Assessment of harvest blocks generated from operational polygons and forest-cover polygons in tactical and strategic planning

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Abstract: Manually designing harvest units for strategic planning is expensive. This paper compares blocking methods based on forest-cover polygons and manually designed harvest units. Routines are used to split and aggregate polygons into three block size distributions: (*i*) uniform 40-ha blocks; (*ii*) uniform 120-ha blocks; and (*iii*) by area, one-third 20 ha, one-third 60 ha, and one-third 150 ha. Three harvest rules that influence adjacency and the cutting of polygons within a block are applied to each block size distribution to compare forecasts generated by forest-cover and operational blocks. Generally, volume flows from the two methods deviate by less than 5%, and the highest deviations usually occur during the first 20 years. Projected landscape structure, as measured by interior forest area, is also similar under the two blocking methods. The results indicate that forest-cover data provide a reasonable alternative to manual blocking in tactical and strategic plans. This is significant because it removes an important barrier to timely and cost-effective planning, especially for large geographic problems where manual blocking is not an option.

Résumé : La délimitation manuelle des unités de coupe est une opération coûteuse de la phase de planification. Cet article compare les résultats obtenus via une compartimentation des superficies à récolter qui s'appuie sur les polygones liés aux couverts forestiers avec ceux obtenus en délimitant manuellement les unités à récolter. Des routines informatiques sont utilisées pour séparer et agréger les polygones selon trois répartitions : (*i*) des blocs uniformes de 40 ha; (*ii*) des blocs uniformes de 120 ha; et (*iii*) par superficie, un tiers 20 ha, un tiers 60 ha, et un tiers 150 ha. Trois règles de récolte influençant la contiguïté et la coupe des polygones situés à l'intérieur d'un bloc sont appliquées à chacune des répartitions afin de comparer les prévisions générées par chacune des méthodes de compartimentation. De façon générale, les volumes obtenus diffèrent de moins de 5%, et l'écart le plus important se produit habituellement au cours des 20 premières années. La structure anticipée des paysages, telle que mesurée par la superficie forestière intérieure, est similaire pour les deux méthodes de compartimentation. Les résultats indiquent que les données du couvert forestier fournissent une alternative acceptable à la compartimentation manuelle lors de la planification stratégique et de la planification tactique. Ce résultat est significatif puisqu'il élimine une barrière importante à une planification efficace et économique, spécialement pour les situations impliquant de grandes superficies géographiques pour lesquelles la compartimentation manuelle n'est pas envisageable.

[Traduit par la Rédaction]

Introduction

For large-scale planning problems (50 000 – 1 000 000 ha forecasted over 20+ periods), the most significant barrier to timely timber supply and landscape structure analysis is the preparation of spatial data. Designing and digitally recording potential harvest units is time consuming and expensive, plus it is quite inflexible for sensitivity analysis related to opening size and patch size distributions. In British Columbia, this is a significant problem for the provincial Forest Service that is responsible for strategic timber supply planning on approximately 50×10^6 ha of productive forest land. This includes 37 large timber-supply areas that must be analyzed every 5 years. The geographic scale is so large that the task of manually designing harvest units is prohibitive in terms of meeting the 5-year planning cycle. Computer-generated harvest units from forest-cover polygons is an alternative, but little work has been done to compare harvest and landscape structure forecasts using the two methods. This paper investigates the use of manual and computer-generated harvest units for tactical and strategic planning.

To better understand the choices available for creating harvest units, it is useful to place them in the context of a planning hierarchy. Temporal and spatial scales along with policy, objectives, and uncertainty are used to define each level of the hierarchy (Gunn 1991). Operational plans usually cover 1–3 years for watersheds and contain detailed objectives and constraints. Tactical plans generally have 20- to 30-year planning horizons and are applied with less operational detail at the landscape unit scale. Strategic plans cover long time horizons and are applied to the entire forest estate to explore uncertainty and set policy. These are generic definitions that can easily change, depending on ownership objectives, policy, and the nature of the forest.

At the operational level, where decisions are actually implemented, we must be confident that the harvest units are correctly engineered, meet short-term market demands, sat-

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isfy current policy, and are accessible. These harvest units are always manually designed, because the need for accuracy and detail cannot be confidently captured from maps and aerial photographs or be computer modelled (certainly in mountainous terrain). At the tactical level, harvest units can be manually planned from maps and aerial photographs, or they can be generated with computer models that attempt to capture fundamental design principles such as operability, opening size, and matching timber types. It is rare when these planned harvest units, regardless of the design method, match the operationally engineered units used in the actual harvest. Differences can be traced to changes in objectives, policy, logging systems, and additional field constraints that are introduced over time. However, foresters still have a greater comfort level when using manually designed harvest units, probably because the exercise forces an improved understanding of the timber harvesting land base.

The manual design approach (using maps, photos, and ground checks) has been applied to timber supply areas covering over 1×10^6 ha (Rouck and Nelson 1995; Nelson and Price 1997). Allocating this much effort to a strategic problem with so much uncertainty is rightly questioned. At the strategic level, we want to be able to quickly block areas to reflect changes in objectives, policy, and knowledge of ecosystems. The problem is not to refine block-building algorithms until they ultimately generate operational blocks, since this is an unachievable goal. Rather, the problem is to determine what is the minimum spatial detail necessary to meet the objectives of the strategic plan.

