

Habitat patterns in forested landscapes: management practices and the uncertainty associated with natural disturbances

W. Klenner ^{a,*}, W. Kurz ^b, S. Beukema ^b

^a BC Ministry of Forests, 515 Columbia St., Kamloops, BC, Canada V2C 2T7

^b ESSA Technologies Ltd., Suite 300, 1765 West 8th Ave., Vancouver, BC, Canada V6J 5C6

Abstract

We present the results of a study to examine the effects of management actions and natural disturbances in influencing the evolution of habitat patterns on forested lands. TELSA, a spatially explicit vegetation succession model with the ability to apply user-defined management actions and stochastic wildfires calibrated to local conditions, was used to evaluate changes in several indicators of habitat condition. We assessed seral stage and patch size changes over multiple 200-year simulations under a constant rate of harvest within each of these analyses. In the absence of natural disturbances, old growth habitat and large patches of forest of similar age and tree species composition decreased unless special management practices were applied. Old-growth management area reserves and periodic ‘aggregated cutblock’ harvesting entries helped maintain forest seral stage distribution at the target level, and patch size characteristics similar to the patterns that would have occurred under historic natural disturbances. Adding wildfire to the management scenarios substantially reduced the amount of old-growth habitat in designated old-growth management area reserves, compromising the ability to maintain old-growth at target levels. A 50% increase in the area designated as old-growth management area reserves would be required to offset the loss of old growth due to wildfire. Although the amount of old-growth habitat was diminished by wildfire, the availability of large habitat patches greater than 250 ha increased. We discuss the need to consider the role of management and natural disturbances in landscape planning, and suggest that redundancy is essential to maintain those features vulnerable to stochastic disturbances. Landscape scenario modeling can facilitate the devel-

* Corresponding author. Tel.: +1-250-8284158; fax: +1-250-8284154.

E-mail addresses: walt.klenner@gems7.gov.bc.ca (W. Klenner), wkurz@essa.com (W. Kurz)

opment of risk averse plans, and encourage the development of innovative approaches to achieving timber and non-timber objectives. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Maintaining biological diversity has become an important land management issue internationally and in local jurisdictions (Wilson, 1988; Fenger et al., 1993). In British Columbia, initiatives to maintain biological diversity focus on managing for the diverse habitats across landscapes (British Columbia Forest Service and British Columbia Environment, 1995; Fenger, 1996), using the conditions that would likely evolve in unmanaged landscapes to develop habitat objectives (Hunter, 1993; Bunnell, 1995; DeLong and Tanner, 1996). General guidelines have been established for habitat indicators such as the seral stage distribution, the patch size distribution of cut and leave areas, riparian management practices and the retention of critical habitat structures such as residual live trees, snags, and downed wood in harvested areas (Franklin and Spies, 1991; Franklin et al., 1997). This initiative to maintain habitat complexity and tree species diversity in forests managed for timber commodities is a recognition of the importance of maintaining ecological processes in managed forests and protected areas (Hansen et al., 1991). It also reflects a strategic, ‘coarse filter’ approach to habitat management (Hunter, 1990) that complements other initiatives such as managing for individual species of concern where necessary.

Two concerns about conventional forest management practices, the loss of old-growth habitats and habitat fragmentation, have received much attention in the recent literature (Harris, 1984; Wilcox and Murphy, 1985; Wilcove et al., 1986; Angelstam, 1992; Mladenoff et al., 1993; Spies et al., 1994). Although they can be treated separately, these two issues should also be considered together since large patches (e.g. greater than 200 ha) of old forest are important to some species because of the forest interior conditions these habitats provide (e.g. special microclimate conditions), or the large spatial requirements of some species (Harris, 1984; Shafer, 1990; Angelstam, 1992; Essen et al., 1992). In some areas of the Pacific Northwest (Harris, 1984), there are few remaining stands of old-growth forest that are greater than 150 ha. Spies et al. (1994) report a similar pattern from an analysis of a managed landscape in Oregon. Less than 12% of private lands had patches of coniferous forest with forest interior conditions (i.e. greater than 100 m from adjacent early seral habitat), compared to $\approx 43\%$ on public lands. Much of this difference was attributed to the dispersed cutblock pattern of harvesting, along with higher rates of harvest on many private lands. The only large patches (e.g. > 1000 ha) of contiguous interior forest were found on lands managed as wilderness areas or research natural areas.

The role of forest harvesting rules in determining landscape pattern has drawn attention to the long-term fragmentation consequences of dispersed harvesting

practices (Li et al., 1993; Wallin et al., 1994). Although fragmentation may not be a concern in the early stages of harvesting, by the time an area is $\approx 50\%$ harvested using a dispersed, small cutblock approach with adjacency constraints, it has reached the stage of maximum interspersion of different seral stages (Franklin and Forman, 1987). Landscape simulation models that project current management practices or evaluate alternative planning scenarios have consistently demonstrated that dispersed cutting patterns lead to high levels of fragmentation (Li et al., 1993; Wallin et al., 1994; Gustafson and Crow, 1996; Crow and Gustafson, 1997). The pattern of harvest is not the only concern, high rates of harvest exacerbate landscape fragmentation and diminish the abundance of late seral habitats.

