Modeling Alternative Zoning Strategies in Forest Management

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Abstract

To satisfy public demands for environmental values, forest companies face the prospect of reduced wood supply and increased costs. Some Canadian provincial governments have proposed intensifying silviculture in special zones dedicated to timber production as the means for pushing out the forest possibilities frontier. In this paper, we compare the traditional two-zone land allocation framework, which includes ecological reserves and integrated forest management zones, with the triad (three-zone) scheme that adds a zone dedicated to intensive timber production. We compare the solutions of mixed-integer linear programs formulated under both land allocation frameworks and, through sensitivity analysis, explore the conditions under which the triad regime can offset the negative impact on timber production from increased environmental demands. Under realistic conditions characteristic of Coastal British Columbia, we show that higher environmental demands may be satisfied with the triad regime without increasing the financial burden on the industry or reducing its wood supply

Keywords: integrated forest management, mixed-integer programming, reserves, timber production, zoning

1. Introduction

Forests are increasingly managed for multiple values. Among the multiple benefits of forests we focus on timber production and ecological services that are often in a direct conflict. Nature reserves are critical for protecting ecological values, but in most cases protection of ecological values cannot be achieved merely by reserves. A combination of fully protected reserves and management of the remaining forestland for timber production and the maintenance of ecological values is considered the best approach to biological conservation (Noss 1987, Franklin 1988). It is referred to in literature by such terms as ecosystem management, integrated management and multiple-use forest management (Bowes and Krutilla 1989). We use the term *integrated management* in this paper to describe forest management where silvicultural activities, rates and the timing of harvests are chosen to take into account all of the various benefits of the forest simultaneously.

Integrated management has been adopted by many countries to manage both public and private forestlands. The achievement of the goals of integrated management is usually provided by means of regulatory mechanisms. There are many examples of successful implementation of integrated systems but the requirements of integrated forest management, mainly driven by a greater emphasis on environmental objectives, resulted in a shortfall in wood supply and increased production costs in some regions. Negative timber production effects of integrated management are especially serious in the Pacific Northwest and Western Canada where conflicts over the forestland are the most dramatic.

Increased pressures for protecting the environment expressed as requests for larger areas of reserves and tighter regulations on forestland managed for multiple uses, led some analysts to advocate spatial segregation of forest uses instead of their integration (Vincent and Binkley

1993). In this paper, we refer to this segregation of land uses as zoning. To improve ecological and economic management of forests, Seymour and Hunter (1992) suggested a three-zone (triad) framework that included an intensive timber production zone in addition to reserves and an integrated management zone.

The major question posed by policy makers, forest managers and academics in the USA (Hunter and Calhoun 1996) and Canada (Binkley 1997, Sahajananthan et al. 1998, Ontario Ministry of Natural Resources 1999) is whether and under what conditions zoning can offset the impact on timber production from increased environmental demands. In this paper, we develop a triad model to determine the minimum size of the timber production zone, its location and the schedule of treatments that will compensate for the volume lost and economic opportunities foregone. The performance of the two-zone alternative (without the timber production zone) is used as a benchmark.

We begin in the next section by discussing the zoning problem in more detail. Model formulations are presented in section 3. In section 4, we use the models to analyze and assess land allocation and management alternatives for different policy scenarios in the context of a case study that is representative of forestry on the coast of British Columbia, Canada. The scenarios include different regulatory requirements, overall environmental constraints as well as different assumptions regarding the productivity and costs of intensive management prescriptions. The discussion and conclusions follow in section 5.

2. Problem description

Spatial segregation of management for multiple forest uses through zoning and the creation of intensive timber production zones is an idea that has been around for a long time, but it has recently attracted significant attention because of measures taken to provide greater environmental protection through harvest restrictions. Numerous studies in the forestry literature have discussed specific questions relevant to zoning. Decisions about zoning at the strategic planning level typically deal with the size of the zone and its location, with only a few studies addressing the viability of zoning and its ability to achieve multiple objectives.

Davis and Johnson (1987) were among the first to discuss allocation of spatially defined forest units to different uses. They formulated the land allocation problem as a mixed-integer linear program, thereby extending the classical aspatial harvest scheduling models of FORPLAN (Johnson et al. 1986). Adding a spatial land allocation component to the harvest scheduling model resulted in a decline of both net present worth and total harvest volume (Davis and Johnson, 1987, Table 15-17, p. 650). Weintraub and Cholaky (1991) addressed zoning at the strategic level of hierarchical planning and added a road building component to the land allocation problem. Their problem is also formulated as a mixed-integer linear program. Bos (1993) studied allocation of forestland among timber production, nature conservation and recreation. He formulated the zoning problem as a quadratic assignment model with an objective function that combined spatial relationships of land units with their suitability for specific uses. Gustafson (1996) examined the effect of clustering timber harvest zones and changing the land use categories over time. He used a simulation timber harvest allocation model to compare static zoning with different dynamic alternatives.

In some policy decisions about zoning, the least productive and/or inoperable forestland has been allocated to reserves without attention to the ecological consequences of such decisions. A possible way to protect ecological values is to set targets for preserving specific proportions of distinct ecological types. The concept of various ecosystems being represented on non-harvested forestlands was introduced by UNESCO's Man and the Biosphere program (UNESCO 1974) and used as a prototype in designing nature reserves. In our models, we formulate ecological constraints in terms of ecological representation.