The need for spatial resolution in strategic forest planning is well documented. The most common reasons relate to opening size and adjacency rules (Gross and Dykstra 1988; O'Hara et al. 1989), operational feasibility of harvest schedules (Sessions and Sessions 1991; Merzenich 1991), tracking landscape structure (Franklin and Forman 1987; Wallin et al. 1994; Gustafson and Crow 1996; Baskent and Jordan 1996), and forecasting habitat (Mealey et al. 1982; Hof and Joyce 1992). While true optimization of large problems remains elusive, substantial advances in computing technology and scheduling heuristics have led us to the point where algorithms and computing resources are not limiting factors. Many approaches to the harvest blocking and scheduling problem have been used. These range from time-step simulation models that use predetermined harvest units (Nelson and Finn 1991) to dynamic programming that simultaneously builds and schedules blocks for individual stands (Hoganson and Borges 1998). Included are heuristic models that use simulated annealing and tabu search to simultaneously build and schedule blocks from either individual stands (Lockwood and Moore 1993; Dahlin and Sallnas 1993), or predetermined harvest units (Murray and Church 1995; Boston and Bettinger 1999; Kong 1999). The effect of land classification systems on nonspatial model results was investigated by Jamnick et al. (1990). An analysis of management unit design and adjacency constraints on spatial indicators and timber revenues is found in Borges and Hoganson (1999). While many scheduling algorithms and blocking methods have been described in the literature, there remains a void in documenting how model results are affected by the choice of blocks constructed from forest-cover polygons and those constructed from harvest units.

The purpose of this paper is to determine if computer-generated harvest blocks formed from spatial forest-cover data can be used for timely and relevant decision making at the tactical and strategic levels. The blocking and modelling method must capture trends and inform us if the forecast is within acceptable tolerances for harvest flows and landscape structure. It must also provide strategic targets to guide more detailed operational planning. The specific objectives of this paper are, firstly, to investigate how well blocks generated from forest cover can forecast harvest flows and interior forest area relative to operationally designed blocks and, secondly, to identify fast and inexpensive ways to generate computer-designed blocks from forest cover.

Using a case study, long-term harvest forecasts are made using blocks generated from forest-cover polygons and blocks generated from operational harvest units. Simulations are made with the ATLAS/FPS model (Nelson 1999) and include combinations of opening size, adjacency rules, and rules for cutting polygons within the blocks. The methodology is described in the first section. This includes a description of the study site, spatial data sets, derivation of resultant polygons, the block building routine, and model simulations. In the second section, results of the simulations are presented for the combinations of opening size, adjacency rules, and rules for cutting polygons within the block. This includes a discussion of results for harvest volume and landscape structure. Finally, conclusions are drawn and recommendations made for further research in this field.

Methodology

The methodology is presented in four sections: (*i*) description of the study site, (*ii*) methods for generating resultant polygons, (*iii*) description of the block-building procedure, and (*iv*) description of the model runs.

An outline of the methodology is shown in Fig. 1.

Figure 1 outlines the overlay of forest cover and harvest units to form resultant polygons (left) and the splitting of forest-cover polygons (right). Resultant and split polygons are then aggregated into three block sizes, which are used in the harvest simulations.

Description of the study site

Landscape unit 26 in the Golden Timber Supply Area is used as a case study. The total area of the study site is 23 926 ha. Of this, 20 558 ha are considered productive and accessible forest land. Landscape unit 26 forest was chosen, because it has complex patterns already established on the landscape that present some challenging harvest scheduling and landscape modification problems. The age-class pattern of the existing inventory is shown in Fig. 2, which demonstrates a history of harvesting and fire disturbance. The large patch on the bottom right originated from fire, the large patch on the bottom left originated from progressive clear-cutting, and the younger, smaller openings show the decreasing opening-size policy implemented over the past 20 years. A number of the inoperable polygons are very young, either because of natural disturbances or poor classification of these noncommercial forests. The remainder of the forest is 250+ years old.

The forest-cover map (1166 polygons) and the manually designed harvest units (2271 "operational" polygons) are shown in Figs. 3 and 4, respectively. The B.C. Ministry of Forests interpreted forest cover from 1 : 15 000 aerial photographs (1997) and the polygons are plotted on 1 : 20 000 maps. Forest-cover polygons are defined by tree species (19), age-class (1–9), height class (1–8), and stocking class (1–4). The operational polygons were prepared

Fig. 1. Overview of the procedure used to generate harvest blocks used in the simulations. The number of polygons or blocks is shown in parentheses.

