RURAL ECONOMY

Environmental and Financial Sustainability of Forest Management Practices

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Abstract

One of the guiding themes for forest management policy throughout much of North America is sustained yield. The basic premise behind this theme is that a constant or non–declining flow of services from the forest is socially desirable. Unfortunately, the act of capturing the benefits of this service (timber harvesting) often has detrimental effects on the timber–productive capacity of a forest site. This paper presents a dynamic program that is used to determine the optimal harvest system choice for a timber stand described by average piece size, stand density, a measure of site quality, and stumpage value. The harvest systems are defined by logging costs, reforestation and rehabilitation costs, and the impact of the system on the productivity of the site.

An application of the model is presented for lodgepole pine in Alberta. We conclude that at high discount rates, soil conservation is not economically rational. At lower discount rates, some degree of soil conservation is desirable on the more productive sites. At lower discount rates, there also appears to be an incentive for more intensive forest management. Limitations on acceptable harvest practices can have a large impact on optimal rotation age and the volume harvested. There is a large opportunity cost resulting from a requirement for sustainable volume production because of the impact of harvesting on soil productivity.

1 Introduction

One of the guiding themes for forest management policy throughout much of North America and Europe is sustained yield. The basic premise is that a constant or non–declining flow of services from the forest is beneficial to society. The production of timber is an important service that forests provide. Unfortunately, in order to capture the benefits of timber production, activities are undertaken that can damage the timber–productive capacity of the forest site and the underlying soils. This conflict between the ideal of sustained yield and the likelihood of declining forest productivity has sparked a great deal of interest in the degradation of forest soils. There have been several international conferences devoted to this subject. See, for example, Lousier and Still (1986), Harvey and Neuenschwander (1990), and Stone (1984).

Forest operations can reduce the productivity of forests in a number of ways(Froehlich (1986), Standish, Commandeur, and Smith (1988), and Utzig and Walmsley (1988)). Removal of biomass from the site will affect the level of nutrients available for future growth. Areas developed as part of the permanent road network are obviously unavailable for future timber growth. Soil displacement resulting from skid trail excavation on steep slopes can affect tree growth through changes in the depths of the humus and surface layers of the soil. The heavy equipment used in logging and reforestation operations can damage the soil through compaction and puddling. This will affect the ability of roots to penetrate the soil and the water holding capacity of the forest soils. Road construction and harvesting activities will also affect rates of erosion and mass wasting on the areas affected.

A fairly substantial literature on the biophysical aspects of soil degradation is developing, but the economic aspects of the problem are still relatively unexplored. Bowden (1986) sets the stage for an economic analysis by discussing the internal and external costs and benefits of degradation, the social costs of mitigating measures (regulations and prescriptions), and the problems of discounting, forecasting, and valuation. Utzig and Walmsley (1988) try to quantify the economic effects of forest soil degradation in British Columbia in terms of reduced industrial activity. Hammond (1986) discusses the costs of rehabilitating degraded soils to the costs of improved planning and concludes that improved planning is the more cost–effective way of dealing with a soil degradation problem. Routledge (1987) examines the impact of soil–degrading logging practices on the bare land value of forest land using a dynamic programming technique. Not surprisingly, he finds that at near–zero discount rates, the impact of degradation is critically dependent on projections of future growth and that at higher discount rates, the importance of future rotations is lessened considerably.

The objective of the study reported here is to develop a model that can be used to determine economically optimal timber management activities when reduced productivity due to soil degradation is taken into account. We follow Routledge (1987) in assuming that the objective of forest management is to maximize the net present value of the stream of benefits flowing from the forest.[1] We build on this work by allowing for an optimal choice of logging systems and the associated amount of soil degradation. The remaining sections describe the model , present an example analysis for lodgepole pine in Alberta, and discuss the implications of the work and room for further research.

2 Mathematical Model

The forest manager in the problem modeled here is faced with the task of managing a stand of timber[2] in order to best meet a specified objective. In this analysis, we assume that the forester's objective is to maximize the net present value of the stand. The current state of the stand is known and can be described by the number of trees in the stand (stems/ha), the average size of each tree (m^3/stem), and by a measure of site quality. The forester also knows the current value of the timber ($/$m^3$).

At any point in time, the forester can choose to let the stand grow for another period, or choose from a set of available logging and regeneration systems. Each of these logging and regeneration systems has a logging cost, a reforestation and rehabilitation cost, and a level of impact on site productivity associated with it. Those logging systems with lesser impacts on site productivity are likely to be those with higher logging and reforestation and rehabilitation costs. Regardless of the harvest system chosen, annual costs are incurred. These might relate to road maintenance, fire protection, land taxes, and so on.

Given the current state of the stand and the marketplace, the forester will have some idea of the state of the system in the next period. If the forester chooses to harvest the stand, there is clearly an impact on stand density, average tree size, and perhaps site quality for the next period. If the choice is to let the stand grow, the stand density and average tree size in the next period can be predicted using a growth model that uses current stand density, average tree volume, and site quality as parameters.

