It exhibits, however, the typical lack of a strong link and absence of a feedback loop between strategic and operations considerations. The New Brunswick Crown Forest Licensees used the process to develop their 1987 management plans. As part of the process, the FORMAN (Wang et al., 1987) wood supply model assisted in developing harvest schedules. Change in the process for 1992 will occur since Licensees will have access to improved versions of the FORMAN model: FORMAN+1 (Vanguard, 1991) and GISFORMAN (Baskent, 1990).

A shortcoming of FORMAN, FORMAN+1, and other aspatial wood supply models, is that they lack the capability to spatially allocate, i.e. map, the schedules produced. Aspatial models use forest aggregates or classes (hectares of common development type), as opposed to stand level information, to first, forecast development of the forest, and second, determine a sustainable harvest level. The aspatial harvest schedules that Licensees created in 1987 using FORMAN, required “translation” into stand-by-stand schedules. Staff at the Department of Natural Resources and Energy (DNR) completed this task for Licensees by using the Department’s GIS to break out stands comprising forest aggregates (Erdle and Frame, 1991). The result was a series of harvest schedule maps showing the 5-year harvest period for each stand targeted for harvest. The scheduled stands were then manually grouped by the Licensees to form operational harvest blocks, primarily on the basis of economics (proximity to existing road networks and mills), but also in an attempt to minimize mortality losses and maximize volume harvested. Unfortunately, accurate harvest volume statistics associated with the manually blocked harvest schedule were not produced. Determination of harvest level was by visual inspection and approximation. That is, an estimate was made of the percentage contribution of each harvest block to the block’s total harvest volume. This process was required for every block laid out for a license a labourious and inaccurate process. Due to the time involved, investigation of alternative blocking patterns was not possible.

A recent development in GIS-based, or spatial, wood supply modelling has created an opportunity to improve the management planning process in New Brunswick. The GISFORMAN model takes a GIS-based forest inventory, forecasts development of the forest over time, and creates a harvest schedule that can be mapped easily. Furthermore, stand attributes such as maturity class and species composition, are used by the model to form pseudo-blocks (neighbourhoods of similar stands) that can then be used as a guideline for manual harvest blocking. Even though the planning process could be significantly more automated, i.e. shortened, using GISFORMAN, consideration of many operational factors is still lacking and thus the capability to accurately determine a sustainable harvest level remains impaired.

Currently in New Brunswick, the Crown Forest Licensees are going through the process of updating their 25-year management plans. Three Licensees, J.D. Irving Ltd., Fraser Inc., and the Juniper Lumber Co. Ltd., will make use of the GISFORMAN wood supply model to assist in determining harvest and silviculture schedules. The remaining Licensees will use only the
aspatial FORMAN+1 model and, therefore, a planning process similar to that used in 1987.

This paper will discuss recent enhancements to and planned application of the GISFORMAN model in 1992 management planning in New Brunswick. The enhancements provide a link between strategic and operations considerations in the planning process by providing the capability to measure the effect of harvest blocking on sustainable harvest level and to modify the harvest block schedule should the result be unacceptable. All three Licensees aforementioned will make use of this additional functionality, but Juniper Lumber Co. Ltd. will be the main test case and it is their situation that will be discussed in detail.

The GISFORMAN model

The GISFORMAN model is a GIS-based, or spatial, wood supply model developed at the University of New Brunswick. What distinguishes this model from other contemporary wood supply models is: (i) the ability to forecast forest development based on stand level information, and (ii) the ability to incorporate the geographic position of stands into the testing of harvesting strategies and development of harvest block schedules (Baskent, 1990). The current GISFORMAN model makes use of a front-end process (SCAN routine) that identifies neighbouring stands for each stand of a subject forest based on similarities in user-defined thematic attributes. Thus, for a forest comprised of 1000 stands for example, 1000 neighbourhoods would be created. Then, to test harvest levels and strategies, GISFORMAN creates pseudo-blocks by analyzing each neighbourhood in terms of contribution to requested harvest level and compliance with the given strategy. There are two types of output from GISFORMAN. The first is a report detailing the inputs used and the results of the wood supply analysis (periodic levels of harvest, planting, and thinning, area cut, growing stock condition, etc.). The second is a dataset containing the identification and location of stands to be harvested in each period (number of periods and period length are user-defined). GISFORMAN maintains an ARC/INFO dataset in the modelling process and through the use of the ARCPLOT subsystem, maps may be generated showing location of cutting, planting, and thinning by period of application.