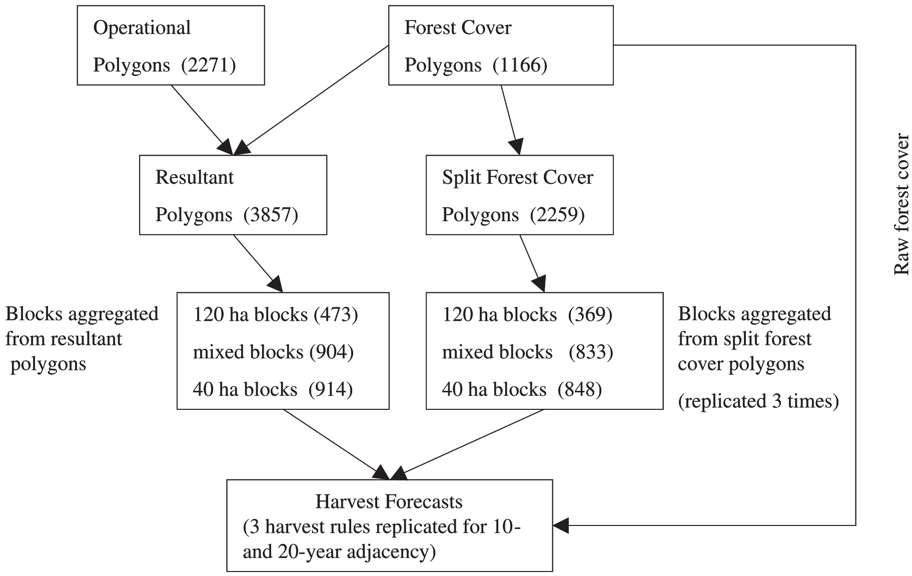
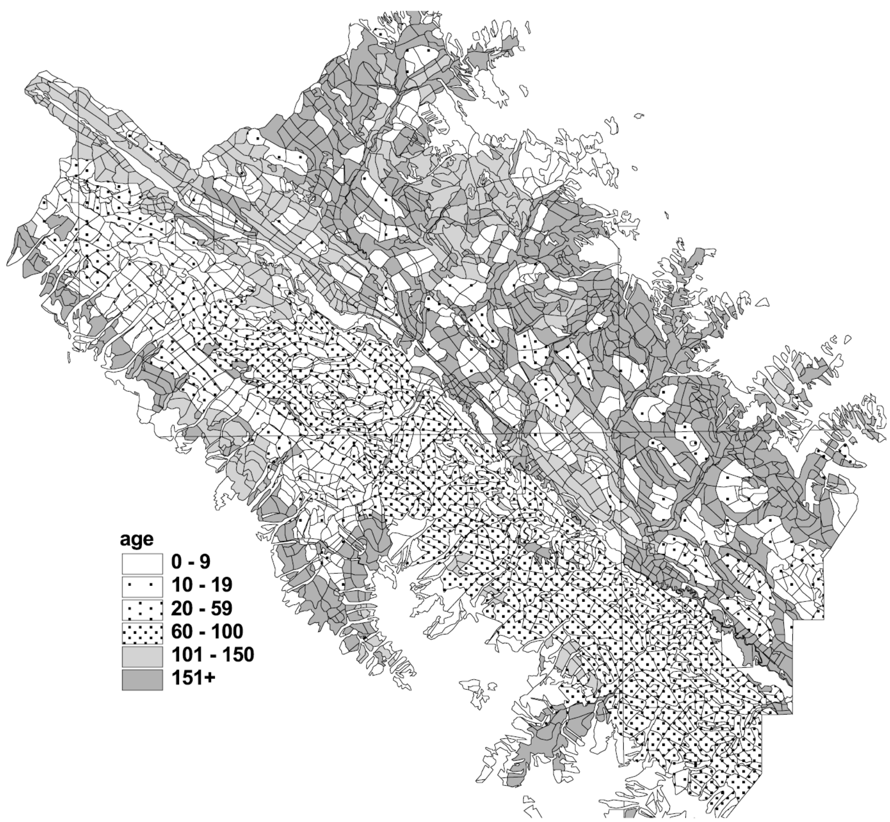


Fig. 2. Age-class distribution of the resultant polygons. Lightly shaded areas are young stands and darker areas are older stands. Complex patterns have resulted from natural disturbance and evolving harvest regulation that favours small openings.



as part of an earlier planning project, and took one person 1 month to complete. These polygons were derived from aerial photographs, topography maps, forest-cover maps, and field checks by a qualified forester. This project also included projecting road access and prescribing a logging system (ground-based, cable, aerial) for each polygon. The operational polygons are relatively small, and represent the area that can be harvested from one landing. The objective was to design small, feasible harvest polygons that, when necessary, can be aggregated into larger blocks.

Generation of resultant polygons

The forest-cover polygons and the operational polygons differ because of the additional design criteria used in generating the operational polygons. To ensure that the original operational polygons

Fig. 3. Forest-cover polygons (1166).

contain the same forest-cover data (type, area, age, etc.) as the forest-cover polygons, these layers were combined through a geographic information system (GIS) overlay to form resultant polygons. The resultant polygons ensure that the original forest cover is correctly represented in the operational units. Sliver polygons less than 0.01 ha were removed by merging them with their largest neighbour. A sample of the resultant polygons (3857 polygons following sliver removal) is shown in the upper panel of Fig. 5.

Splitting forest-cover polygons

When forest-cover polygons are larger than the minimum block size, they need to be split into smaller units. In addition to violating block size objectives, these large polygons can also create harvest scheduling problems by exceeding periodic timber flow targets and (or) creating unnecessary adjacency conflicts. Our objective was to use a simple polygon-splitting routine to ensure that all polygons are less than or equal to the minimum block size specified in the harvest simulations. More eloborate splitting procedures, including Voronoi tessellation, are described in Barrett (1997). We used a multiple-pass splitting routine as described below.

(1) Specify the maximum and minimum polygon size to direct the splitting. For example, if the maximum size is 40 ha, and the minimum size is 2 ha, a 41-ha polygon will not be split into a 40-ha and a 1-ha polygon.
(2) Specify the number of polygon vertices that will be considered as starting or terminal points for arcs that split the polygon. Since large polygons may have several thousand vertices (nodes), it is important to limit the search to a reasonable subset of these.
(3) Calculate the polygon topology of the map.
(4) Create a list of all polygons that need to be split.
(5) Select a polygon to be split from the list.
(6) Generate an arc between every candidate node. Any arc that passes outside the polygon (similar to the test for convex hulls) is rejected as a candidate.
(7) From the candidate arcs, find the minimum arc length such that the area ratio of the resultant polygons is within a specified tolerance. This controls the splitting so that the new polygons will be approximately equal in size and that the edge between them is minimized. The new arc is then populated with additional vertices that can be used in subsequent splits, should that be necessary.
(8) Assign the attributes of the parent polygon to the newly created polygons.
(9) Return to step 5 until all polygons have been processed.
(10) Return to step 3 until all polygons are within the maximum polygon size.

Island polygons (polygons fully contained within another polygon) are common in forest-cover data, so it was necessary to modify the above procedure. Step 6 was modified so that those arcs that crossed an island polygon were not discarded. If one of these arcs proved to have the minimum arc length, it would be accepted as the splitting arc, and two new vertices were added at the intersection points of the island polygon and the splitting arc. The new polygon boundaries then follow the island polygon boundary between these intersection points. This procedure splits the outer polygon and preserves integrity of the inner polygon, which is no longer an island polygon.