In British Columbia, publicly owned forested lands are being divided into large (20 000–200 000 ha) ‘landscape units’ for which strategic habitat management objectives have been established (British Columbia Forest Service and British Columbia Environment, 1995). Targets for seral stage distribution, the patch-size distribution of cut and leave areas and the retention of old-growth forests across diverse ecosystems are being addressed. This shift towards targets for old growth and acceptable levels of fragmentation is proving to be a challenge to resource managers and planners. The long-term implications of management actions are not always clear, and social or economic impacts must be considered. This difficult task is exacerbated by the interaction between managed disturbances and stochastic natural disturbances for which the probability of occurrence may be well known, but the location and timing remains uncertain. We explore the utility of two management approaches for addressing the seral stage and patch size characteristics of forested habitats: (1) the use of old-growth management area (OGMA) reserves to achieve desired old-growth targets, and (2) the use of aggregated harvesting approaches to reduce fragmentation and maintain a diverse range of patch sizes. We used the TELSA landscape projection model (Klenner et al., 1997; Kurz et al., 2000) to explore the efficacy of several management scenarios in achieving specific habitat targets, and the role of natural disturbances in compromising our ability to achieve planning objectives.

2. Methods

2.1. General description of the TELSA model

The Tool for Exploratory Landscape Scenario Analyses (TELSA) model was used to project current forest characteristics under a range of forest management and natural disturbance scenarios to evaluate the future habitat conditions that would likely develop. TELSA is a spatially explicit model that incorporates a detailed forest succession simulator (VDDT; Beukema and Kurz, 1995), stochastic natural disturbances, user specified management actions and a diverse range of spatial and non-spatial indicators to evaluate landscape scenario projections. A more complete description of the TELSA model is presented in Klenner et al. (1997); Kurz et al. (2000). The model was developed primarily to facilitate the

comparison of landscape management scenarios on forested lands, with common applications focused at areas in the 10 000–200 000 ha range, although smaller or larger areas can be modeled.

Multiple management scenarios, and multiple simulations of the model within a scenario are used to assess the effects of stochastic natural disturbances and user-defined management actions in user-defined combinations. This approach allows both the average response, and the variability within and between scenarios to be examined. TELSA imposes a user-defined set of natural disturbance agents onto the landscape. Only wildfire was considered in the present manuscript, but several defoliators, bark beetles and root disease can also be applied and the consequences of these disturbances on stand structure evaluated. The frequency and extent of wildfire disturbances, and consequences to stand structure and succession were calibrated to local conditions.

2.2. TELSA model conditions

The TELSA model was applied to a 62 966 ha study area in British Columbia known as the Tranquille landscape unit (Fig. 1). Forest characteristics, previous management and natural disturbance history, and current management issues are similar to those found in many areas in south-central BC, and represent the scale at which landscape planning is being addressed in BC. Approximately 74% of the Tranquille landscape unit is forested (46 300 ha) and most of the remainder is classified as open grassland. Over half (26 133 ha) of the forested land is dominated



Fig. 1. Location of the Tranquille landscape unit study area in south-central British Columbia.

by forests that have developed under a disturbance regime characterized by frequent stand maintaining fires (primarily low intensity underburns in ponderosa pine (*Pinus ponderosa*) or Douglas fir (*Pseudotsuga menziesii*) stands). These forests will be referred to as natural disturbance type 4 forests (NDT4, British Columbia Forest Service and British Columbia Environment, 1995). The remainder of the area is dominated by forests that historically have had frequent stand replacing fires (primarily crown fires in lodgepole pine (*P. contorta*), Englemann spruce (*Picea engelmannii*) or subalpine fir (*Abies lasiocarpa*)) and will be referred to as NDT3 habitats.

Stand development, natural disturbance characteristics and the management systems used to simulate landscape scenarios in the Tranquille landscape unit were calibrated by a team of plant ecologists and silviculture researchers familiar with the ecology of the area. For the purposes of the analyses presented here, wildfire was the only natural disturbance agent considered as the effects on seral condition and patch characteristics are clearly defined. The size, probability of ignition, and ecological consequence of wildfires was determined from the long-term historic estimates (British Columbia Forest Service and British Columbia Environment, 1995) and the previous 50 years of wildfire records for the region. Harvesting was not necessarily additive to wildfire. When mature stands burned, TELSA automatically selected acceptable areas (greater than 2.0 ha and > 80 years old as practiced operationally) and salvage harvested these at an efficiency level of 85%. For example, if 100 ha burned in a wildfire, this would contribute 85 ha to the annual harvest target.

Two aspects of landscape planning were examined: (1) the use of defined old-growth management area (OGMA) reserves to achieve a target level of old-growth seral condition within the landscape unit, and (2) the utility of periodically aggregating harvest blocks into large patches to reduce fragmentation and maintain a diverse range of patch sizes.

2.2.1. Efficacy of old-growth management area reserves

We developed scenarios to assess three approaches to managing for a 15% old-growth seral target within the forested landscape unit: (1) no OGMA reserves, with harvesting acceptable across the entire landbase except in non-forested areas; (2) 15% of the landbase designated as no harvesting zones. There were 40 of these zones derived from a draft management plan for the study area, ranging in size from 9.5 to 1000 ha (average of 180 ha) and centered around areas that currently have a high proportion of mature or old-growth forest. (3) 21.5% of the landbase designated as no harvesting zones. There were 47 of these zones, with an extra 6.5% of the landbase reserved from harvesting in addition to the 15% in the above scenario. The reserve zones ranged in size from 9.5 to 1034 ha (average of 217 ha), centered around areas that currently have a high proportion of mature or old-growth forest. Each of these scenarios was projected under three wildfire scenarios: (1) no wildfires, (2) wildfires at 25% of the historic level, and (3) wildfires at 100% of the historic level (Table 1). An additional scenario, historic levels of wildfire without harvesting, was included for comparison. Forests became eligible for

Table 1

Summary of the scenario conditions used to simulate long-term changes in the amount of old growth in the study area

Code	Harvesting	% area as OGMA	Wildfire: % of historic level
0M	Yes	0	0
15M	Yes	15	0
21M	Yes	21.5	0
SF	Yes	0	25
15F	Yes	15	25
21F	Yes	21.5	25
0H	Yes	0	100
15H	Yes	15	100
21H	Yes	21.5	100
H	No	0	100

harvesting when they reached 100 years of age in each of the above nine combinations. We established a 200-m adjacency buffer around harvested openings, and all potential harvest blocks in this zone were not eligible for harvest until the harvested stand reached 3 m in height (17 years).