Remedies that can be used to compensate for increasing environmental demands include reducing management costs, increasing productivity by enhanced silviculture, relaxing environmental constraints on a portion of forestland base and land-use specialization. Some of these measures conflict with each other. Other means such as low management cost plantations of fast growing species may not be environmentally or socially acceptable.

In this paper, we examine the possibilities of a combination of land-use specialization and relaxation of environmental constraints on a portion of the forestland base. The triad problem is discussed in relation to the two-zone approach where the land allocation choice is either the integrated management zone or reserves. We determine the minimum area of intensive timber production that will compensate for the loss of timber harvest and financial opportunities foregone (in terms of net present value) due to increased area set aside to reserves and tighter ecological constraints in the two-zone scheme. The potential economic benefits of the triad land allocation may come from increased production efficiency and reduced management costs in the timber production zone. Reduction of management costs in the timber production zone is a consequence of relaxing regulatory constraints. Relaxing environmental regulations in timber production zone does not necessarily mean elimination of all constraints. It simply recognizes that not all environmental constraints are equally important for forest conservation, or that they do not need to be applied equally throughout the forest. Nor do all regulations have the same effect on harvest costs. Top priority ecological constraints, such as the protection of riparian areas and retention of wildlife corridors, may remain in force in the timber production zone, while other costly regulations, such as adjacency constraints and other requirements to preserve and/or improve the visual quality of the forest landscape, may be relaxed or discarded. If zoning is to be effective in increasing timber output while meeting environmental objectives, enhanced silviculture in the timber production zone is required to increase growth and yield. At the same time, enhanced silviculture must be profitable in the timber production zone. Management and regulatory compliance costs are reduced in both timber production zones and the reserves relative to the costs incurred under integrated management.

3. Model Formulation

We develop two models for solving classic land allocation and management scheduling problems over large temporal and spatial scales (Davis and Johnson 1987, Weintraub and Cholaky 1991). The forest is divided into units reflecting administrative, geographic and operational considerations. A large spatial resolution is used to deal with general land allocation issues while leaving other spatial decisions (like adjacency constraints and roads building) for the tactical or operational levels of planning. The problem is modeled from the private operator perspective assuming that lands allocated to ecological reserves do not provide economic benefits. An additional assumption is that land allocated to different uses does not change over time.

The problem of land-use allocation and scheduling of management treatments is modeled as a mixed integer linear program. The model elements are defined as follows. Suppose that the forest is divided into units $u \in U$ and let M be the set of management strata. A management stratum $m \in M$ is defined in terms of species, site quality, ecosystem and age class. If specific forest characteristics are to be emphasized in the model, M can be partitioned accordingly. Here, we express ecological constraints in terms of the required representation of ecosystems $e \in E$, where E is the ecosystems index set. Let $N_e \subseteq M, e \in E$ represent a partition of M by the ecosystems $e \in E$ ($N_i \bigcap N_j = \emptyset, \forall i, j \in E$, $M = \bigcup_{e \in E} N_e$). Other partitions of the set M are possible if needed.

Let Z be the set of mutually exclusive zones to which land units can be assigned, namely, timber production (TP), reserves (R) and integrated management (IM), Z={TP, R, IM}. $P(z)$ is the set of management regimes appropriate to zone z and $P = \bigcup_{z \in Z} P(z)$ is the set of all regimes. Regimes differ by the intensity of management for timber, and range from no harvest to basic, extensive and intensive management. The 'no harvest' regime consists of planning, protecting and limited access to the areas set aside for ecological purposes. Under the basic regime, we consider natural regeneration of harvested stands, while the extensive regime assumes artificial regeneration. Neither the basic nor extensive regimes include silvicultural activities after regeneration. Intensive management includes different silvicultural practices following artificial regeneration of denuded stands. We assume that once a regime is selected for a stratum, it will be applied thereafter. All the regimes except the 'no harvest' one include harvesting as a management activity. Each regime consists of a set of treatments. We consider a treatment to be the schedule of silvicultural activities and harvest over the planning horizon for a given management stratum. If we denote P_1 = {no harvest} and P_2 = {basic, extensive, intensive}, then P(R) = P_1, and P(IM) = P(TP) = $P_1 \cup P_2$.

Let $vl_{m,p}$ be the volume (m^3/ha) and $v_{m,p}$ the present value ($/ha) of timber from stratum m

managed by treatment p. The cost of a treatment depends on the management stratum and on the specific use for which the stratum is managed. Let $c_{z,m,p}$ be the discounted cost ($/ha) of managing stratum m by treatment p in zone z, where z is either the integrated management (IM) or timber production zone (TP). We assume that the management cost ($/ha) of the reserve zone is constant and denote its present (discounted) value by c_R. Let $A_{u,m}$ be the area (ha) of management stratum m in unit u; ρ the minimum area (ha) to be allocated to reserves and ε_e the minimum non-harvested area (ha) of ecosystem $e \in E$.