Both forest-cover and resultant polygons often contain long, narrow polygons that are difficult to incorporate into blocks and cause adjacency problems, because they have many neighbours. These polygons are often small and, therefore, do not get split during the splitting routine. To identify these long, narrow units, we

Fig. 4. Operational harvest polygons (2271).

use a “sinuosity” index that is calculated as the ratio of the polygon area to the area of a standard circle determined by the widest diameter of the polygon. Once identified, these polygons are then split using the previously described routine, with the exception that maximum and minimum polygon sizes are not applicable.

In the case study, the maximum and minimum forest-cover polygon size was set at 20 and 2 ha, respectively. Approximately 260 of the 1166 forest-cover polygons were split to meet the 20-ha maximum size, including four polygons greater than 400 ha, and one over 850 ha. A sample of split forest-cover polygons is shown in the bottom of Fig. 5.

Block-building procedure

The block-building routine aggregates polygons into harvest blocks. First, the area is randomly seeded and the blocks grow around the seeds until opening-size objectives are met. Polygons with the greatest common edge are selected first to keep the block clustered and to prevent the formation of long, narrow blocks. When building block distributions (i.e., 20, 60, and 150 ha), large blocks are built first, since these are difficult to construct once other blocks are present. Inoperable polygons were not included in the blocks. Age and site qualities were not used to screen polygons during the construction of the blocks, resulting in young and old polygons within the same block. Age differences within the blocks are addressed in the harvest scheduling stage. The intent was to keep the block-building routine simple and fast. When forming forest-cover blocks, split forest-cover polygons were aggregated. When operational blocks were formed, aggregation was based on the original operational polygons; however, this was subsequently linked back to the resultant polygons to ensure consistency with the original forest cover. On completion, the operational blocks contain resultant polygons that are consistent with the operational polygon aggregation process and the forest-cover data.

The three block sizes built from the harvest polygons and split forest-cover polygons are summarized in Table 1. When used in a harvest-scheduling model, the operational blocks are assumed to represent a feasible harvest forecast against which corresponding projections from forest-cover blocks are compared. To test the sensitivity of the block-building procedure on these comparisons, the block sizes were replicated three times for the split forest-cover polygons (using different random seeds).

Examples of mixed blocks generated from operational and split forest-cover polygons are shown in Fig. 5.

Description of the harvest simulations

The ATLAS/FPS model was used to simulate harvests over a 235-year planning horizon using 10-year planning periods. This is a time step, spatially explicit harvest simulation model. The strategy was to maximize short-term harvests subject to a maximum 10% decline per period and not to allow the harvest to drop below the long-term sustained yield. Increases in the harvest flow were not restricted. Clear-cutting was the only silviculture system modelled. Polygons were assigned growth and yield curves based on the forest cover, resulting in 14 inventory types with minimum rotation ages ranging from 80 to 120 years.

Combinations of block size and harvest rules were designed to explore how well the forest-cover blocks approximate forecasts made with the operational blocks. The three harvest rules are summarized in Table 2. The “hard” rule enforces adjacency and requires that all polygons within the block be at their respective minimum harvest age before the block can be cut. Under this rule, all polygons within the block are cut simultaneously. This is a very restrictive rule in terms of timber supply; however, it is the fastest way to convert the landscape to the prescribed block pattern. The "adjacency" rule only enforces adjacency around the block perimeter. If adjacency is satisfied, then all polygons within the block that have reached the minimum harvest age are cut. The remaining polygons are cut in subsequent periods when they reach the minimum harvest age, provided there are no adjacency conflicts around the block boundary. The adjacency rule does not meet the blocking distribution exactly, but it is less restrictive on timber supply than the hard rule. The third simulation category is labeled "priority," because the harvest follows a nonadjacent block pattern. The blocks are sorted into approximately five or six groups, such that the blocks within each group are not adjacent (i.e., similar to chromatic numbering described in Nelson et al. (1993)). These groups are then used to set harvest priorities. Harvest units in each priority are not adjacent to each other, so while harvesting within a priority, no adjacent units can be cut. Some adjacency violations may occur just as one priority is exhausted and the next priority starts; however, these are minor. Green-up ages tend to be satisfied through other constraints, such as periodic harvest flow targets and seral stage targets. The priority method has almost no effect on timber supply, because there are no spatial constraints and it can deviate from the block distribution. A seral stage constraint was applied to all simulations to retain a minimum level of older stands in the forest. The three harvest rules represent options that range from strict adherence to the blocking distribution to compromises between timber production and landscape pattern.

As shown in Table 2, the hard and adjacency rules were run with 10- and 20-year adjacency constraints.

For each run, harvest and interior forest area were reported. Interior forest is an indicator of landscape pattern, especially fragmentation. Interior forest is defined as being 150+ years of age and not within 100 m of stands aged 0–20 years. Growing stock was also monitored, but since it added little insight over the harvest schedules, it is not reported here.

The adjacency and priority harvest rules were also applied the "raw" forest cover to check how well the original forest-cover polygons estimate timber supply and landscape structure. In this case, each polygon is a block, so the hard rule and the adjacency rule are redundant; hence, only the adjacency rule is reported for raw forest cover.

Fig. 5. The top figure shows resultant polygons (3857) formed from the GIS overlay and subsequently aggregated into operational blocks. The bottom figure shows split forest-cover polygons (2259) that have been aggregated into blocks. Bold lines are the block boundaries.