Three harvesting systems were used: small (5–15 ha) clear cuts in NDT3 and NDT4 forests, medium sized (15–40 ha) clear cuts in NDT3 forests, and partial cut harvesting where 45% of the stand volume was removed with a minimum 45 year re-entry period in NDT4 forests. Following harvest, clear-cut areas began succession at age zero, while the age of partially cut stands was reduced by 45% at each entry. Maximum annual harvest levels of 370 ha of clear cutting and 250 ha of partial cutting were established. All forests became eligible for harvesting when they reached 100 years of age. Four Monte Carlo simulations were conducted for all scenarios that involved wildfire, and mean values for the four simulations are presented. Management only scenarios are deterministic and showed little spatial variability between runs.

2.2.2. Aggregated harvesting and patch size objectives

We developed simulations to harvest timber using either a conventional dispersed cutblock system or a dispersed cutblock system with periodic aggregated entries. In the dispersed cutblock system, 15–40 ha clear-cuts were applied across the entire study area, with a 400-m adjacency constraint. All forests became eligible for harvesting when they reached 100 years of age. A network of 72 potential aggregated harvesting areas ranging in size from 242 to 1435 ha was established over the study area. When an aggregated area was selected, all forested habitat greater than 80 years old was harvested with the intent of creating one large opening. Aggregated harvest areas were implemented at 2-, 5- and 20-year intervals to determine the implementation frequency necessary to maintain current patch size patterns (Table 2). Succession and wildfire necessitated an evaluation and ranking of each of the 72 candidate areas at each implementation period. Three approaches

to choosing the aggregate harvest area were evaluated with respect to maintaining the current patch size distribution in the study area: (1) the aggregate area was chosen at random from the 72 available; (2) the area containing the greatest proportion of area as large patches (greater than 80 ha) of mature or old-growth forest; or (3) the most fragmented area, based on the highest proportion of the area as patches less than 40 ha.

We developed three additional scenarios for comparison: (1) an historic wildfire scenario with no harvesting and calibrated to the estimated frequency and size distribution of historic wildfires in NDT3 and NDT4 forests (H), (2) a conventional dispersed harvesting scenario that used 15–40 ha clear cuts with adjacency constraints, aggregated harvesting every 5 years, and wildfires that had the same size distribution as determined from historic patterns but which burned $\approx 25\%$ of the area as in the historic wildfire scenario (5F), and (3) a conventional dispersed harvesting scenario that used 15–40 ha clear cuts and no wildfire (D). A target maximum annual harvest level of 500 ha was established and four Monte Carlo simulations were conducted on those scenarios that involved natural disturbances.

2.3. Indicators

We used simple indicators of landscape condition for two reasons. (1) We wanted the current simulations to reflect the implementation of current policy guidelines (British Columbia Forest Service and British Columbia Environment, 1995; Fenger, 1996) which use seral stage, patch size, old-growth representation and stand structure as habitat management targets. (2) The relationship between most spatial statistics and the ecology of individual species or ecosystems is not clear. For example, Schumaker (1996) found that most spatial indicators were only weakly correlated with the results of a simulation model of animal dispersal. There has been little field testing of the correlation between spatial statistics and ecological processes in complex and dynamic forested environments.

Table 2

Summary of the scenario conditions used to simulate long-term changes in the patch size distribution in the study area

Code	Aggregated frequency	Harvesting type ^a	Dispersed harvesting	Wildfire, % of historic level
2Y	2	Fragmented	Y	0
5Y	5	Fragmented	Y	0
20Y	20	Fragmented	Y	0
5R	5	Random	Y	0
5L	5	Largest	Y	0
H	0	N/A	N	100
5F	5	Fragmented	Y	25
D	0	N/A	Y	0

^a Fragmented, most fragmented area chosen; largest, area with the greatest proportion of large patches chosen; random, area chosen at random.

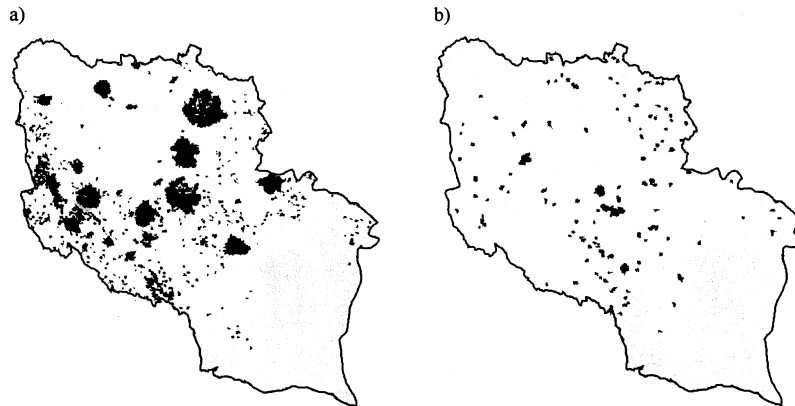


Fig. 2. Spatial differences in the occurrence of wildfires (black areas) over a 10-year period (years 50–60) in two Monte Carlo simulations with wildfires calibrated to 100% of historic levels. The largest wildfire is ≈ 1000 ha. Gray areas represent non-forest habitat (lakes, marshes and grasslands).

We used four categories to classify the seral condition of habitats: early, young, mature and old growth. In NDT3 forest types, the respective age categories were 0–40, 41–100, 101–140 and > 140 years. In NDT4 forest types, the respective age categories were 0–40, 41–100, 101–250 and > 250 years.