A mapped schedule from GISFORMAN provides a forest manager with better information than does the tabular schedule produced by aspatial wood supply models such as FORMAN+1. The first drawback associated with an aspatial model is that it lacks any consideration of the location of timber a key component in determining the economic feasibility of extraction (Baskent, 1990). The sustainable wood supply projected by an aspatial model is therefore an overestimate. Second, the schedule produced exists in tabular format as aggregates of stand types. The aggregates must be broken out into component stands so that harvest block mapping can occur. The result of this process is a map featuring stands with like harvest periods spread over the extent of the forest. Blocking of these stands is a long and tedious manual activity. GISFORMAN, on the other hand, provides a map-based harvest schedule that is a closer approximation to operational reality. Therefore, the forest manager is provided with a better starting point from which to begin the manual blocking process.

GISforman, however, still lacks consideration of many operational realities of timber harvesting. Important criteria for block placement, such as proximity to existing road networks and mills, seasonal harvest distribution, product mix, and timber flow, are ignored by the model. Furthermore, the pseudo-blocks formed by GISFORMAN follow stand boundaries. A large portion of the manual blocking exercise involves changing harvest periods and "squearing-up" stand boundaries to make operational blocks. Even though the pseudo-block map produced by GISFORMAN provides a better starting point for the manual blocking process, there is still a great deal of editing required.

Establishing the missing link

In order to improve upon the existing management planning process, a feedback loop has been created that provides a link between strategic and operations considerations (Figure 2). To accomplish this, a new routine has been created and some modifications made to the GISFORMAN model. The new routine, BLOCKER, will permit forest planners to digitize harvest blocks and assign harvest periods as part of the operational editing of model harvest schedules. The model was modified to include two new harvest scheduling options: pre-blocking, the default option, whereby only the block boundaries are used, and pre-scheduling, where harvest periods, as well as block boundaries, are used. The model can now be instructed to cut harvest blocks exactly as digitized and either determine the harvest periods based upon a user-supplied strategy (pre-blocking) or schedule blocks according to user-assigned periods (pre-scheduling). It is expected that forest planners will employ a mix of the two options.

Effectively, the forest landbase is netted down to the area held within the blocks digitized, in a fashion similar to the netting down of the landbase for wildlife concerns and riparian buffers. The end result is that forest response statistics normally provided on a pseudo-block basis (growing stock volume, volumes, areas cut, planted, and thinned, etc.) can be developed for the digitized harvest block schedule.

Although a manual blocking step is still required, the improved planning process addresses several known problems. First, it will be easier (faster) to perform manual blocking with GISFORMAN's pseudo-block
Figure 2: The modified forest management process with a feedback loop between strategic and operations considerations.

harvest schedules. Second, an accurate measure of harvest level reduction due to operational blocking is determined. Third, the wherewithal now exists in the planning process to develop and analyze alternative harvest blocking patterns. Fourth, the final harvest schedule is in digital format, permitting easy updating. Such common occurrences as destruction of stands by fire and insects, and removal of blocks from the schedule due to changes in policy, can be quickly made to the digital version. New maps showing the changes can be created just as easily.

Specific steps in the new management planning process are illustrated in Figure 3 and itemized below.

1. Strategic planning
   Run GISFORMAN 3.0 (latest release of GISFORMAN that incorporates all functionality of the FORMAN+1 model and the modifications described previously) to test strategies in a spatial context, and select one.

2. Harvest blocking
   Manually re-block the mapped schedule of pseudo-blocks created for the selected strategy to incorporate operationally important information (e.g. inventory data gathered from ground and aerial reconnaissance and personal knowledge of the landbase — i.e. any supplemental information that is inaccurate or missing from the provincial digital database).

3. Digitizing harvest blocks
   Digitize the harvest block schedule created in step 2 and assign harvest periods if the pre-scheduling option is chosen (period assignment is not required for the pre-blocking option). Process the information through the BLOCKER routine to create a digital, harvest block schedule.

4. Rerunning GISFORMAN
   Using either the pre-blocking or pre-scheduling harvest schedule option, rerun GISFORMAN with the schedule produced in step 3 and generate statistics regarding the new harvest level and its sustainability.