Decision variable $x_{z,u,m,p}$ represents the area (ha) of unit u of stratum m managed by treatment p for use z, and $Y_{z,u} = 1$ if unit u is assigned to use z, with $Y_{z,u} = 0$ otherwise.

The two-zone model

The first problem is to determine the allocation of units to either the reserves or integrated management zone, and to schedule management treatments to maximize the net present value of timber benefits while meeting ecological requirements. The ecological requirements include the minimum area of reserves and minimum non-harvested area of ecosystems. We refer to this as the two-zone problem and model it as:

Maximize $$N(x) = \sum_{u \in U} \sum_{m \in M} \sum_{p \in P} (v_{m,p} - c_{IM,m,p}) x_{IM,u,m,p} - c_R \sum_{u \in U} \sum_{m \in M} A_{u,m} Y_{R,u} \qquad (1)$$

subject to:

Land availability by units and strata

$$\sum_{p \in P(z)} x_{z,u,m,p} = A_{u,m} Y_{z,c} \qquad \forall u \in U,\ m \in M,\ z \in \{IM, R\} \qquad (2)$$

Minimum area of reserves

$$\sum_{u\in U}\sum_{m\in M} A_{u,m} Y_{R,u} \geq \rho \qquad (3)$$

Minimum non-harvested area of ecosystems

$$\sum_{z\in\{IM,R\}}\sum_{u\in U}\sum_{m\in N_e}\sum_{p\in P_1} x_{z,u,m,p} \geq \varepsilon_e \qquad \forall e \in E \qquad (4)$$

Allocation of each unit to only one use

$$\sum_{z\in\{IM,R\}} Y_{z,u} = 1 \qquad \forall u \in U \qquad (5)$$

Non-negativity and integrality

$$x_{z,u,m,p} \geq 0,\ Y_{z,u} \in \{0,1\} \qquad z \in \{IM, R\},\ u \in U,\ m \in M,\ p \in P(z) \qquad (6)$$

Denote by $(\tilde{x},\tilde{Y})$ the optimal solution of the mixed-integer linear program (1)–(6), by $\tilde{N} = N(\tilde{x})$ the optimal net present value and by $\tilde{V} = V(\tilde{x}) = \sum_{u\in U}\sum_{m\in M}\sum_{p\in P} vl_{m,p}\,\tilde{x}_{IM,u,m,p}$ the volume generated by the optimal combination of the land allocation and the management schedule.

The triad model

Suppose now that newly introduced environmental legislation tightens the rules regarding both the area of reserves and protected area of specific ecosystems. Denote by α the required increase (ha) relative to ρ of the minimum area to be allocated to reserves, and by β_e the required increase (ha), relative to ε_e, the minimum area of ecosystem $e\in E$ not to be harvested. Under tighter environmental regulations that increase the area of nature reserves and/or non-harvested area by ecosystems, the net present value of timber benefits declines if all other conditions remain unchanged. This comes as a reduction of the optimal value of the two-zone model (1)-(6) under tighter constraints.

Introducing an additional zone for intensive timber production increases the number of management options and allows for better performance in terms of the objective value achieved. The new zone permits relaxation of regulatory constraints and the possibility of intensive silviculture. The size and location of timber production zones may vary depending on regulatory constraints and the application of different silvicultural regimes.

Under the triad framework, we determine the minimum size of the timber production zone, its location and the management schedule that will make up for the volume lost and economic opportunities foregone. The performance of the two-zone alternative is used as a benchmark to evaluate the triad option. We use the model to analyze and assess land allocation alternatives for different policy scenarios in the context of a case study. The scenarios include different regulatory requirements, overall environmental constraints, and different assumptions regarding productivity and costs of intensive management prescriptions.

The problem that we formulate now is to allocate each unit to one of the three zones and schedule management treatments to minimize the area of the intensive timber production zone, while meeting tighter ecological constraints in addition to timber supply and economic performance requirements. The timber supply requirement is formulated as a constraint on harvest volume – it cannot be less than the harvest volume $\tilde{V}$ achieved with the two-zone model (1)-(6) under the original environmental regulations. The economic performance requirement is expressed as a constraint that the net present value of timber benefits be at least as high as the optimal value $\tilde{N}$ of the two-zone model under the original environmental regulations. The ecological requirements include minimum areas of reserves and ecological type protected from harvest under the new (tighter) regulations. This is modeled as:

$$\text{Minimize } TA(y) = \sum_{u \in U} \sum_{m \in M} A_{u,m} Y_{T,u} \qquad (7)$$

subject to:

Minimum net present value (requirement of economic performance)

$$\sum_{z\in Z\setminus\{R\}}\sum_{u\in U}\sum_{m\in M}\sum_{p\in P}(v_{m,p}-c_{z,m,p})x_{z,u,m,p}-c_R\sum_{u\in U}\sum_{m\in M}A_{u,m}Y_{R,u}\geq\tilde{N} \tag{8}$$

Minimum volume (requirement on timber supply)

$$\sum_{z\in Z\setminus\{R\}}\sum_{u\in U}\sum_{m\in M}\sum_{p\in P}vl_{m,p}\,x_{z,u,m,p}\geq\tilde{V} \tag{9}$$