For determining the patch size of the habitats within the study area, we used a combination of seral stage and leading species in the forest inventory label to determine a patch. For example, two adjacent forest polygons classified separately in the landbase inventory (one age 15, the other age 27) and which are both characterized as lodgepole pine leading would be combined as one seral stage-leading species patch. However, two adjacent forest polygons of the same age but with different leading species (e.g. lodgepole pine in one and Douglas fir in the other) would remain as two separate patches. This approach is not an absolute measure of patch size, but an index used to evaluate current conditions and to assess changes over time.

3. Results

Within a specific scenario, natural disturbances (wildfires) created high levels of spatial variability between Monte Carlo simulations (Fig. 2). The total area affected by wildfire during the 200-year projection was identical between simulations, but the spatial and temporal patterns for a specific year were highly variable. The very different conditions that developed, and the uncertainty associated with the development of these spatial patterns, present a challenge to planners who seek to maintain target levels of an indicator, or to control the long-term spatial dynamics of the landscape.

3.1. *Old-growth management area reserves and old-growth objectives*

The ability to maintain a 15% target level of old-growth forest in the study area is a function of initial habitat conditions, assumptions about future wildfire conditions, and the amount of area reserved from harvest. There was an abundance of mature seral forest in NDT3 habitats in the study area, stemming from a period of high wildfire activity about 100 years ago. A large amount of mature habitat will be recruited into old-growth in the near future (Fig. 3a), and the 15% target was easily exceeded in all the scenarios we evaluated. In contrast, NDT4 habitats (Fig. 4a) currently exhibit a shortage of old-growth and this continues for ≈ 100 years, again regardless of the management scenario we imposed. Under an historic wildfire regime and no harvesting, an average level of 30% old growth is established in NDT3 habitats by year 125, while in NDT4, the levels continue to increase until a peak is reached in year 150 (27%). The current condition of the landscape, in combination with the difference in age when old growth is achieved (141 years for NDT3, 251 years for NDT4) plays an important role in determining the long-term dynamics of old-growth forest over time. In NDT3, 14.9, 20.2, 48.9 and 16.0% of the study area is currently in the early, young, mature and old-growth categories, whereas in NDT4, the proportions are 6.9, 11.9, 78.0 and 3.2%, respectively.

In both NDT3 and NDT4 habitats, less than half of the 15% old-growth target developed outside of the OGMA reserves, illustrating the need for special management areas to maintain old forest habitat. Following the recruitment phase (Fig. 3b, Fig. 4b), only about 7 and 4% of the area outside of the OGMA develops into old growth in NDT3 and NDT4 forest, respectively. This old growth occurs primarily in small slivers between treatment areas, and on potential cutblocks that are prevented from being harvested by adjacency constraints surrounding recently harvested areas. The proportion of old growth in the study area contributed by OGMA reserves increases as expected for both NDT3 and NDT4 habitats for the two scenarios without natural disturbances (Fig. 3c, Fig. 4c). However, when wildfire is incorporated into the management scenario at 25% of historic average levels, 25–30% of the OGMA is maintained in an earlier seral condition. A 50% increase in the area designated as OGMA (from 15 to 21.5%) is necessary if the 15% old-growth target in the study area is to be derived solely from the OGMA's. In landscapes where most of the landbase is available for harvest, adjacency constraints are minimal, or where inoperable land does not support suitable old-growth forest, OGMA's will likely be the only source of old-growth forest. If wildfires in the study were to increase to historic levels (for example, as a consequence of short or long-term climate change), even a 50% increase in the area being maintained as OGMA's (21.5%) does not achieve the desired 15% old-growth target. An example of the patterns of old-growth forest that develop under the above management scenarios is illustrated in Fig. 5.

The loss of old growth from OGMA's due to wildfire, and the limited potential for recruiting old growth from outside the OGMA's (Fig. 3b, Fig. 4b) indicates maintaining old growth solely on the limited OGMA landbase is a risk-prone strategy. Furthermore, since harvesting targets stands as they reach the early

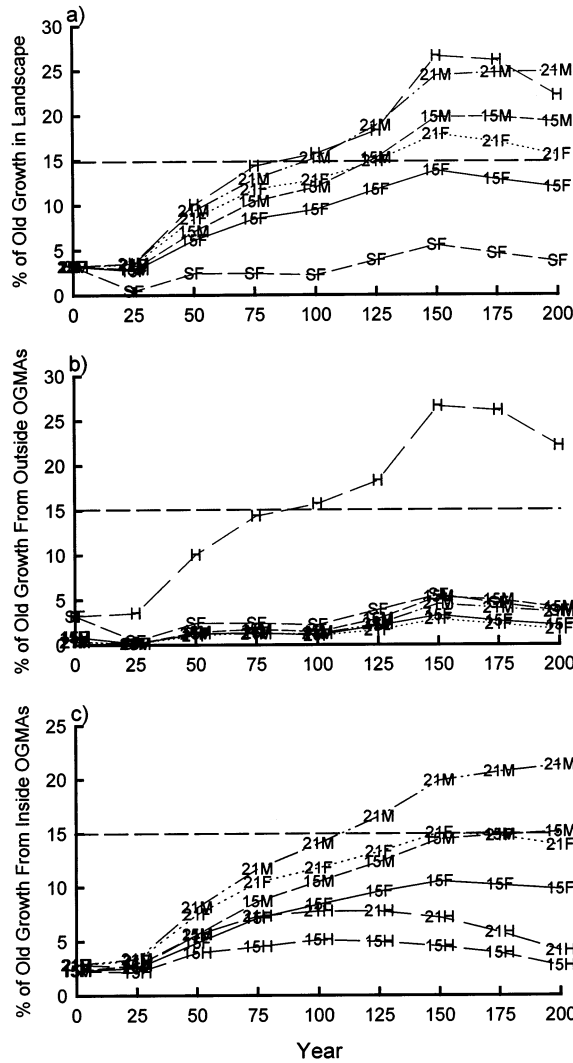


Fig. 4. Changes in the amount of old-growth forest in NDT4 habitat in the Tranquille landscape unit, (a) % of old growth in the landscape unit, (b) % of old growth in the landscape unit from outside old-growth management areas, and (c) % of old growth in the landscape unit from inside old-growth management areas. Symbols as indicated in Table 1.