5. Iterating
   Repeat steps 2 through 4 if the sustainable harvest determined in step 4 is unacceptable.

Making it work

Crown Forest Licensees in New Brunswick are currently in the process of preparing 25-year management plans, due April 30, 1992. Three Licensees J.D. Irving Ltd., Fraser Inc., and Juniper Lumber Co. Ltd will make use of the GISFORMAN model, and the modified planning process described previously, to assist in assessing harvest and silviculture strategies and developing associated schedules.

Juniper Lumber Co. Ltd will serve as the principal test case. The company is situated in the west-central portion of the province and holds the smallest of the 10 Crown Forest Licenses, with a landbase of 135,000 hectares. Annually, 30-40 harvest blocks of various sizes are harvested to attain the annual allowable cut of 165,000 m³ of softwood. Juniper Lumber Co. Ltd does not possess the computer equipment required to run GISFORMAN and BLOCKER software. The facilities
Figure 3: Modified harvest scheduling process showing the iterative use of GISFORMAN and the link between strategic and operations considerations.
at the Department of Forest Resources of the University of New Brunswick will be employed.

Participation in the actual 1992 planning process with Juniper Lumber Co. Ltd. will permit assessment of the new planning process. First, the functionality of new software will be tested and repaired if necessary. Second, the efficiency of the new process will be documented. In 1987, three employees of Juniper Lumber Co. Ltd. spent 220-250 person-hours over the course of 4-6 weeks on the management planning process. It is expected that due to an improved starting position (pseudo-blocks instead of scattered stands), the amount of time spent on blocking will be reduced considerably in 1992. Third, the pre-blocking and pre-scheduling harvest options of GISFORMAN will be compared. Allowing the model to assign harvest periods to digitized blocks (pre-blocking) has the advantage of maintaining a closer link to the original harvest schedule (and strategy) and its associated harvest level. As a result, it is expected that pre-blocking, without pre-scheduling, will have a lesser impact on sustainable harvest level reduction. Further, it should also be a time saver, since manually assigning harvest periods to blocks (pre-scheduling) is a rather complicated process due the need to satisfy adjacency limits (a two period (10-year) delay in cutting is mandatory for adjacent blocks in New Brunswick).

Although a mechanism has been created for linking strategic and operations considerations in management planning, its doubtful that Licensees will be able to take advantage of it in 1992 management planning. The stumbling block is a lack of cause-effect relationships. Foresters won’t know how to change a blocking pattern across a whole forest to improve sustainable harvest level fall down. Basically, they lack a collection of blocking strategies comparable to harvest and silviculture strategies. A blocking strategy would be comprised of the best combination of block size, block shape, period deviation (from original model assignment), block dispersion, block pattern, and perhaps other, as yet undetermined blocking factors, that yields a certain sustainable harvest level for a particular harvest and silviculture strategy.

A study (experiment) is planned to establish some fundamental cause-effect relationships between the manner in which operational harvest blocking is done and sustainable harvest level reductions. The measurement of the blocking factors will be made in several ways. Block size will be varied from a minimum size to a maximum size. Block shape will be varied from a regular shape (circle) to a completely irregular shape. Shape will be measured as a function of perimeter to area in determining the degree of irregularity. Period deviation will be varied from 1 period of deviation from the model assignment to n periods. Block pattern will be varied from a regular arrangement of blocks (checkerboard) to a an irregular arrangement. Block dispersion will be varied likewise from clustered to widely dispersed. In order to develop blocking strategies, testing of various combinations of blocking factors is planned. Figure 4 details a proposed testing procedure that should reveal the effect of various factors on harvest level reduction and interaction with harvest/silviculture strategies. The first step will vary one factor while holding all others constant. Subsequent testing will involve varying combinations of factors and/or eliminating factors that have no measurable effect.
Summary

The need for incorporating operational blocking considerations into the strategic level of the forest management planning process is obvious. The current New Brunswick approach of building elaborate schedules by incorporating extensive details about the dynamics of the forest is certainly taking the forest management process in the right direction. However, ignoring the impact of operational realities during the early planning stages is inefficient at best. A great deal of time is currently spent attempting to manually block the schedules produced by an aspatial modelling approach, but very little effort is exerted in determining the negative impact of operational modifications on initial strategies and its cause(s).

A BLOCKER routine and new harvesting options for the GISFORMAN spatial wood supply model have been developed to establish a loop between the strategic and operations considerations in the management planning process. While the loop in the process is currently not practical to execute due to a lack of cause-effect connections, a study is proposed to fill the void. It is expected that the study will permit some key factors contributing to harvest level reductions following operational blocking to be identified or confirmed. The payoff will be the capability to create and test, in a knowledgeable way, alternative harvest blocking patterns in the management planning process.