As set out above, the forester's problem is a good candidate for solution using stochastic dynamic programming (Kennedy 1986). The stages of the dynamic program correspond to the time periods in which decisions are made. The state of the system at any stage can be described by a combination of the state variables (stand density, average tree volume, site quality, and timber value). The dynamic program for this problem is set out mathematically below. The variables used in the model are summarized in table 1.

Because the forester is maximizing expected net present value, the discount rate becomes an important parameter. The discount factor ($\beta(t)$) shown in eq. 1 represents the relative value of a dollar received t years from now (given an annual discount rate of i) to a dollar received today.

$$\beta(t) = \frac{1}{(1+i)^t} \tag{1}$$

[1] We concentrate on timber but the model could be extended to consider non timber aspects as well. However, less is known about these relationships.

[2] We use the term "stand" to refer to a tract of forest land and the timber occupying the land.

Table 1: Summary of variables used in the dynamic program.

Type	Variable	Description
Stage	time	number of years between stages
State	density	stems/ha
	tree size	m^3/stem
	site quality	performance index
	stumpage price	\$/m^3
Control	harvest system	no harvest (growth)
		highly soil–conservative
		moderately soil–conservative
		unrestricted

Annual costs are incurred. If an annual cost, a, is incurred every year for t years, the present value of that stream of costs with a discount rate of i is calculated as

$$A(t) = a\,\frac{(1+i)^t - 1}{i} \tag{2}$$

The stage return or periodic payoff (N_t) is calculated as shown in eq. 3. The payoff is calculated for the midpoints of each price class (p_{ip}), piece size class (v_{iv}), and density class (d_{id}), and for each of the possible harvest systems (h). If the stand is not harvested ($h = 0$), the periodic payoff would be the net present value of a stream of annual costs occurring over a growth period of g years.[3] If the stand is harvested ($h > 0$) the annual costs are incurred over the regeneration lag period (r years), harvest revenues (HR) are received, and harvest costs (HC) and reforestation and rehabilitation costs (RC) are incurred.

$$N_t\{p_{ip},v_{iv},d_{id},h\} = \begin{cases} -A(g) & (h=0) \\ -A(r) + HR\{p_{ip},v_{iv},d_{id}\} - & \\ \quad HC\{v_{iv},d_{id},h\} - RC\{h\} & (h>0) \end{cases} \tag{3}$$

The return for the last stage in the problem (R_T) is initialized to zero.

$$R_T\{p_{ip}, s_{is}, v_{iv}, d_{id}\} = 0 \tag{4}$$

This assumption is justifiable because T can be far enough in the future that discounting, at any positive discount rate, will make the present value of R_T essentially zero.

The recursive objective function for this problem is given in eq. 5. It includes the stage return function given in eq. 3 and the appropriately discounted returns for each of the possible harvest systems.

$$R_t\{p_{ip}, s_{is}, v_{iv}, d_{id}\} \;=\; \max_h\,[N_t\{p_{ip}, v_{iv}, d_{id}, h\} +$$

[3]The model allows for variable stage length depending on the decision taken. If the no harvest decision is taken, the time period between stages is g years. If the stand is harvested, there are r years between the current stage and the next.

$$\left\{ \begin{array}{ll} \beta(g)[R_{t+1}] & (h=0) \\ \beta(r)[R_{t+1}] & (h>0) \end{array} \right], \quad t = 1, T-1 \tag{5}$$

This equation defines the objective function for the stages $T - 1$ down to 1 for each possible combination of state variables. It calculates a return for each of the logging systems (including no harvest) and selects the harvest system that results in the maximum return as the optimal choice for the state combination in that stage.

3 Application To Lodgepole Pine in Alberta

3.1 Basic Assumptions

In this example, three different logging systems with different costs and productivity impacts are considered. The first system is the least conservative of soil productivity. Each clearcut harvest results in a ten percent reduction of the stand's productivity as measured by performance index. The reduction in soil productivity occurs as a result of road construction, and soil compaction and puddling resulting from the operation of heavy equipment in the stand. Logging costs \$20/m^3 and reforestation and rehabilitation costs \$300/ha. This is meant to represent the costs of compliance with the regeneration requirements of the Alberta Forest Service (AFS).[4] The second system is moderately conservative of productivity. The logging system is the same as in the first system, so harvesting costs remain at \$20/m^3. More effort is spent to rehabilitate the site after harvest, so reforestation and rehabilitation costs increase to \$500/ha and the impact on performance index decreases to five percent. The third logging system is designed to completely preserve soil productivity. Logging is done with smaller equipment that is less damaging to the soil, and roads and other compacted areas are completely rehabilitated after harvest. Logging costs increase to \$25/m^3 and reforestation and rehabilitation costs increase to \$700/ha.