Results and discussion

Harvest volume

Harvest schedules generated under 10- and 20-year adjacency constraints are shown in Figs. 6A–6F and Figs. 6J–6O, respectively. Harvest schedules generated under the priority rules are shown in Figs. 6G–6I. The forest-cover volumes in Fig. 6 are the average values for the three runs created when different random block building seeds were used. These harvest schedules are compared by calculating the percent difference between using forest-cover blocks and using operational blocks for each harvest rule – block size combination in Fig. 7 (10-year adjacency) and Fig. 8 (20-year adjacency). The percent difference is calculated using

$$[1] \qquad \%\ \text{difference} = \frac{(\text{forest cover block volume} - \text{operational block volume})}{\text{operational block volume}} \times 100\%$$

Because the priority runs do not have an adjacency constraint, they are shown only in Fig. 7. The summaries in Figs. 7 and 8 are calculated for short (0–55 years), medium (56–105 years), and long term (106–235 years). The columns show the difference between the operational blocks and the average of the three forest-cover runs. The error bars show the range of differences observed over the three forest-cover runs. The first general observation from Fig. 6 is that the forest-cover blocks capture the same trends as the simulations that use the operational blocks. Exceptions occur in the raw forest-cover runs, where the harvest of large polygons create volume spikes (Figs. 6E and 6H). Because the raw forest cover has a range of polygon sizes, it is compared with the mixed-block runs, rather than the uniform 40- and 120-ha blocks. The second general observation from Figs. 7 and 8 is that the forest-cover blocks generally produce more volume than the operational blocks, especially in the short term. The reason appears to be the more complex spatial topology of the resultant polygons contained in the operational blocks. A comparison of the split forest-cover polygons to the

Table 1. Block distributions built from resultant polygons and split forest-cover polygons.

Block distribution	Description	Resultant polygons (no. of blocks)	Split forest-cover polygons (no. of blocks)
120 ha	All blocks built to a target size of 120 ha	473	Average 369 (394, 352, 362)
Mix	By area, one-third 20 ha, one-third 60 ha, and one-third 150 ha	904	Average 833 (847, 847, 806)
40 ha	All blocks built to a target size of 40 ha	914	Average 848 (814, 828, 903)

Note: Block distributions for split forest cover were replicated three times using different random seeds.

Table 2. Rules and priorities applied to harvest simulations.

Harvest rule	Adjacency (all neighbours within 75 m)	Minimum harvest age applied to every polygon within a block	Seral stage constraint	First harvest priority	Second harvest priority
Hard	10 and 20 years	Yes	14% ≥ 141 years	Oldest first	Closest to mill
Adjacency	10 and 20 years	No	14% ≥ 141 years	Oldest first	Closest to mill
Priority	na*	No	14% ≥ 141 years	Nonadjacent pattern	Oldest first

*na, not applicable.

resultant polygons shows that the average number of adjacent neighbours per polygon was 6.21 and 7.77, respectively. Furthermore, the percentage of polygons exceeding a four-colour topology (more than four polygons sharing a node) was 16 and 67% for the split forest cover and the resultant polygons, respectively. Adjacency conflicts are most evident in the short term and tend to diminish over the long-term, which is consistent with the results shown in Figs. 7 and 8.

Focusing on specifics in Figs. 7 and 8, it is apparent that the raw forest cover runs mostly produce more volume in the short to medium term, but at the expense of the long term. This is mostly caused by cutting large polygons, but it is also influenced by the less complex spatial topology of the raw forest-cover data. Under 10-year adjacency, the short-term raw forest-cover runs exceed the operational block runs by 9% (Fig. 7). When adjacency is increased to 20 years, the greatest increase in the raw cover runs is observed in the medium term (Fig. 8). With the exception of the adjacency 120 and hard 120 combinations (the range bars for 0–55 years in Figs. 7 and 8), the remaining differences are less than or equal to 5%. The highest difference observed is 10% in the short term for the adjacency 120 and hard 120 combinations. The reason is that these large operational blocks contain more polygons than the corresponding forest-cover blocks. The design of the operational polygons included more criteria than just forest cover, so the overlay created small adjacent polygons of different ages. This results in more adjacency conflicts and more scheduling delays caused by polygons that are below the minimum harvest age.

There is a notable difference for the period 1 harvests in Fig. 6D, and there is no simple explanation for this. It appears that the blocks constructed from the resultant polygons contained an unfortunate mix of adjacency problems and mixed age-classes that limit initial harvests more than the blocks constructed from forest-cover polygons. As the adjacency constraint increases to 20 years (Fig. 6M) or the restrictions on cutting polygons within a block increase (Fig. 6A), initial harvests for the two blocking methods converge.

With the exception of the adjacency raw cover run (Fig. 8), the medium- and long-term differences for all runs are relatively small, ranging from –4 to 4%, with most falling within 3%. These lower differences are expected as the harvest pattern becomes established on the landscape and spatial constraints become less restrictive.

Figure 6 also illustrates the impacts of block size and harvest rule on timber supply. Generally, the greatest impacts are observed in the short term for large blocks under strict harvest rules (i.e., hard 120 with 20-year adjacency; Fig. 6J). The priority rule has the least impact on timber supply, and it is insensitive to block size.

Interior forest area

Interior forest areas generated under 10- and 20-year adjacency constraints are shown in Figs. 9A–9F and Figs. 9J–9O, respectively. Interior forest areas generated under the priority rules are shown in Figs. 9G–9I. The areas for forest cover in Fig. 9 are the average values for the three runs created when different random block-building seeds were used. These interior forest areas are compared by calculating the percent difference between using forest-cover blocks and using operational blocks for each time period using

$$[2] \qquad \%\ \text{difference} = \frac{(\text{forest cover block interior area} - \text{operational block interior area})}{\text{operational block interior area}} \times 100\%$$

In Fig. 9, the common pattern across all runs is that interior forest area increases for several decades, then declines until around year 70 when a large patch of forest reaches 150 years of age. Beyond 70 years, the decline continues until a large increase occurs around year 150. This large increase is really an artifact of the way that reserves and inoperable stands were classified in the beginning inventory. These stands were assigned an age of zero, so when they reach 150 years, they abruptly become classed as interior forest. If the reserves and inoperable stands are excluded,

Fig. 6. Harvest schedules generated under 10-year adjacency constraints (A–F), 20-year adjacency constraints (J–O), and the priority rules (G–I). The forest-cover volumes are the average values for the three runs created from different random block-building seeds.