Land availability by land units and strata

$$\sum_{p\in P(z)}x_{z,u,m,p}=A_{um}\,Y_{zc}\qquad\forall u\in U,\ m\in M,\ z\in Z \tag{10}$$

Minimum area of reserves

$$\sum_{u\in U}\sum_{m\in M}A_{u,m}Y_{R,u}\geq\rho+\alpha \tag{11}$$

Minimum non-harvested area of ecosystems

$$\sum_{z\in Z\setminus\{T\}}\sum_{u\in U}\sum_{m\in M_e}\sum_{p\in P_1}x_{z,u,m,p}\geq\varepsilon_e+\beta_e\qquad\forall e\in E \tag{12}$$

Each unit allocated to only one use–no split of units between uses is allowed

$$\sum_{z\in Z}Y_{z,u}=1\qquad\forall u\in U \tag{13}$$

Non-negativity and integrality

$$x_{z,u,m,p}\geq 0,\ \ Y_{z,u}\in\{0,1\}\qquad z\in Z,\ u\in U,\ m\in M,\ p\in P(z) \tag{14}$$

4. Numerical Example: Coastal British Columbia

Different land allocation approaches are illustrated and compared using a numerical example that is representative of the ecological and forest management conditions in coastal British Columbia.

The study area consists of a 13,322 ha forest estate. The forest is divided into the ten units illustrated in Figure 1.

<Insert Figure 1 about here>

Growth types, site quality, age and ecosystem types define a management stratum. Several growth types are aggregated into two major species, Douglas-fir and Western Hemlock, grown on three site quality classes. Existing stands of age between 5 and 250 years are classified into eight 20-year groups with one class for all stands older than 140 years. An accepted and well-mapped biogeographic ecosystem classification is available for British Columbia (Pojar et al. 1987). This classification consists of forest-type zones, climatic sub-zones within each zone, and elevational variants within each sub-zone. The ecological targets for our case study are formulated using five variants present in the study area – CWHmm1, CWHmm2, CWHxm1, CWHxm2 and MHmm1. Lower-elevation ecosystems, CWHmm1 and CWHxm1 had higher rates of harvest in the past than the remaining higher-elevation systems. The two most abundant types, CWHmm2 and CWHxm1, occupy about 60% of the total area with the former mainly occurring in units #1–#5 and the latter present exclusively in units #6–#10.

The planning horizon is 200 years divided into ten equal sub-periods. No initial management conditions are imposed. After harvest of the existing stands, three silvicultural regimes – basic, extensive and intensive – are considered for both the integrated management and intensive timber production zones. While the basic regime assumes natural regeneration of harvested forestland, the extensive regime applies artificial regeneration. The intensive management regime includes four thinning treatments. Management regimes differ by the implied growth and yield and corresponding costs. The economic criterion consists of net discounted returns using a 4% discount rate. Forest inventory data by units and selected ecosystem types are provided in Table 1.

<Insert Table 1 about here>

At present all lands in British Columbia are subject to the 1995 British Columbia Forest Practices Code (hereafter Code). In addition to an increase in the protected area to 12% of the provincial forestland base, the Code established strict regulations on the management of areas for multiple-use. Since the introduction of the Code, delivered wood cost on the B.C. coast have increased by $30.65 per cubic meter (Pearse 2001). About $19.68/m^3 of this increase is considered Code related (KPMG 1997). To compensate for the increase in protected areas and tightening of regulations, the B.C. legislation made provision for single-use management areas, one of which is intensive timber production. Although possible, no intensive timber production zones have yet been created. The debate now focuses on whether and how to create zones of intensive timber production where environmental regulations would be relaxed, and regulatory costs decreased, compared to current practice (Binkley 1997).

Specification of Alternative Management Scenarios

We compare the outcomes of the two-zone and triad land allocation frameworks under different scenarios of environmental protection, relaxation of regulatory costs and options for intensive management in the timber production zone (Table 2). Scenarios differ according to the minimum area allocated to reserves and the minimum proportions of various ecosystems that must be protected. The requirement on the minimum size of reserves in combination with spatially distinguished units provides for the creation of contiguous areas of forest not managed for timber, while the later requirement is introduced to provide for a specific representation of the range of ecosystems.

In practice, land is allocated to reserves based on several ecological criteria with the inclusion of representative ecosystems being one of them. The location of protected areas in B.C. is determined through negotiations between several stakeholder groups. Since the introduction of the Code, the protected areas in British Columbia have increased to slightly over 12% of the total forestland. The forest ecology literature is not very helpful in determining a minimum area of reserves. Recommendations range from 5% to almost 99.7% (Hunter 2002, p.263). Given the uncertainty about the optimal size of reserves, we start with an initial reserve target of 8% of total forest area. This target is increased to 12% and 15% in all scenarios that represent rising demands for environmental protection (Table 2, column 4). In addition, there are targets for protecting representative ecosystems. The figures provided in column 5 of Table 2 indicate the minimum proportions of non-harvested land in each ecosystem, with area determined as this proportion multiplied by the total area of that ecosystem available (provided in the last five columns of Table 1). Thus, both the reserve and integrated management zones contribute to non-harvested forestland. For ecosystem preservation, the baseline target is 10% protection, with 15% and 20% ecosystem protection targets for the scenarios of enhanced environmental protection; these targets were set arbitrarily in this numerical example. The purpose of the requirement for ecological representation in non-harvested areas is to preserve a range of ecosystems. Similar to the targets for the area of reserves, the targets for protecting specific ecosystems are to be applied to larger forest areas. When dealing with areas of smaller scale as in our case study, the target figures should be considered in the context of preservation at the larger scale. Although based on the current practice in British Columbia, the target figures in our example should be considered with a great deal of caution because of the necessary simplifications of this illustration.