The logging revenue per hectare is calculated as the price per cubic metre multiplied by the merchantable volume per hectare. Logging costs are calculated as the cost per cubic metre multiplied by the total volume per hectare. Revenue is expressed as a function of merchantable volume because we assume that unmerchantable stems and the unmerchantable portions of stems are not processed into a product. Logging costs are expressed as function of total volume because the unmerchantable stems in a clearcut must be either cut or avoided, and because it takes more small trees to provide a cubic metre of merchantable wood.

The dynamic program used here requires that the state variables are divided into discrete classes. Five timber price classes are considered (\$30/m^3 to \$50/m^3 in \$5 increments). There are 21 performance index classes ranging from 0.3 to 1.3 in 0.05 increments. The piece size and density classes are expressed in natural logarithms reflecting the form of the growth model developed in Armstrong, Novak, and Adamowicz (1994). There are 41 logarithmic piece size classes with midpoints ranging from -3.6 to 0.4 (0.0273 to 1.49 m^3/stem) in 0.1 increments. There are also 41 logarithmic density classes with midpoints ranging from 4.5 to 8.5 (90 to 4915 stems/ha) in 0.1 increments.

The period length is 5 years if the stand is left to grow. If it is harvested, the stand regenerates to a 35 year old stand with an average piece size of 0.0408 m^3 and a density of 3641 stems/ha. In logarithms, these correspond to -3.2 and 8.2 respectively. For this analysis, the regenerated piece size and density is assumed to be independent of site class and harvest system.

The base real discount rate used for the analysis is five percent per annum. The dynamic programming model is run for fifty periods. Because the minimum period length is 5 years, this

[4]These costs are based on estimates from the literature but are considered representative of actual conditions.

means the model will run for a minimum of 250 years.

The results from two sets of runs plus a base run are presented next. The base run is used to provide a basis of comparison. The base run uses a five percent real discount rate and the choice of harvest systems is unrestricted.[5] The harvest system control runs are used to examine the effects of requiring more soil–conservative harvesting systems. The discount rate runs are used to examine the effects of the choice of discount rate.

3.2 Base Run

Several "slices" of the optimal decision rule[6] for the base run are shown in fig. 1. In all possible piece size, density, price, and performance index classes in the base run, the optimal decision is either to delay harvest, or to harvest using the least soil–conservative harvest system. The increased harvesting and regeneration costs of the more soil–conservative harvest systems always dominate the costs of lost soil productivity in the base run. Fig. 1 also shows that as price increases, the proportion of volume–density combinations for which the optimal decision is to harvest increases. This occurs because there is an opportunity cost associated with delaying harvest and this cost is larger with greater prices. This also shows that there is decreasing proportion of state variable combinations for which the optimal decision is to harvest with increasing performance index. This too is reasonable as increasing site productivity means that there is a greater benefit to be gained from delaying harvest and allowing the stand to grow.

Table 2 presents bare land values by performance index and price class combinations for the base run. The bare land value is the value of untreed forest land for perpetual timber production. The bare land value (BLV) for this table (and the others) was calculated by discounting the value of the land and regenerated timber calculated by the dynamic program after the thirty-five year regeneration period, subtracting the discounted value of thirty-five years of annual costs, and subtracting the reforestation and rehabilitation costs.

For all price and performance index combinations, the bare land values for the base run are negative. This indicates that, given the prices, costs, discount rate, and harvest system choices assumed for this analysis, even the optimal forest management regime is economically inefficient.[7] The reforestation and rehabilitation costs for the least soil–conservative logging system is \$300/ha. There are several price–PI combinations where bare land values would be less than zero even if reforestation and rehabilitation were costless (*i.e.* those combinations for which the BLV is less than -\$300/ha).

Fig. 2 shows a simulated plot of stand volume over time for the base run assuming that the optimal decision rule is followed. The peaks in the figure occur at harvest. Because the optimal decision results in soil degradation, the harvest volume decreases over time. For the most part, the optimal harvest age is 65 years, although the fourth harvest occurs at 70 years of age.

[5] The choice of systems is unrestricted in the sense that any of the three logging systems specified is available.

[6] The decision rules are four–dimensional (piece size, density, price, and performance index). The decision rules are "sliced" so that they can be presented in two dimensions.

[7] In the simplest situation, the correct management decision in cases where the BLV is negative is to abandon the forest land immediately after harvest. However, the situation is complicated in jurisdictions like Alberta where most of the forested land is publicly owned. In Alberta, a logging company's rights to harvest a stand of timber are contingent on satisfactory regeneration of stands harvested previously. Because companies can profitably harvest existing trees, they may logically view reforestation as a cost of harvest. For this reason, land abandonment was not considered to be an acceptable reforestation option for this study.