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Up the GIS learning curve: 
The New Brunswick forest management experience

Robert C. Dick
Director
Timber Management Planning
New Brunswick Department of Natural Resources and Energy
Fredericton, N.B.

Abstract
Forest management planning in New Brunswick is a given. Since the adoption of the
Crown Lands and Forest Act in 1980 Crown land licensees have been required to prepare
detailed plans that project long term wood supplies. Like most other skills however,
perfecting the planning process takes time. This paper chronicles forest management
planning in New Brunswick through three iterations from 1982 to 1992. It describes the
increasing sophistication of the planning effort in a number of areas including use of GIS
data; yield curve development and implementation tools. It concludes with the vision that
future planning efforts will require sophisticated tools that take the drudgery out of data
compilation but at the same time maintaining key user input.

Introduction
Forest management has been a reality in New Brunswick for a full decade. The catalyst for
this effort has been the 1980 Crown Lands and Forests Act (CLFA) that put responsibility for
management in the hands of Crown Licensees. The success of forest management in New Brunswick has
been well documented by others (Jordan & Erdle, 1990; Erdle & Frame, 1991) and is due, in no small way, to
the use of a geographic information system (GIS). Under the Act, planning schedules require that management
plans be revised on a 5-year cycle. The third iteration of this process will take place in 1992 and it is perhaps useful
to reflect on the process — to see where it has been, where it is now and where it is going.

This story cannot be told without including discussion of developments in wood supply and growth and yield
modelling techniques. These discussions will be, however, kept to the minimum and this paper will highlight where GIS
has aided the New Brunswick forest management planning process and brought it forward in significant ways.

Origins of forest management
in New Brunswick
As far back as 1971, New Brunswick became concerned that there were severe problems with its forest resource.
In that year the Forest Resources Study (Anon, 1974) was initiated and delivered its final report in 1974. That Study
recognized that there was no available surplus of the primary softwood species used in the Province and that there was
an immediate need to take a proactive role in managing the forests to realize their full potential. The Study spun-off
a short-lived Pilot Project in which organizational and management strategies were tested that eventually evolved
into the Crown Lands and Forest Act.
The Act was adopted in 1980 and provided for the division of provincial Crown forest lands into 10 timber licenses. Each was assigned to 10 of the larger indigenous forest-based companies in the Province, in return for which each assumed specific obligations as stipulated in the forest management agreement and in accordance with the Crown Lands and Forests Act and its regulations.

These obligations, among others, involve the development and periodic revision by the Licensee, subject to the approval of the Minister of the Department of Natural Resources and Energy (DNRE), of three types of plans — the Industrial Plan, the Management Plan and the Operating Plan. The Industrial Plan describes the Licensee infrastructure and projects planned modifications to their business objectives for a 25-year period. While an important document, it is relatively easy to prepare and is developed by senior managers who have knowledge of long term company objectives. The Operating Plan is for a one year period and details the specific forest management initiatives to be implemented on the Licensee for that year. Because it is drawn from the Management Plan, it also is relatively easy to prepare and is done so on a routine basis.

The Management Plan, is perhaps the most onerous of the planning documents required of Licensees. It is required to:

(i) describe development types within the forest on the basis of physical and biological differences;
(ii) estimate stand growth rates for these development types;
(iii) specify the level and types of silvicultural methods to be employed; and,
(iv) provide detailed mapping of the locations and quantities of product to be harvested by operating period and indicate the location and extent of silvicultural activity with respect to planting and thinning.

While the plan is revised on a 5-year cycle, it establishes sustainable wood volumes over an 80-year horizon and maps harvest and silviculture operations for 25-years.

In order to make this level of management planning possible it was recognized early on that there would have to be detailed inventory information available and that it would have to be handled in an efficient manner. Almost two decades after they were written, it is interesting to reflect on the words from the 1974 Final Report of the Forest Resource Study that tried to encapsulate this vision. The authors knew that New Brunswick had good inventory statistics on what timber resources there were in the Province but could see that they were very weak on “where timber of certain characteristics can be found”. To fill this void they called for “forest cover maps of the entire Province to be produced as soon as is practicable” and went on to say that “all major disturbances of forest cover (cutover areas, recent burns, new roads or other structures, areas of forest destruction by any natural or man-made causes) be photographed from the air every year”. They concluded by saying “the more information that is gathered, the more difficult it is to store it and to make it readily available for practical uses. We therefore strongly favor the establishment of a comprehensive land-data-bank”.