We now define three scenarios of environmental protection: (1) the *Low* environmental scenario combines the target for reserves to be 8% of the forestland base and the target of non-harvested area per ecosystem to be 10% of the specific ecosystem area; (2) the *Medium* environmental scenario involves at least 12% of the forestland base to be allocated to reserves and 15% of the ecosystem area to remain non-harvested, and (3) the *High* scenario includes the 15% and 20% targets for the reserves and non-harvested area of ecosystem.

Finally, the figures in column 6 of Table 2 indicate the proportion to which regulatory costs are reduced in the timber production zone. For our numerical example, we consider three levels of regulations. The *Stringent* regulations apply to the integrated management zone and no relaxations are allowed. For the *Lax* regulations scenario we assume that all regulations, except the protection of riparian areas and retention of wildlife corridors, are eliminated in the timber production zone. Based on the KPMG (1997) analysis of the cost drivers, this will result in an average decrease of delivered wood cost of $15/m^3, or by about 75% of the total regulatory cost. For the last *Moderate* regulations scenario, we assume an approximate 25% reduction in regulatory costs.

<Insert Table 2 about here>

Alternative ecological requirements in terms of the size of reserves and minimum non-harvested area of ecosystems are combined with different intensities of regulatory constraints. We now consider three scenarios under the two-zone land allocation approach and five scenarios under the triad scheme (Table 2, columns 1-3). The two-zone scenarios differ only with respect to ecological requirements because all regulations are in place within the integrated management zone. The four triad scenarios include combinations of the *Medium* and *High* environmental requirements for the total forestland base with the *Moderate* and *Lax* regulations. The last scenario involves the possibility of establishing fast-growing plantations in the timber production zone under the overall *Medium* environmental requirements and *Moderate* regulations in the timber production zone.

Comparison of the Results of Different Scenarios

First, the two-zone problem (1)-(6) is solved for the *Low*, *Medium* and *High* scenarios. The problem is solved using the CPLEX mixed-integer linear programming routine on the GAMS platform. The assignments of units to two zones for different scenarios are provided in Table 3 and illustrated in Figure 2. We first compare land allocations under the two-zone framework. Requirements of the *Two-Zone Low* scenario are satisfied by allocating unit #9 to the reserve zone and managing the remaining areas in an integrated management fashion (Table 3, row 1; Figure 2, panel (a)). To satisfy the requirements of the *Two-Zone Medium* scenario, non-adjacent units #1 and #3 are allocated to reserves, while a contiguous area consisting of the units #2 and #3 is created under the *Two-Zone High* scenario (Table 3, row 2 and 3; Figure 2, panels (b) and (c)).

<Insert Table 3 about here>

<Insert Figure 2 about here>

In addition to the very same ecological targets as the two-zone models, the triad model (7)–(14) has requirements for timber supply and economic performance. A special zone dedicated to timber production can compensate for the loss of harvest volume and foregone timber values more successfully than using integrated management because of the relaxed regulatory costs within the timber production zone. Similar to the two-zone problem, the triad problem (7)-(14) is solved using the CPLEX mixed-integer linear programming routine on the GAMS platform. The triad models are solved for the *Medium–Moderate, Medium–Lax, High–Moderate and High–Lax* scenarios. The last set of results comes under the *Triad Fast Plantation High-Lax* scenario. The assignments of units to three zones for different scenarios are provided in Table 4 and illustrated in Figure 3.

<Insert Table 4 about here>

<Insert Figure 3 about here>

The land allocated to reserves under the triad framework for *Medium–Lax* and *High-Lax* scenarios has a similar pattern to that under the two-zone scheme for corresponding *Medium* and *High* ecological targets (compare Table 4, rows 2 and 4 to Table 3, rows 2 and 3). Under the

Triad Medium–Lax scenario, units #5, #6 and #10 are allocated to the timber production zone, and, under the *Triad High–Lax* scenario, the timber production zone consists of the units #4, #5, #7 and #10. A dramatic difference in land allocation occurs under *Moderate* regulations compared to the *Lax* group of regulations. Under the *Triad Medium–Moderate* scenario, units #1, #3, #4, #5, #6, #8 and #10 are allocated to the timber production zone, units #2 and #9 to reserves, and unit #7 is managed using an integrated approach. A further increase of ecological targets combined with the moderate relaxation of regulations in the timber production zone under the *Triad High–Moderate* scenario cannot be satisfied by any combination of land allocation and management treatments available. Therefore, we consider establishment of fast growing hemlock plantations as an additional management option in the timber production zone. Under the *Triad Fast Plantation* framework and *High–Moderate* scenario of ecological targets and regulations, units #6, #7 and #10 are allocated to the timber production zone, units #1, #2 and #3 to reserves, and the remainder is managed using an integrated approach.