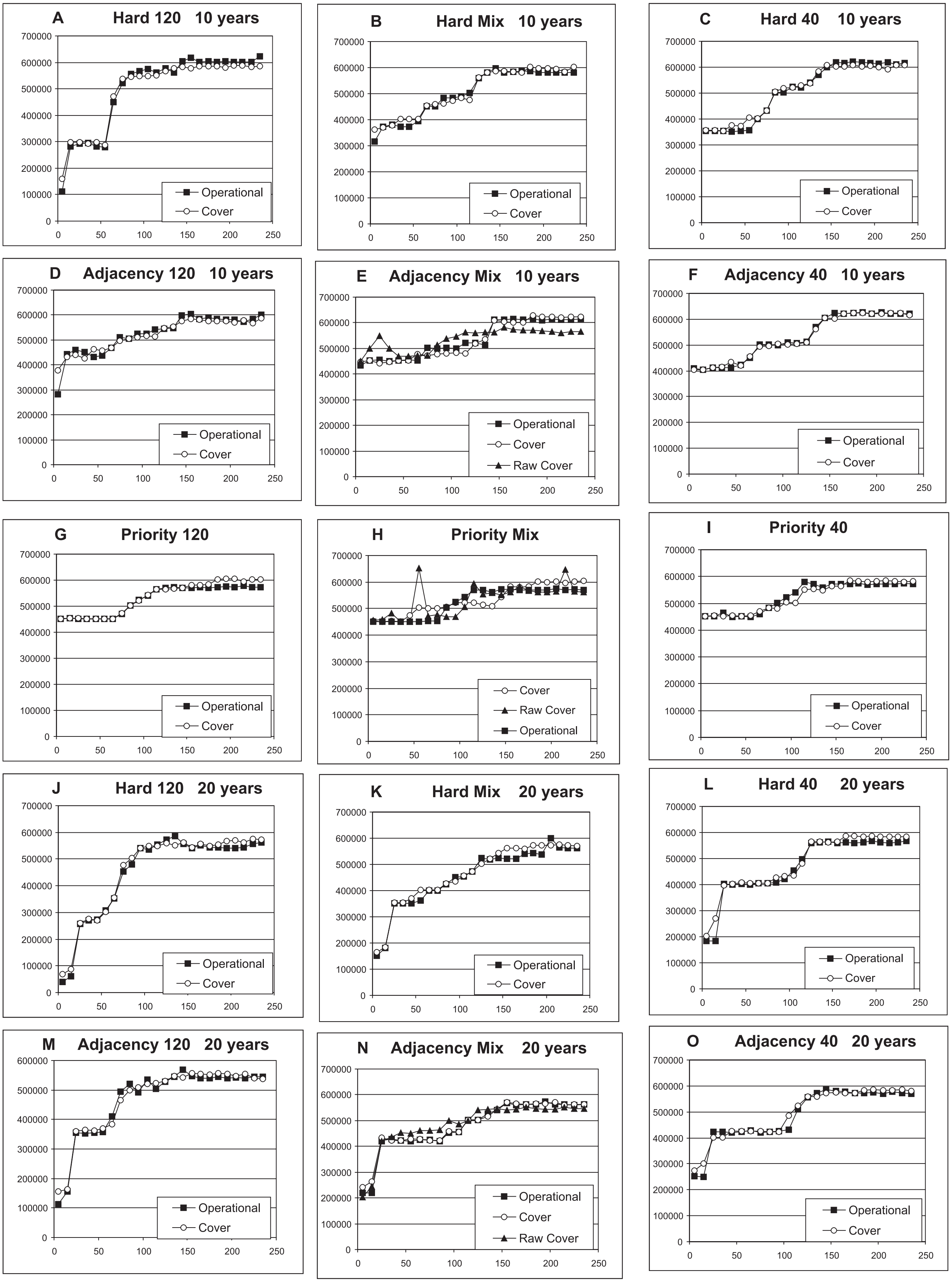


Fig. 7. Percent volume differences of forest-cover blocks relative to operational blocks for the short term (0–55 years), medium term (56–105 years), and long term (106–235 years). Results are for the harvest rules with 10-year adjacency. The columns show the difference between the operational blocks and the average of the three forest-cover runs. The error bars show the range of differences observed over the three forest-cover runs.