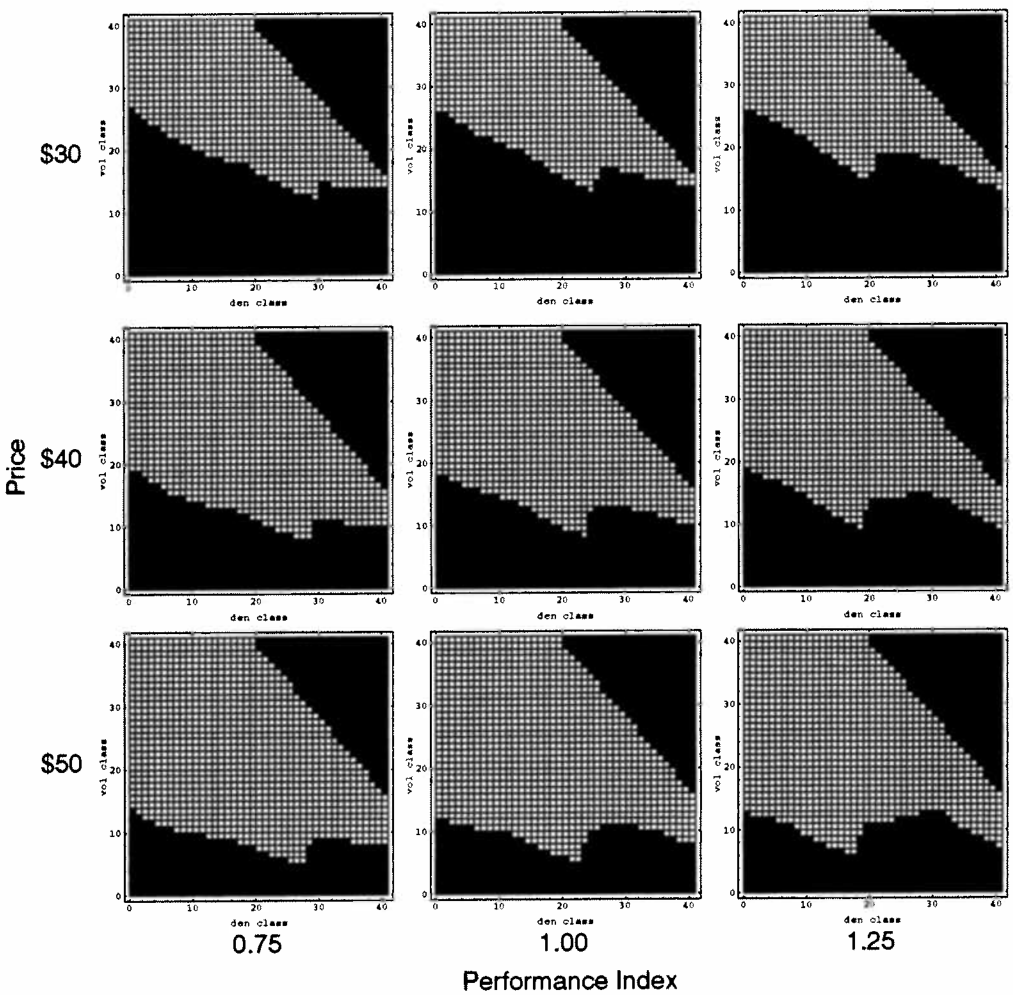

Figure 1: Slices of the decision rule for the base run for different price/site combinations. The white squares indicate piece size and density classes where the optimal decision is to harvest using the least conservative logging system. The black squares indicate that the optimal decision is to postpone harvest. The black in the upper right corner of each panel indicates invalid piece size–density combinations.

Table 2: Bare land value ($/ha) by performance index and price classes for base run.

	Price ($/m^3)				
PI	30	35	40	45	50
0.30	-319.92	-319.48	-318.11	-311.93	-259.99
0.35	-319.91	-319.44	-316.98	-297.08	-247.68
0.40	-319.89	-319.30	-312.07	-277.65	-232.81
0.45	-319.90	-319.12	-305.17	-265.03	-222.99
0.50	-319.89	-317.25	-294.22	-256.02	-215.75
0.55	-319.79	-310.57	-281.22	-247.39	-208.30
0.60	-319.47	-301.00	-273.32	-240.01	-200.07
0.65	-317.87	-295.43	-267.59	-232.86	-191.85
0.70	-312.96	-290.73	-261.97	-225.71	-183.69
0.75	-308.74	-286.53	-255.95	-218.41	-175.22
0.80	-305.97	-282.19	-249.56	-210.41	-165.72
0.85	-303.44	-277.59	-242.99	-201.98	-155.92
0.90	-300.93	-273.13	-237.05	-194.64	-147.71
0.95	-298.56	-269.23	-232.05	-188.96	-141.55
1.00	-296.51	-266.31	-228.56	-185.54	-138.34
1.05	-294.82	-264.25	-226.58	-184.11	-138.07
1.10	-293.65	-263.23	-226.51	-185.18	-140.07
1.15	-293.10	-263.46	-227.99	-187.77	-143.54
1.20	-293.18	-264.81	-230.53	-191.25	-147.66
1.25	-293.91	-266.89	-233.65	-195.16	-152.11
1.30	-295.16	-269.37	-237.08	-199.34	-156.84