The outcomes of the two-zone and triad models for several scenarios of ecological requirements over the total forestland base and specific regulations in the timber production zone are provided in Table 5. The outcomes are presented in terms of the net discounted value of timber benefits, harvest volume, area of each zone and non-harvested land within the integrated management zone.

<Insert Table 5 about here>

The results of the *Two–Zone Low* scenario (presented in bold italic characters) are used as the benchmark for further analyses (Table 5, row 1). The net present values of the *two–zone Medium* and *High* scenarios are 7.6% and 10.9% lower, respectively, than the net present value of *Two–Zone Low* scenario. The rate of harvest volume reduction is significantly lower: Respective timber volumes under the *two–zone Medium* and *High* scenarios are reduced by 2.7% and 1.7% relative to the volume under the *Two–Zone Low* scenario. These reductions in timber benefits are compensated for by the increases in non-harvested areas in the integrated management zone of 14.2% and 50.6% for the *Two–Zone Medium* and *High* scenarios, respectively (Table 5, columns 7 and 9, rows 2 and 3).

Under the *Triad Medium-Moderate* and *Lax* scenarios, volumes increase by 31.1% and 27.7%, respectively, relative to that under the *Two–Zone Low* scenario (Table 5, column 5, rows 4 and 5). At the same time, the total non-harvested area under the *Triad Medium-Moderate* scenario decreases by 21.1%, but increases by 5.2% relative to the non-harvested area under the *Two–Zone Low* scenario (Table 5, column 7 and 9, row 4 and 5).

Finally, both the harvest volumes and cumulative non-harvested areas in the reserves and integrated management zone increase under the two scenarios. Under the *Triad High-Lax* and the *Triad Fast Plantations High-Moderate* scenarios, harvest volumes increase by 15.1% and 22.6%, respectively, relative to what they would be under the *Two-Zone Low* scenario. The areas of non-harvested land also increase by 27.7% and 32%, respectively, for the *Triad High-Lax* and the *Triad Fast Plantations High-Moderate* scenarios.

The results thus show that, under particular conditions, concentrating intensive timber production on a smaller area may lead to better economic performance. It is less clear, however, whether the ecological performance of triads will be acceptable. In particular, the establishment of fast-growing plantations is likely to be controversial. We suggest, therefore, that experimental introduction of the triad system involve field studies by conservation biologists.

5. Discussion and Conclusions

Sustainable forest management requires attention both to economic and ecological benefits and costs. Increases in environmental protection demands have stimulated an interest in the triad land allocation approach that involves intensive management. The argument is that such an approach can push out the forest production possibilities frontier, enabling society to achieve greater environmental protection without a loss in wood supply and accompanying financial benefits. This is, for example, the key objective of Ontario's Forest Accord (Ontario Ministry of Natural Resources 1999), which promises higher environmental standards while maintaining intact available wood fiber. This can result from the use of special timber production zones, where regulatory costs are reduced and intensive silviculture is practiced. Whether these options indeed push out the production possibilities frontier depends on the extent of economies of scale resulting from reduced regulatory transaction costs, and the costs and effectiveness of the specific silvicultural strategies used.

In this paper, we explored the consequences of the triad approach and the conditions that could make it feasible. In the context of a case study, we investigated how the optimal land allocation and schedule of management treatments under the triad framework change for different scenarios of ecological protection and alternative regulatory conditions. These scenarios assume the application of environmentally friendly, high-cost intensive silvicultural treatments, such as thinning. We also examined the impact on land allocation and the economic performance of planting fast growing species within the timber production zone.

We have shown that the optimal land allocation and schedule of management treatments under the triad framework are less sensitive to altering environmental regulations than to the changes in management costs and production efficiency. The required timber production zone area increases sharply with an increase in regulatory costs. With the full regulatory costs in place for the timber production zone, there is no solution to the triad model that can offset the impacts of increased environmental demands.

Some of these results are related to the unit size. Smaller scale units may allow for greater flexibility in meeting economic and environmental targets at the strategic level, but the cost may be a loss of economies of scale. Furthermore, some ecological values can be obtained only when a minimum contiguous area is dedicated to these values.

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Figure 1: Study area divided into ten units.