3.2. Aggregated harvesting and patch size objectives

We examined changes in the patch size distribution of early, young, mature and old-growth forests in NDT3 and NDT4 habitats in relation to the patterns created by historic wildfires and five other management scenarios (Table 2): (1) conventional dispersed cutblock harvesting with adjacency constraints (D), (2) aggregated

harvesting entries applied every 2 years (2Y), (3) aggregated harvesting entries applied every 5 years (5Y), (4) aggregated harvesting entries applied every 20 years (20Y), and (5) aggregated harvesting entries applied every 5 years combined with wildfire at 25% of historic levels (5F).

After 200 years, the amount of area represented by small (0–80 ha) patches in NDT3 habitat was twice as high under the dispersed cutblock harvesting system as in the historic fire scenario (Fig. 6). A similar pattern developed in NDT4 habitat (Fig. 7), but the difference between the historic scenario and the other management systems was not as great because of the greater frequency of small fires in NDT4 habitats. Aggregated harvesting every 2 years led to a marked decrease in the proportion of small openings in relation to the pattern created by historic fires.

A more significant feature of these scenarios is the marked reduction in area represented by large patches (251–1000 ha) under dispersed cutblock harvesting by year 125, and the complete loss of very large habitat patches (> 1000 ha) in NDT3 habitats in all but the historic fire and aggregated harvest at two year interval scenarios (Fig. 6c and d). A similar pattern develops in NDT4 habitats (Fig. 7c and d). Applying aggregated harvesting at 2-year intervals in NDT4 habitats leads to a

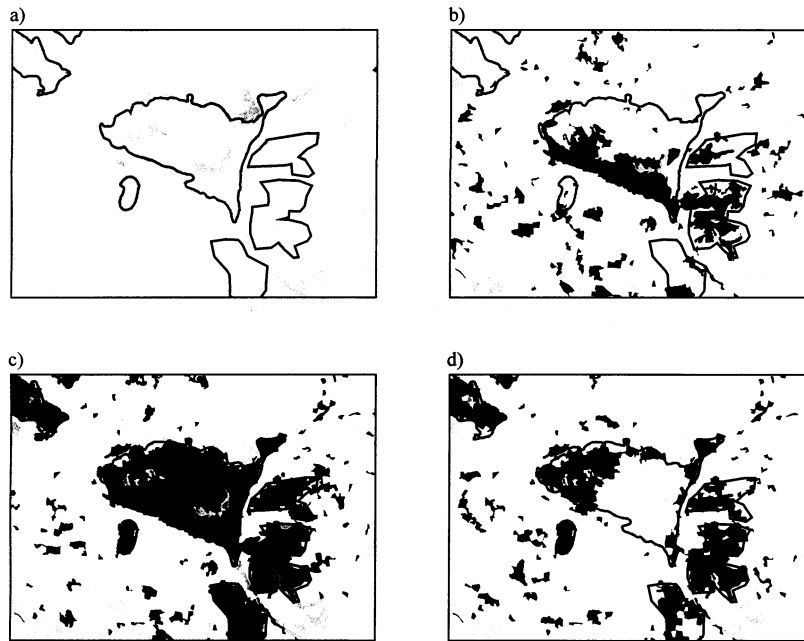


Fig. 5. The distribution of old-growth forest in a representative old-growth management area in relation to management scenario. Dark areas represent old-growth forest, white areas are early, young or mature forest and gray areas non-forest habitat. (a) OGMA boundaries. The large OGMA in the center is ≈ 1000 ha. (b) The cumulative effects of harvesting and wildfire at year 150, OGMA not in effect, outline provided for reference only, scenario F (Table 1). (c) Year 150 conditions with OGMA in effect and no wildfires, scenario 15M, (d) year 150 conditions with OGMA in effect and wildfires at 25% of historic levels, scenario 15F.

