben(k)*delta2(k,"0"))+
vrecben*beta("0")*beta2*(varea("0")+newparea("0")));

etcofparc.. tcofparc =E=(1/10**6)*(sum((i,t), beta(t)*c(i)*park(i,t)));

etclp.. tclp =E=(1/10**6)*(sum((i,t), beta(t)*clp*ptor(i,t)));

etopc.. topc =E=(1/10**6)* sum((i,t), beta(t)*beta2*opc(i)*p(i,t));

obj.. NPV =e=tntfb+ tnonuse + toption+ tlogben+ tcarbus - tcarbrel + trecben -
tcofparc - tclp -topc;

Model FPPC /ALL/;
FPPC.optfile=1;

Solve FPPC MAXIMIZING NPV USING MIP;

*-----
* Report
*-----

\$STitle FPPC REPORT

Parameters aofp Capital Recovery Factor;

$$aofp = (\rho * (1 + \rho)^{((card(t)-1) * int)}) / ((1 + \rho)^{((card(t)-1) * int)} - 1);$$
 Display aofp;

Parameters	antfb	annualized non-timber forest benefits
	anonuse	annualized nonuse benefits other than option value
	aoption	annualized option value
	alogben	annualized timber benefits
	acarbup	annualized carbon uptake benefits
	acarbrel	annualized cost of carbon released
	arecben	annualized recreational benefits
	acofpark	annualized cost of creating a park
	aclp	annualized transactions cost of logging a park
	atopc	annualized operating costs
	aNPV	annualized total benefits;

antfb=aofp*tnfb.l;
 anonuse=aofp*tnonuse.l;
 aoption=aofp*toption.l;
 alogben=aofp*tlogben.l;
 acarbup=aofp*tcarbup.l;
 acarbrel=aofp*tcarbrel.l;
 arecben=aofp*trecben.l;
 acofpark=aofp*tcofpark.l;
 atopc=aofp*topc.l;
 aclp=aofp*tcip.l;
 aNPV=aofp*NPV.l;

Parameters

state(i,t) state of area i in period t "1"=protected oldgrowth
 "2"=unprotected oldgrowth "3"=protected regenerated
 "4" unprotected regenerated "5" rotation;

$$state(i,t) = 1\$ (ogpark.l(i,t)=1) + 2\$ (oldgrowth.l(i,t) - ogpark.l(i,t)=1) + 3\$ (newpark.l(i,t)=1) + 4\$ (v.l(i,t)=1) + 5\$ (p.l(i,t) + v.l(i,t) + oldgrowth.l(i,t)=0);$$

Display park.l, cut.l, state;

Display tnfb.l, tnonuse.l, toption.l, tlogben.l, tcarbup.l, tcarbrel.l, trecben.l, tcofpark.l, topc.l, NPV.l;

Display antfb, anonuse, aoption, alogben, acarbup, acarbrel, arecben, acofpark, aclp, atopc, aNPV;