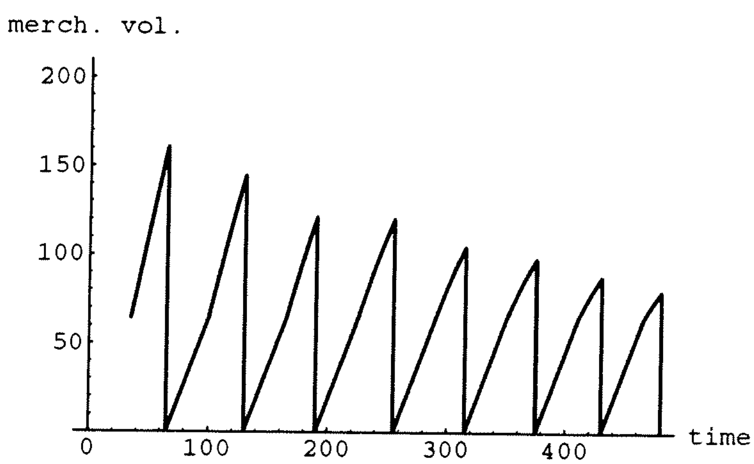

Figure 2: Simulated standing volume for the base run.

3.3 Effect of Harvest System Controls

Governments in Canada place restrictions on forest practices on public and private land to accommodate environmental and other concerns. In this section the harvest system choice was restricted to a system with no measurable effect on site productivity. This system has higher logging costs than the base system and a higher reforestation and rehabilitation cost. The decision rule for this highly restrictive run is shown in Fig. 3. Less of the piece–size density class combinations are optimal for harvest, reflecting the greater cost. Table 3 shows the bare land values for the price and PI

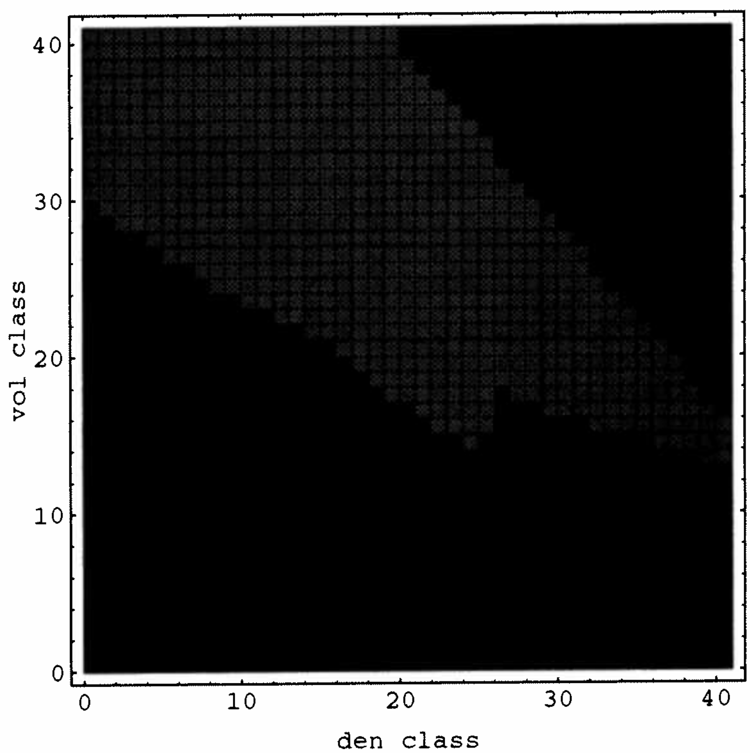

Figure 3: Decision rule for highly restrictive run. Price is \$40/m^3. Performance index is 1.0.

combinations for this highly restrictive run. The -\$685/ha BLV for the \$40 price and 1.00 PI class is \$485/ha less than that for the unrestricted run. Fig. 4 shows a constant flow of harvest volume every 80 years reflecting the unchanging site productivity under the restricted harvest regime.

3.4 Effect of Changing Discount Rates

Because of the long–term nature of forestry investments, the choice of the discount rate can have a major impact on the timing and choice of management activities. In this section, the results of unrestricted harvest system runs using one percent and nine percent annual discount rates are examined.

3.5 1% Discount Rate

Fig. 5 presents the \$40 price and 1.0 PI slice of the decision rule for the one percent discount rate run. Two things are noticeable when compared to the decision rule for the five percent base run

Table 3: Bare land value by performance index and price classes for the extremely restrictive run.