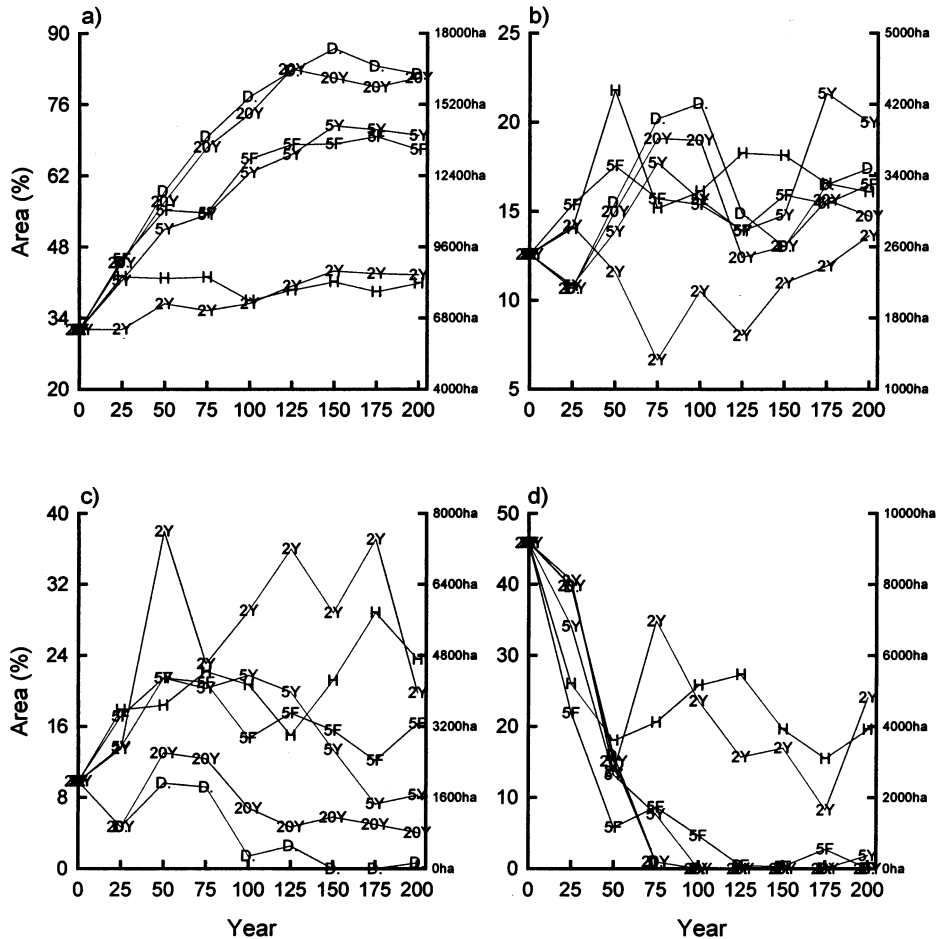


Fig. 6. The effect of conventional and aggregated harvesting strategies on patch size distribution in NDT3 habitat. (a) Patches 0–80 ha, (b) 81–250 ha, (c) 251–1000 ha, (d) > 1000 ha. Symbols as indicated in Table 2.

strong increase in the area in very large patches over the patterns created by historic fires. These scenarios illustrate two principles: (1) the need for implementing alternatives to conventional dispersed cutblock harvesting if a diverse range of patch sizes is to be maintained over time, and (2) habitat conditions will likely differ between forest types with different historic disturbances and ecological characteristics (e.g. NDT3 vs. NDT4), and hence, specific management strategies need to be developed for each.

Management strategies to achieve patch size objectives should not be considered in isolation of other habitat management objectives. Although the aggregated cutblock at 2-year intervals scenario clearly illustrates how this approach can help maintain large habitat patches, this success does not come without a cost. This

strategy has the least restrictive adjacency constraints and results in the development of a high proportion of early seral and young forest, and the near elimination of old-growth habitat (Figs. 8 and 9).

3.3. Aggregated harvesting approaches

To determine whether certain approaches to developing aggregated harvesting areas were more effective at maintaining a component of large and very large habitat patches in the landscape, we standardized the frequency of aggregated harvesting at once every 5 years and used three different criteria for selecting the aggregated area from the 72 available. Choosing the most fragmented area to

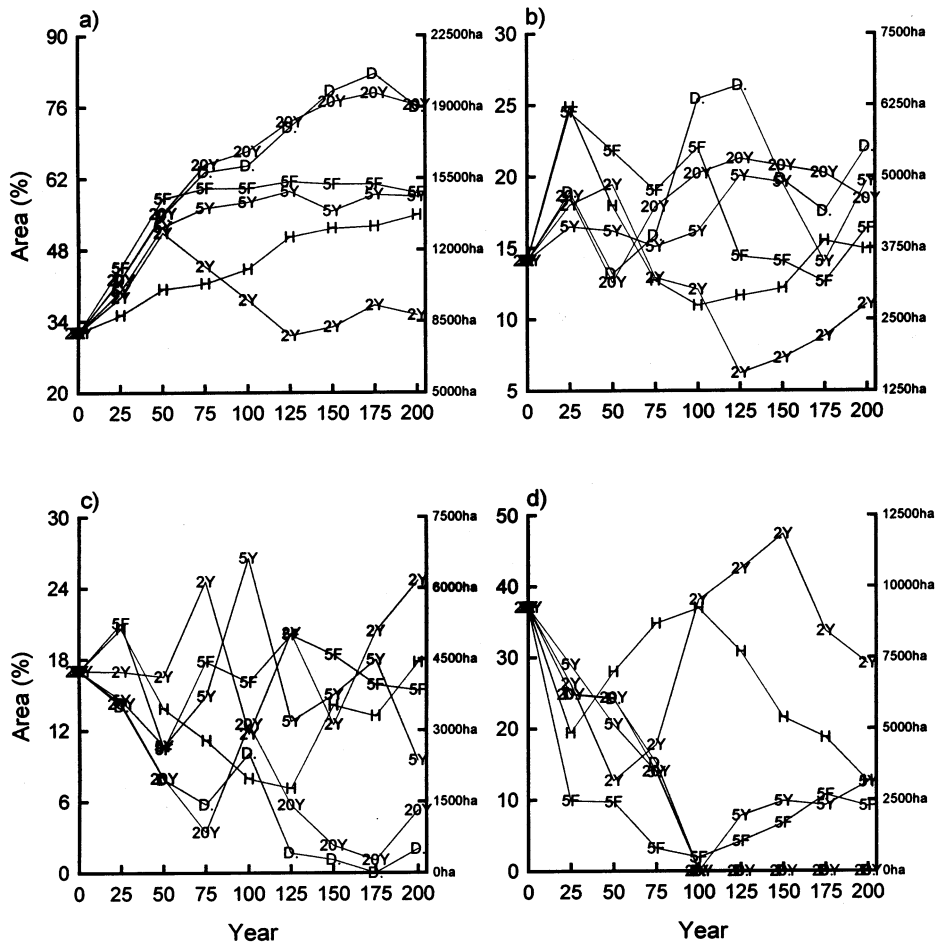


Fig. 7. The effect of conventional and aggregated harvesting strategies on patch size distribution in NDT4 habitat. (a) Patches 0–80 ha, (b) 81–250 ha, (c) 251–1000 ha, (d) >1000 ha. Symbols as indicated in Table 2.