Table 1: Area (ha) by unit and ecosystem

		Ecosystem				
Unit	**Area (ha)**	**CWHmm1 (ha)**	**CWHmm2 (ha)**	**CWHxm1 (ha)**	**CWHxm1 (ha)**	**MHmm1 (ha)**
1	421	0	254	0	0	167
2	856	0	451	0	0	405
3	1200	613	426	0	89	72
4	2099	161	1458	0	42	438
5	868	0	537	0	36	295
6	2022	0	314	796	609	303
7	1947	0	274	1062	611	0
8	1882	32	0	1809	41	0
9	1124	404	0	267	453	0
10	904	51	57	211	584	0
Total	**13322**	**1261**	**3771**	**4145**	**2466**	**1681**

Table 2: Alternative Management Scenarios

Framework	Emphasis	Regulations	Reserves[b] (%)	Ecosystems[c] (%)	Relax of Regul. Costs[d] (%)
Two–Zone	Low	Stringent	8	10	0
Two–Zone	Medium	Stringent	12	15	0
Two–Zone	High	Stringent	15	20	0
Triad	Medium	Moderate	12	15	25
Triad	Medium	Lax	12	15	50
Triad	High	Moderate	15	20	25
Triad	High	Lax	15	20	50
Triad fast plantations[a]	High	Moderate	15	20	25

[a] Establishing low cost fast growing plantations within the timber production zone
[b] Minimum area of reserves is expressed as the portion of the total forest area
[c] Minimum non-harvested area is expressed as the portion of the ecosystem area
d Percentage of relaxation of the full regulatory costs

Table 3: Land-use Allocation under Two-Zone Scenarios

Ecological		Units									
Targets	**Regulations**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Low	Stringent	IM	IM	IM	IM	IM	IM	IM	IM	R	IM
Medium	Stringent	R	IM	R	IM	IM	IM	IM	IM	IM	IM
High	Stringent	IM	R	R	IM	IM	IM	IM	IM	IM	IM

Table 4: Land-use Allocation under Triad Scenarios

			Units									
Framework	**Ecological Targets**	**Regulations**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Triad	Medium	Moderate	TP	R	TP	TP	TP	TP	IM	TP	R	TP
Triad	Medium	Lax	R	IM	R	IM	TP	TP	IM	IM	IM	TP
Triad	High	Moderate	NO FEASIBLE SOLUTION									
Triad	High	Lax	IM	R	R	TP	TP	IM	TP	IM	IM	TP
Triad Fast Plantations	High	Moderate	IM	R	R	IM	IM	TP	TP	IM	IM	TP

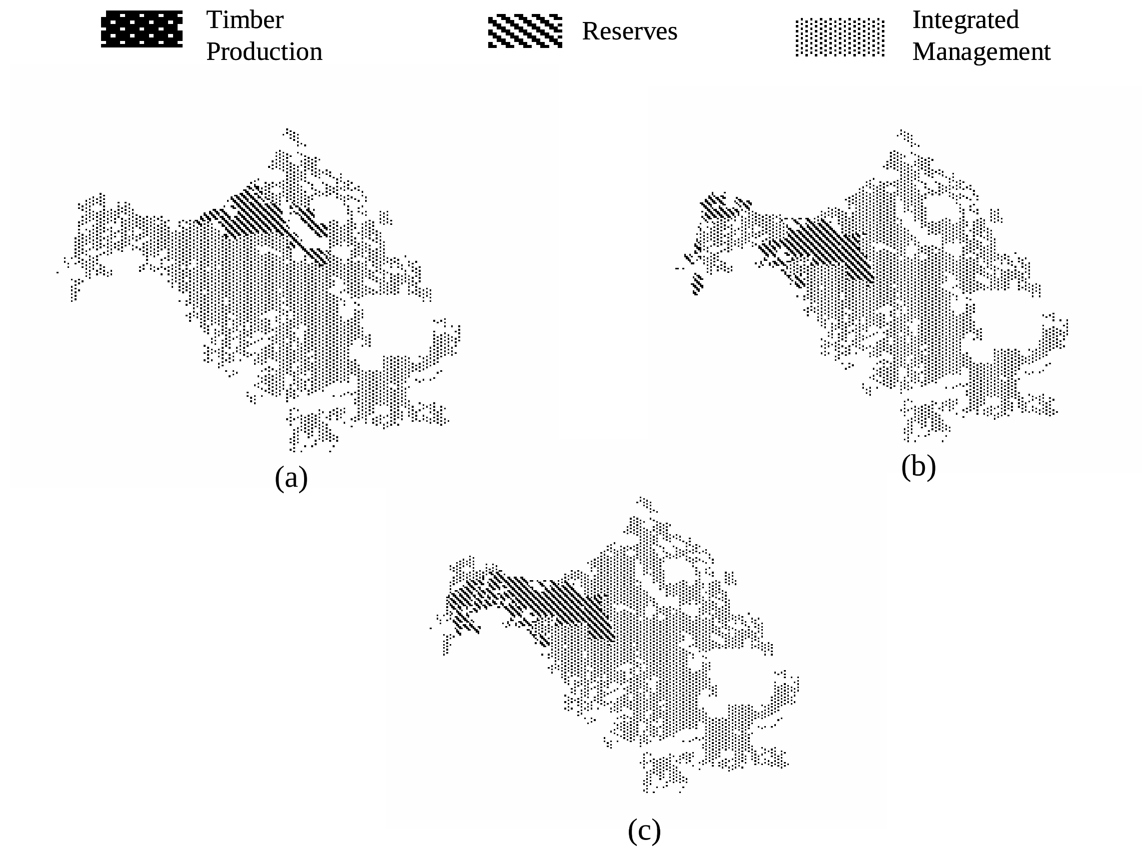

Figure 2: Land allocation under: (a) Two–Zone Low; (b) Two–Zone Medium; and (c) Two–Zone High Emphasis scenarios.