PI	Price ($/m^3) 30	35	40	45	50
0.30	-720.00	-719.99	-719.93	-719.67	-719.04
0.35	-720.00	-719.99	-719.91	-719.63	-718.86
0.40	-720.00	-719.99	-719.89	-719.56	-718.30
0.45	-720.00	-719.99	-719.90	-719.53	-716.13
0.50	-720.00	-719.98	-719.89	-718.93	-707.62
0.55	-720.00	-719.98	-719.78	-714.57	-691.39
0.60	-720.00	-719.97	-719.41	-703.97	-677.94
0.65	-719.99	-719.96	-717.11	-695.98	-669.76
0.70	-719.99	-719.84	-710.32	-688.86	-662.76
0.75	-719.99	-719.23	-704.14	-682.83	-655.34
0.80	-719.99	-717.05	-699.93	-677.04	-647.50
0.85	-719.99	-713.47	-696.03	-670.96	-639.23
0.90	-719.97	-710.95	-692.13	-665.10	-631.50
0.95	-719.74	-708.91	-688.44	-659.85	-624.94
1.00	-719.12	-707.09	-685.28	-655.69	-620.24
1.05	-718.38	-705.44	-682.68	-652.59	-617.15
1.10	-717.69	-704.03	-680.86	-650.92	-616.10
1.15	-717.18	-703.03	-679.98	-650.85	-617.28
1.20	-716.78	-702.45	-680.06	-652.13	-619.88
1.25	-716.48	-702.40	-681.12	-654.60	-623.54
1.30	-716.30	-702.84	-682.90	-657.67	-627.62

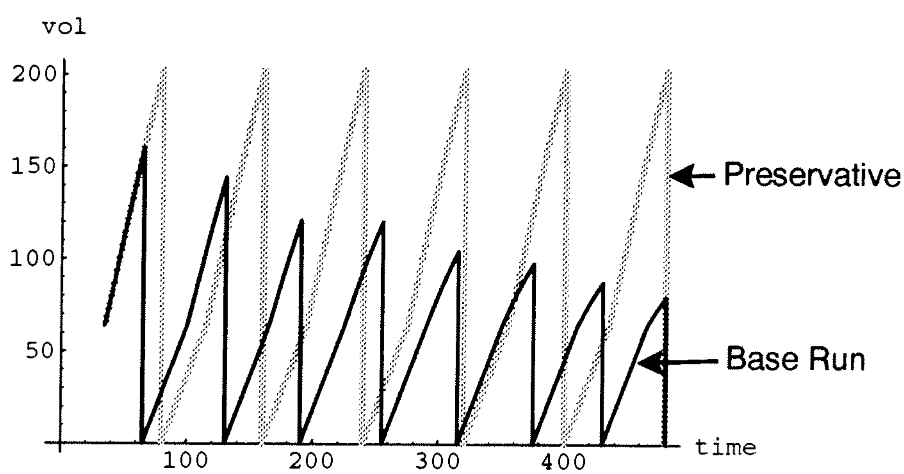

Figure 4: Comparison of simulated standing volume for harvest system control runs.

(middle panel of fig. 1). The first is that the moderately degrading harvest system is chosen for all piece–size density combinations in this decision rule slice. Because of the lower discount rate, future harvests are more valuable and play a bigger role in influencing harvest and soil conservation decisions. Secondly, harvest occurs in low volume classes that are not harvested in the base run. This occurs because it becomes profitable to clear some unmerchantable stands now at a financial loss and to reduce the productivity of the stand in order to regenerate them to a more favourable piece–size density combination.

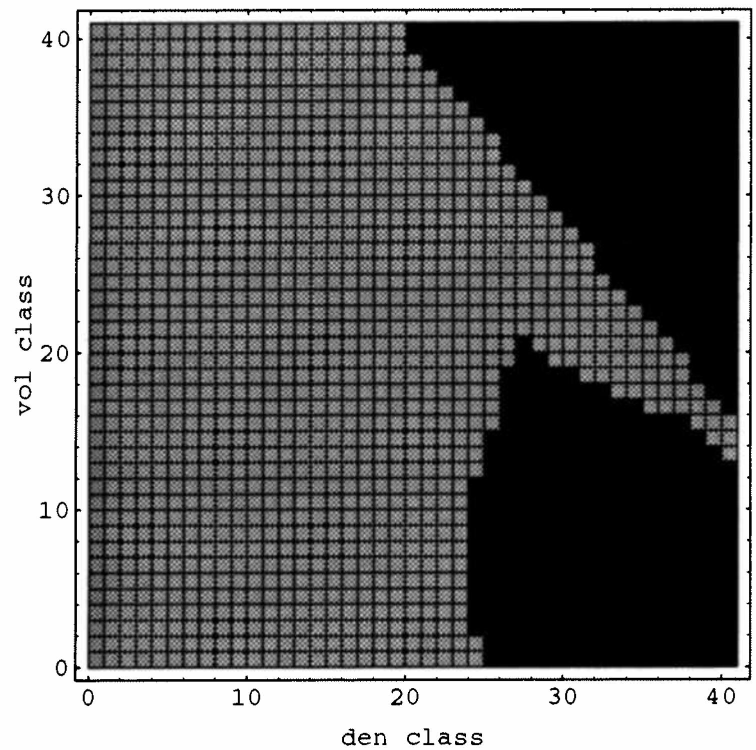

Figure 5: Decision rule for 1 percent discount rate run. Price is $40/m^3. Performance index is 1.0.