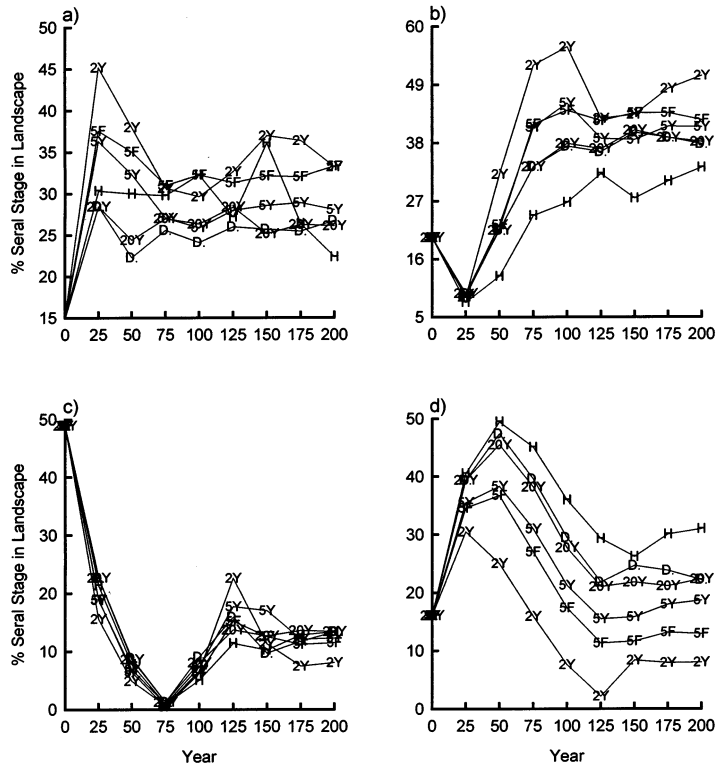


Fig. 8. Seral stage distribution associated with alternative harvesting strategies in NDT3 habitats. (a) Early seral, 0–40 years, (b) young forest, 41–80 years, (c) mature forest, 81–140 years, (d) old-growth forest, > 140 years. Symbols as indicated in Table 2.

harvest did not appear to have any clear advantages with respect to creating large or very large patches of habitat in either NDT3 or NDT4 habitat. Simply choosing the aggregate harvest areas at random from the 72 available, or choosing the ones with the highest proportion of mature or old-growth forest in large patches appeared to be equally effective at maintaining the amount of habitat in large or very large patches at levels approaching the pattern created by the historic wildfires.

4. Discussion

The scenario analyses we conducted illustrate the need for developing special resource management zones to maintain critical habitats such as old-growth forest, and modified harvesting approaches to reduce habitat fragmentation. The inclusion of wildfire in our simulations demonstrates the uncertainty associated with natural disturbances. Robust management approaches are required to diminish the likelihood that desired objectives are not entirely compromised by chance events. As

noted by Agee (1997), “the catastrophic fire that may be unexpected and unmanageable is an event for which few managers plan. They hope that it will not occur on their watch of the resource”. Yet these unexpected and unmanageable wildfires do occur and will likely continue to occur. In our simulations, historic levels of wildfire affected on average 525 ha per year, but annual variability was high. Even though we assumed that fire suppression in managed forests is somewhat effective in diminishing both the number and size of wildfires (e.g. to 25% of historic levels), high fire years in which over 1000 ha burned within the study area still occurred.

Managing for desired landscape objectives will require some level of redundancy in management actions in the event a catastrophic disturbance reduces or eliminates opportunities for maintaining specific values. This principle is illustrated in Fig. 5, and occurred in 1998 in a landscape unit adjacent to the Tranquille study area where a large wildfire (3500 ha) burned a large old-growth management area reserve. Landscape analysis and planning approaches (e.g. Diaz and Apostol, 1992; Diaz and Bell, 1997) need to consider the inevitable natural disturbances that will occur over long time periods, and develop contingencies. Too great a reliance on

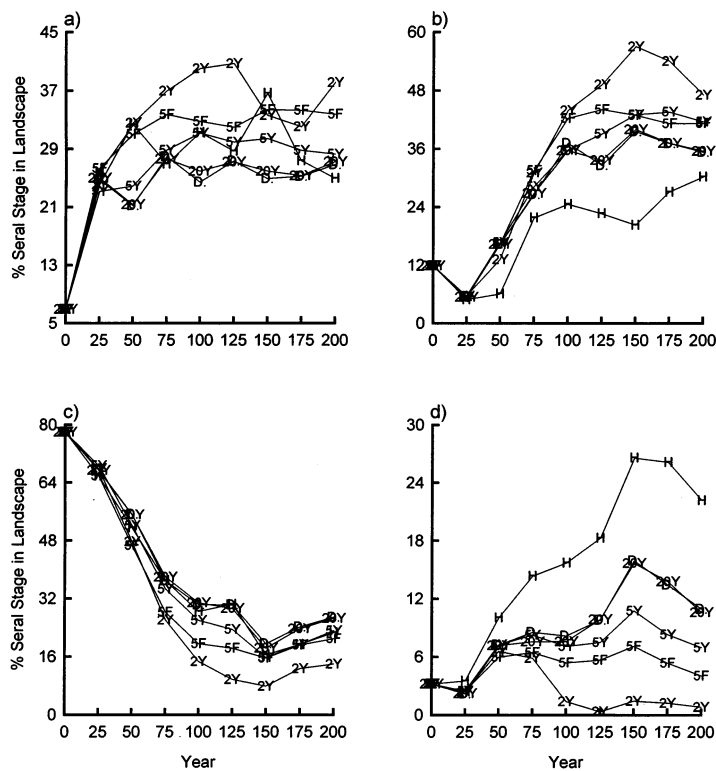


Fig. 9. Seral stage distribution associated with alternative harvesting strategies in NDT4 habitats. (a) Early seral, 0–40 years, (b) young forest, 41–100 years, (c) mature forest, 101–250 years, (d) old-growth forest, >250 years. Symbols as indicated in Table 2.