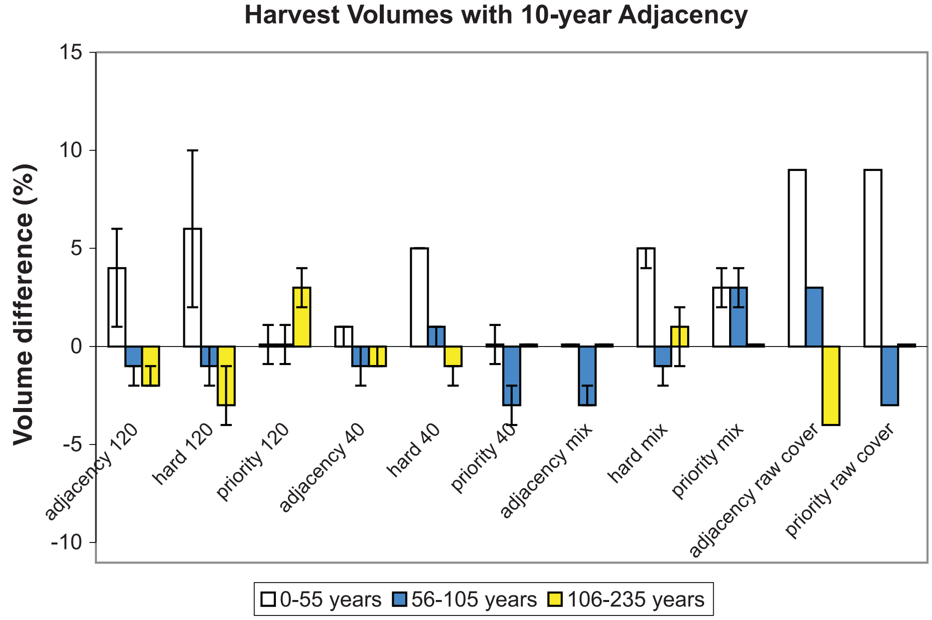
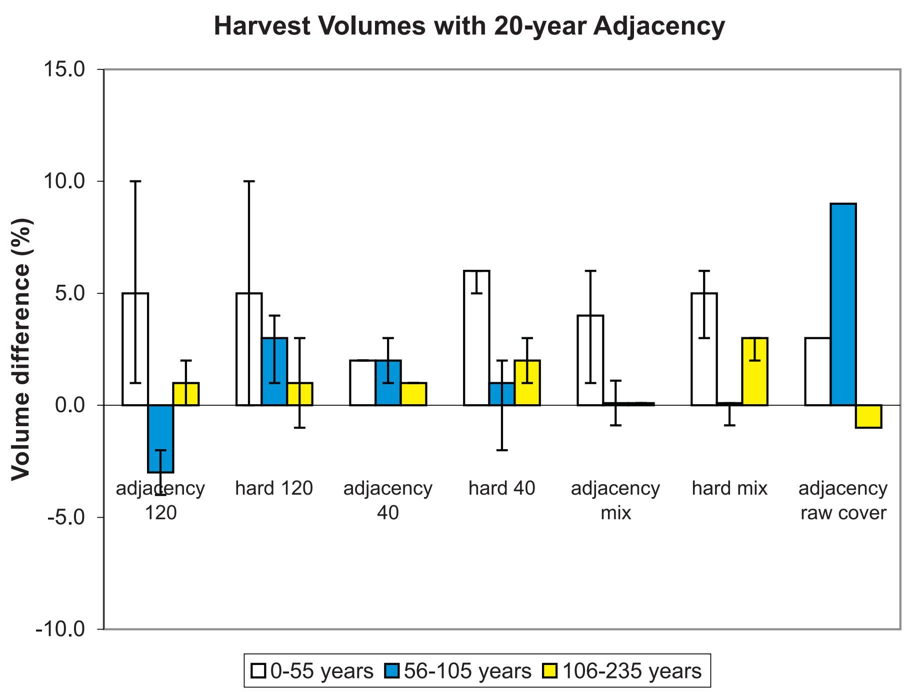


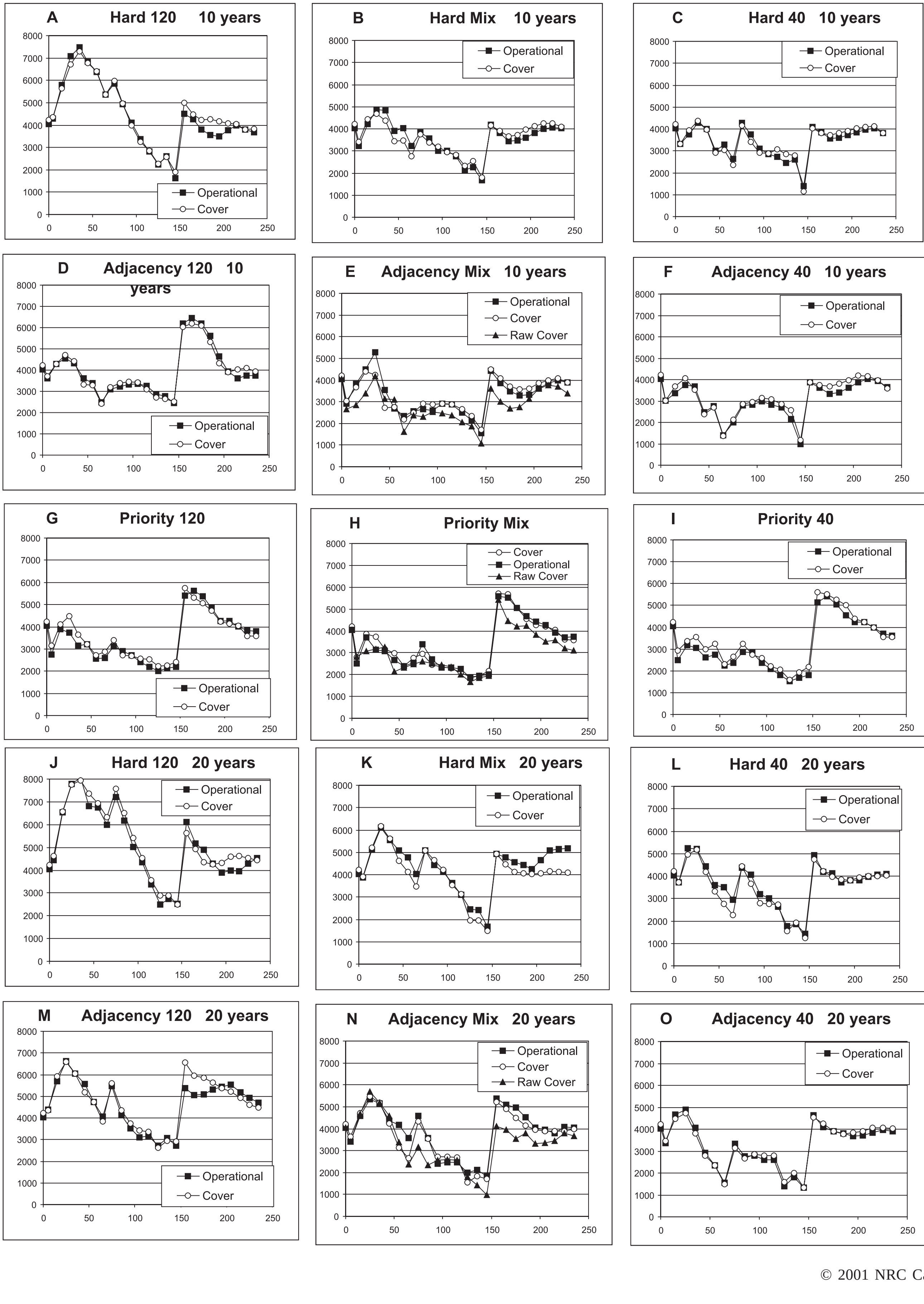
Fig. 8. Percent volume differences of forest-cover blocks relative to operational blocks for the short term (0–55 years), medium term (56–105 years), and long term (106–235 years). Results are for the harvest rules with 20-year adjacency. The columns show the difference between the operational blocks and the average of the three forest-cover runs. The error bars show the range of differences observed over the three forest-cover runs.