This is an interesting result because it departs from the conventional wisdom that lower discount rates would result in a smaller annual area harvested. It is conceivable that allowing for other management activities in the dynamic program (*e.g.* fill–in planting) would reduce the attractiveness of the "cut it down and start again" option, but this result warrants some more exploration. In any case, the lower discount rates seem to encourage more intensive forest management, which may contradict the "environmentally friendly" image that lower discount rates seem to have.

Fig. 6 presents a situation not seen in the base run: more than one harvest system is selected in the optimal decision rule. This figure presents a slice of the decision rule displaying different dimensions than shown in the previous figures. The interesting item illustrated in this figure is the threshold between site classes 13 and 14 (PI = 0.9250). In the higher site classes, the optimal harvest system is more soil–conservative. In the lower site classes, soil conservation does not pay. This suggests that soil conservation will only be employed on sites that are of high enough initial quality. Therefore, if soil conservation is of sufficient public concern (*e.g.* becasue of off–site erosion damages) are high, publicly funded site improvement may be a policy instrument worth considering.

This is also reflected in the simulated standing volume time path (fig. 7). After the second

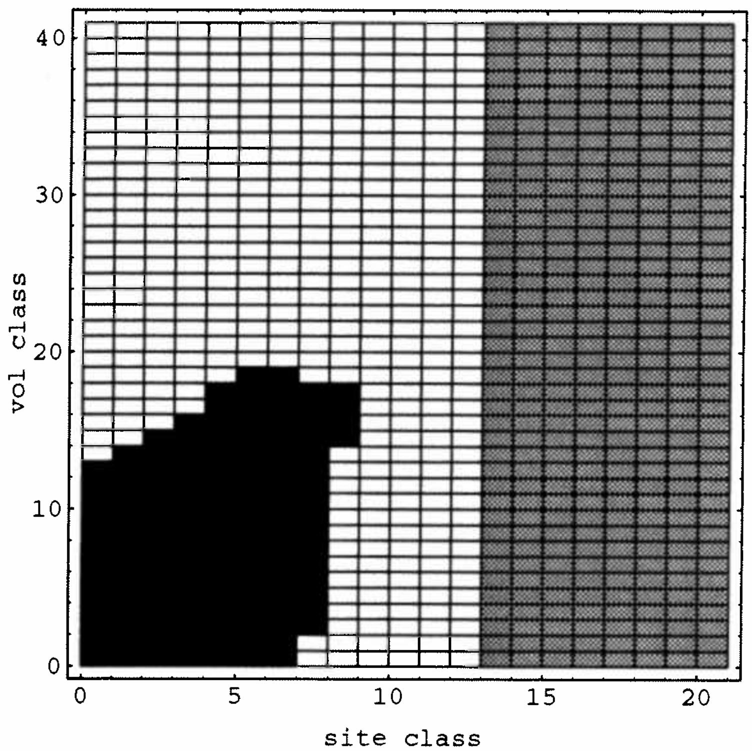

Figure 6: Decision rule for 1 percent discount rate run. Density class is 20. Price is $40/m^3. The black cells indicate that the optimal decision is no harvest, white indicates the optimal decision is to harvest using the least soil–conservative system, and light grey indicates the optimal decision is to harvest using the moderately soil–conservative system.

harvest, the PI threshold is crossed, so from the third harvest on, the least soil-conservative harvest system is chosen.

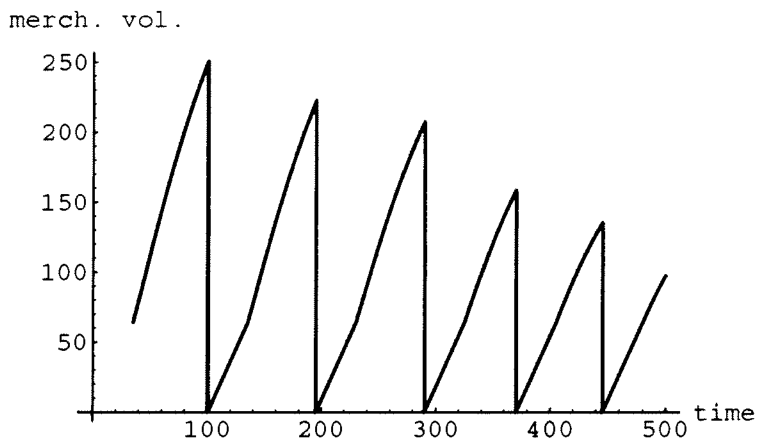

Figure 7: Volume flow for 1 percent discount rate run.