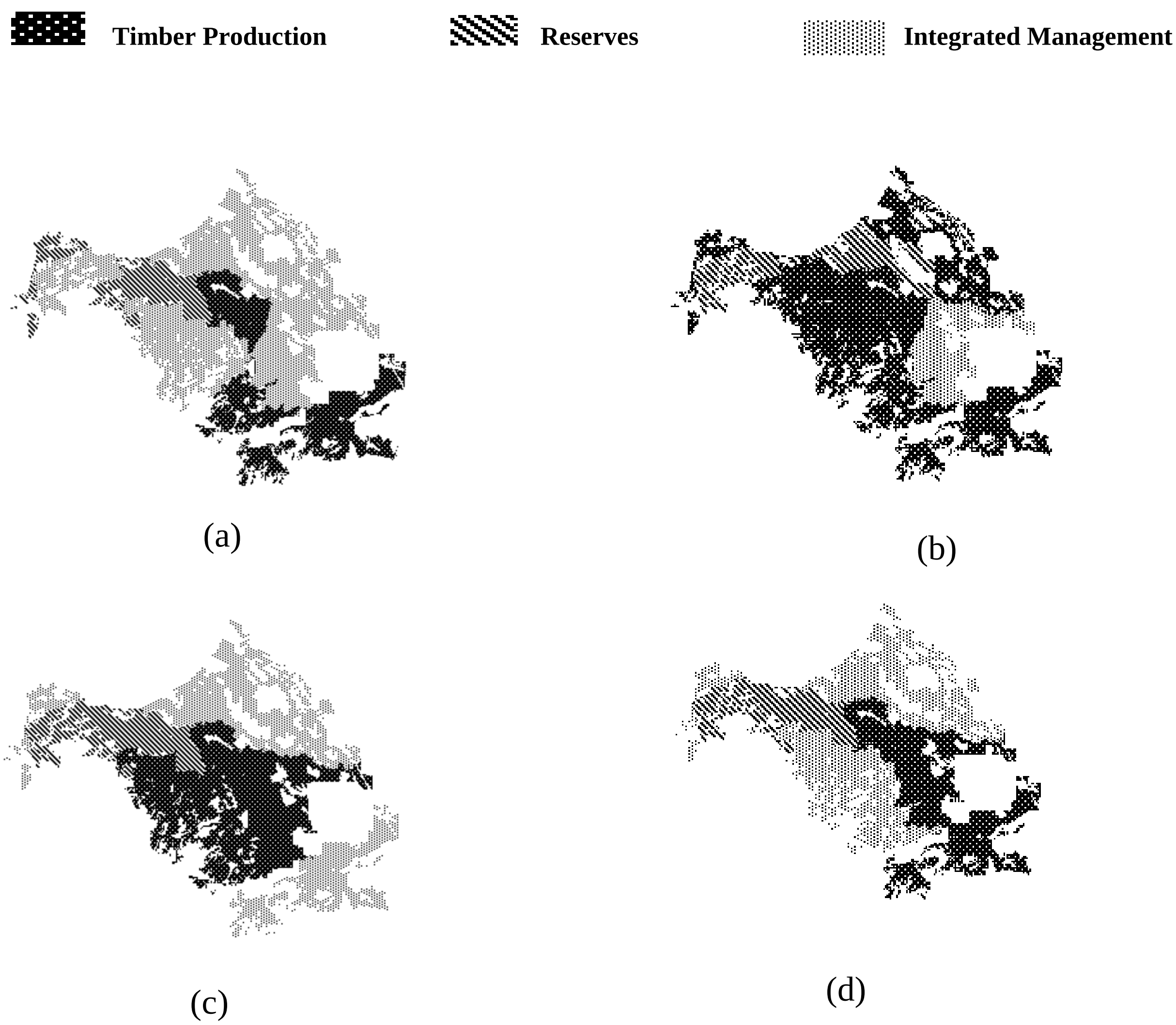

Figure 3: Land allocation under: (a) Triad Medium–Lax scenario; (b) Triad Medium–Moderate Regulation scenario; (c) Triad High–Lax Regulation scenario; and (d) Triad Fast Plantation Medium–Moderate scenario.

Table 5: Projections of the outputs of alternative scenarios

Framework	Ecological Targets	Regulations	NPV (mil. $)	Volume (mil. m^3)	TP (ha)	R (ha)	IM (ha)	Not harvested in IM (ha)
Two–Zone	***Low***	Stringent	***298.980***	***13.550***	***0***	***1124***	***12198***	***2470***
Two–Zone	Medium	Stringent	276.138	13.181	0	1621	11701	2492
Two–Zone	High	Stringent	266.449	13.324	0	2055	11267	3359
Triad	Medium	Moderate	298.980	17.758	9395	1980	1947	855
Triad	Medium	Lax	298.980	17.538	3490	1621	8211	2159
Triad	High	Moderate	NO FEASIBLE SOLUTION					
Triad	High	Lax	298.980	17.309	5819	2055	5448	2083
Triad Fast Plantation	High	Moderate	298.980	17. 892	4873	2055	6394	2350