the interior forest area eventually levels off near the end of the planning horizon.

A general observation from Fig. 9 is that the blocks derived from forest cover capture the same trends in interior forest area as the blocks derived from the operational units. These would be sufficient for identifying times when interior forest area is reaching critical levels and how the harvest rules and opening-size combinations affect the amount and timing of interior forest area. While the trends are adequately captured, there are some notable variances in the periodic values. The raw forest-cover runs (Figs. 9E, 9H, and 9N) have less interior forest area, and these can be correlated with the higher harvest levels that were observed in the corresponding harvest schedules (Figs. 6E, 6H, and 6N).

Fig. 9. Interior forest area generated under 10-year adjacency constraints (A–F), 20-year adjacency constraints (J–O), and the priority rules (G–I). The forest-cover interior areas are the average values for the three runs created from different random block building seeds.



Discrepancies also occur in the hard 40 and adjacency mix combinations at year 60 (Figs. 9L and 9N). In the long-term, deviations after 150 years are observed in the hard 120 (Fig. 9A), the adjacency 120 (Fig. 9M), and the hard mix (Fig. 9K) combinations.

Most percent differences of interior area are within 5–10%. Overall, 87% of the periodic differences are within 10% for runs with the 10-year adjacency constraint, and 76% meet this criterion for the 20-year adjacency constraint. In some cases, differences reach 25–30%, and a number of these occur when the interior forest area is small (around years 130–150), so small deviations result in relatively large percentage differences.

Similar to the harvest schedules, Fig. 9 indicates the relative impacts of the block size and harvest rule combinations on interior forest area. Large blocks with strict harvest rules that have low harvests in the early periods have correspondingly high interior forest areas (Figs. 9A and 9J). The least restrictive rule, priority, has the lowest levels of interior forest area and is insensitive to block size.

Processing time

The original forest cover contained 1166 polygons, of which 260 required splitting to bring the maximum size to 20 ha. On completion, the split forest cover contained 2259 polygons. This required approximately 5 h of processing time on a 200-Mhz Pentium I computer. Processing time is dependent on the number of polygons that require splitting, plus the number of vertices per polygon. Block building was relatively fast, ranging from 2 to 5 min on the same computer. The average time to simulate a harvest schedule and determine interior forest area was under 1 min.

The beginning inventory of the forest is important, especially when we attempt to alter this structure with opening size and other harvest rules. The landscape unit used in this study has a difficult beginning inventory for many of the simulations, and the projected transitions to a steady-state forest are consistent between the two blocking methods. On a cautionary note, most of the blocking and simulations in this study were replicated after setting all polygon ages to 250 years, which delayed all spatial constraints until near the end of the planning horizon. The result was almost no variation in the forecasts for harvest volumes and interior forest areas, regardless of the harvest rule and block size. A short-term analysis based on such a simple beginning inventory could be quite misleading.

Conclusions

This paper illustrates how relatively simple spatial data can be used in tactical and strategic forest planning. Blocks created from forest-cover polygons produced similar timber supply and landscape structure results as blocks created from manually designed harvest units. Building blocks from resultant polygons and split forest cover is much cheaper and faster than manually designing blocks. Block size can be quickly changed, which is an important policy consideration at the tactical and strategic level. This is significant for large-scale planning problems where the cost and time to manually generate spatial harvest units is prohibitive. Manipulating forest-cover polygons into blocks is also an effective means for timely sensitivity analysis of harvest rules and opening size in smaller planning units, as demonstrated in this paper. Other landscape indicators such as patch size distribution and contagion could be included to further assess the performance of the forest-cover blocks relative to the operational blocks.

The block-building routine is quite primitive, and it is likely that algorithms that incorporate operational factors, such as timber type, age, and terrain will produce more consistent schedules than those observed here, especially in the short term. The splitting and blocking method is highly dependent on clean and concise digital data. Polygon line work needs to be vector clean, and polygons should not contain excessive vertices. Weeding of stream digitized data will greatly improve performance with little loss of detail.

Further research in this field should concentrate on four areas. First, polygon splitting is still computationally intensive, so efforts to streamline this process are needed. Second, an investigation of the gains versus the effort for more comprehensive block-building routines should be initiated. Third, a more complete set of landscape indicators should be identified and included in the assessment of the blocking method. Finally, a comprehensive monitoring study is needed to identify how closely our plans match actual harvests and to clearly identify the reasons why we deviated from these plans.

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