3.6 9% Discount Rate

The nine percent discount rate decision rule differs from the five percent discount rate base run in that slightly more piece-size density classes are optimally harvested, especially at lower volumes and higher densities. The optimal harvest system is always the cheapest, least soil-conservative system. The time between harvests for the first seven harvests is 55 years; for the eighth and ninth harvests it is 50 years.

4 Concluding Remarks

We have developed and demonstrated a model that can be used to evaluate optimal forest management strategies when the effects of soil degradation are incorporated. The model requires that harvesting systems are described by their harvesting costs, their reforestation and rehabilitation costs, and their impact on the overall productivity of the site.

Some useful results from the analysis include;

- In Alberta, it appears that stocks of standing timber are driving investment decisions as bare land values are negative for a wide range of parameter values.
- At higher discount rates, soil conservation is not economically rational. Because of the long time period between stand regeneration and harvest, the present value of future harvests is negligible.
- With lower discount rates, some degree of soil conservation is desirable on the more productive sites. As the productivity declines, the incentive to conserve soil also declines.
- At the lower discount rates, there appears to be an incentive for more intensive forest management. This increased management activity conflicts with the "environmentally friendly" reputation of lower discount rates.

- Limitations on acceptable harvest practices can have a large impact on optimal rotation age and the volume harvested.
- There is a large opportunity cost resulting from a requirement for sustainable volume production based on underlying soil productivity. Some of this opportunity cost may be avoided through genetic improvement or increasing the level of other inputs.

As with any modeling exercise, there is room for further refinement and development.

- Improved growth model. The lodgepole pine growth model needs to be refined so that it is valid for stands less than 35 years old. As currently implemented, the growth model assumes that all stands, regardless of productivity index class, grow identically up to 35 years of age. This will have the effect of understating the cumulative effect of a reduction in the productivity index and, therefore, understating the negative economic impacts of soil degradation.
- Off-site effects of erosion. The optimization and simulation programs could be changed to incorporate off-site effects of erosion. It would be interesting to examine the effects on logging practices of internalizing these costs.
- Intensive management. Because of the state variables chosen to describe timber stands (average piece size, density, and performance index), it would be fairly straightforward to add density–controlling management practices such as pre-commercial and commercial thinning, and fill–in planting to the models.
- Two-level description of degradation. The level of soil degradation tends to occur differentially over a cutblock. Areas used as access roads and skid trails tend to be degraded more than the rest of the cutblock. A system of models that incorporated this differential degradation would add a degree of reality to the modeling process.
- Stochastic elements. The DP model is designed to handle stochastic growth, regeneration, and price movements. These features were not used in the example analysis. It would be useful to conduct an analysis incorporating these stochastic effects.

Despite the opportunities for improvement, this system does provide a relatively straightforward way of incorporating soil degradation into optimal stand management strategies and of quantifying the effect of soil degradation on the flows of timber and net financial benefits from an area of forest land.

References

Armstrong, G. W., F. S. Novak, and W. L. Adamowicz (1994). Environmental and financial sustainability of forest management practices. Technical Report, Dept. of Rural Economy, University of Alberta, Edmonton.

Bowden, G. K. (1986). Economics of forest soil degradation and rehabilitiation. In Lousier and Still (1986), pp. 217–222.

Froehlich, H. (1986). Causes and effects of soil degradation due to timber harvesting. In Lousier and Still (1986).

Hammond, H. L. (1986). Soil degradation: Costs of rehabilitation versus costs of prevention. In Lousier and Still (1986), pp. 227–237.

Harvey, A. E. and L. F. Neuenschwander (Eds.) (1990). *Proceedings — Management and Productivity of Western-Montane Forest Soils*, Boise, ID.

Kennedy, J. O. S. (1986). *Dynamic Programming: Applications to Agiculture and Natural Resources*. London: Elsevier Applied Science Publishers.

Lousier, J. and G. Still (Eds.) (1986). *Degradation of Forested Lands - Forest Soils at Risk. Proceedings of the Tenth B.C. Soil Science Workshop*, Victoria. B.C. Ministry of Forests and Lands.

Routledge, R. D. (1987). The impact of soil degradation on the expected present net worth of future timber harvests. *Forest Science 33*(4), 823–834.

Standish, J. T., P. R. Commandeur, and R. B. Smith (1988). Impacts of forest harvesting on physical properties of soils with reference to increased biomass recovery — a review. Technical report, Government of Canada, Canadian Forestry Service, Pacific Forestry Centre, Victoria, BC.

Stone, E. L. (Ed.) (1984). *Forest Soils and Treatment Impacts, Proceedings of the Sixth North American Forest Soils Conference*, Knoxville, Tennessee.

Utzig, G. F. and M. E. Walmsley (1988). Evaluation of soil degradation as a factor affecting forest productivity in British Columbia: A problem analysis: Phase 1. Technical report, Victoria, BC.