maintaining a specific feature may at best be highly uncertain, or at worst, detrimental to planning for long-term objectives as it creates a false sense of security about the future landscape condition.

Landscape scenario tools such as TELSA (e.g. Hansen et al., 1993; Crow and Gustafson, 1997; McCarter et al., 1998), when used in concert with landscape analysis and design approaches (Diaz and Apostol, 1992; Diaz and Bell, 1997) or watershed planning (Sessions et al., 1997) can play an important role in exploring options for dealing with uncertainty. Multiple scenario projections to assess the efficacy of different plans for achieving targets can then be translated into planning scenarios where a full complement of forest values is evaluated. In the case of the Tranquille landscape unit, the loss of old-growth forests in OGMA's due to wildfires is compounded by the lack of old-growth recruitment potential from the non-OGMA landbase. However, redundancies in landscape planning, such as setting aside greater amounts of OGMA reserves than required at the time of implementation (e.g. establishing 21.5% of the landscape as OGMA vs. the 15% target) to anticipate the future loss of old-growth forest to natural disturbances, also reduced the amount of timber that could be harvested. Where such impacts on timber supply are unacceptable, special management practices such as implementing extended rotation zones (Curtis, 1997) may provide opportunities for maintaining some old-growth characteristics in the stand. A review of the seral stage distribution in the planning area, and a realistic appraisal of natural disturbance patterns in managed forests can help determine the likelihood of a shortfall over time.

Forest harvesting with small cutblocks has been criticized because of the high levels of fragmentation associated with this approach (Harris, 1984; Franklin and Forman, 1987). Li et al. (1993), Wallin et al. (1994), Gustafson and Crow (1996), Crow and Gustafson (1997) have clearly demonstrated that larger cutblocks, or harvesting in constrained zones without adjacent leave strips can help reduce the level of fragmentation caused by harvesting. We have extended this concept and assessed the frequency that aggregated harvest entries need to be initiated to approximate the patterns expected from historic levels of wildfire. The study area we choose for our simulations has been harvested for ≈ 30 years, primarily around several 'nodes' of more concentrated activity. This pattern facilitated maintaining a diverse range of patch sizes using periodic aggregated harvest areas since a high proportion of the landscape consisted of very large patches (i.e. 45% of the landbase in patches > 1000 ha). Had the study area been more fragmented with widely dispersed cutblocks (Wallin et al., 1994), aggregated harvesting would have been less successful at maintaining large patches but would have helped reestablish large patches in recently fragmented areas.

We found that aggregated harvest blocks (ranging in size from 300 to 1400 ha) implemented every 2–5 years should maintain a diverse range of patch sizes in the landscape. The frequency and size of aggregated harvesting entries will need to be reconciled with broader resource objectives (e.g. water resources, visual impacts, recreation, etc.), implemented on a landscape or habitat specific basis, and revisited periodically to evaluate the landscape condition in light of the cumulative effects of harvesting and natural disturbances. Our simulations showed that more frequent

aggregated harvesting entries (e.g. up to 50% of the harvesting) may be desirable in NDT3 habitats that historically had frequent large wildfires, but this may not be suitable in NDT4 habitats that historically had a greater proportion of small disturbances.

There did not appear to be any long-term advantages to choosing aggregated harvest areas on the basis of their current level of fragmentation. For the patch size indicator we used, the random choice, ‘mopping-up’ fragmented areas, or choosing large patches of forest were equally efficient approaches to maintaining large areas of mature or old forest. We did not explicitly track information on the amount or dispersion of roads in the present study, but this indicator may help distinguish between the above approaches. Roads and access management are important habitat management issues (Mader, 1984; McLellan and Shackleton, 1992) that need to be considered in landscape planning. Dispersed cutblocks require an extensive and permanent network of roads to access timber on an ongoing basis. Roads can have negative impacts on some species by presenting barriers to dispersing organisms, forming corridors along which invading organisms (e.g. weeds) enter an ecosystem, increasing the incidence of human-caused fires, and facilitating excessive legal hunting pressure and/or poaching by providing access (Thomas et al., 1976; Mader, 1984; McLellan and Shackleton, 1992; Thurber et al., 1994). From the perspective of maintaining large patches of habitat and diminishing roads and access, aggregated harvesting entries should be planned around areas that currently have a high level of roads before new areas are developed.

As landscape projection models that quantify the future condition of landscapes in relation to management scenarios (Hansen et al., 1993; Mladenoff et al., 1993; Wallin et al., 1994; Sessions et al., 1997; McCarter et al., 1998) become more widely used, the information from conceptual or applied exercises will help facilitate landscape planning. Landscape analysis and design approaches (Diaz and Apostol, 1992; Diaz and Bell, 1997) can use the principles generated by modeling to develop realistic plans, and simulation models can in turn be used to test the long-term implications and tradeoffs among alternative strategies. In this context, landscape models can facilitate the exploration of innovative solutions to resource conflicts, assisting in the development of long-term adaptive management installations (Walters and Holling, 1990) to examine alternatives.

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