It would take a number of years for the “land-data-bank” concept to become the geographic information systems that we know today but undeniably these early visionaries were on the right track. By the time the CLFA was adopted in 1980 there was a concerted effort on part of the DNRE to acquire such technology. The urgency for this acquisition was noted in correspondence of one senior DNRE official in 1981 when he said “not only must DNRE have a GIS to implement the intent of the Act, but it must have the system in place and fully operating 1.5 years before the management plan renewals in 1987. Without a GIS it is not possible to have planned scheduling of the harvest, to plan the product distribution, to plan silviculture or to efficiently protect the forest (and) evaluation of performance is silly without an information base” (Anon, 1982).

The Arc/Info GIS was eventually acquired in 1982 and a program of database loading began in earnest. It was in that same year that the first management plans were created. This was followed by revisions in 1987 and 1992. The balance of this paper will look at the development of those management plans in each of these years and will do so by focusing on four main areas of the planning process:

- Land Base Description
- Stand Growth Forecasting
- Forest-level Projections
- Spatial Configuration

The first attempt at management planning in New Brunswick — 1982

With the fundamentals of the CLFA in place and boundaries of the 10 Licenses established, the stage was set for development of the first management plans. But few of the tools were in place.

Land base description

The only complete inventory for the Province was created in the mid to late 1970s and was not designed to provide the types of data required for wood supply analysis. Regardless, the forest was described using coarse aggregations primarily based on broad covertypes. No site specific reductions were made to the land base to account for harvest restrictions. Instead an arbitrary 15% was removed from the entire forest across all classes.
Stand growth forecasting

Because the existing inventory did not contain the right types of information that would allow realistic modelling of stand dynamics, descriptions had to be improvised. For example:

(i) there was little or no data in the inventory that would allow creation of yield curves to describe stand development. In lieu of such data, yield curves were basically drawn freehand using field foresters' knowledge of the forest.

(ii) there was no age information in the inventory that would allow placement of stands on yield curves. However, because volume data was available on a stand by stand basis in the existing inventory, a work around was developed whereby age was assumed to be linked to volume.

Forest level projections

WOSFOP (Hall, 1977), an early vintage wood supply model, was used to forecast forest development and to determine sustainable harvest levels. It was lacking in several areas, e.g., it limited forest description to only ten classes.

Spatial configuration

One of the major factors that the wood supply model did not take into account was the geographic distribution of stands. No formal attempt was made to disaggregate an accepted wood supply strategy into individual stands and resulting operating plans were mere best guesses at where actual wood volumes by stand types could be obtained.

As can be seen, the components needed for wood supply analysis were created in one fashion or another using whatever data and expertise that could be found. While it was Licensee responsibility to develop the actual plans, because of the limited expertise that was available in the Province, the actual wood supply runs were done by DNRE and the results given to the Licensee for inclusion in a formal document. Needless to say the effort was less than perfect but at the very least the program was underway and both Licensees and DNRE were learning. The need for GIS in developing management plans was never more evident and creation of a new inventory database that incorporated those descriptive data important to management planning became the focus of activity for the next several years.

The first revision of management plans — 1987

The GIS-based forest inventory was officially completed in 1987. It covered the entire Province and encompassed approximately seven million hectares on 2000 map sheets defining some one million stands.

It is now updated on a yearly basis for all harvesting on Crown land with periodic updates for small-private ownerships.

Land base description

The new inventory was geared, in part, toward providing stand descriptions suitable for wood supply analysis. Because the inventory was fully in digital form on Arc/Info, stratification of the forest was simplified using the database capabilities of the GIS. However, its spatial analysis capabilities were utilized to only a limited extent. For example:

(i) accounting for the area in riparian zones was generally done manually using hardcopy map products. However, there were two Licensees in the Province who also now owned GIS technology and who did some limited buffer analysis using these systems.

(ii) there was a desire to include a measure of site quality in the planning process. This was conveniently accomplished, albeit at course resolution, by assigning a measure of site to each 1:12 500 map sheet. The GIS was then used to assign a site factor to each stand on each map sheet.

Stand growth forecasting

To obtain a better measure of stand yields, a methodology for yield curve construction was developed that utilized the network of temporary and permanent plots that were established in support of the inventory. The methodology was not precise but gave users some hard data to support or reject yield curves developed in 1982.

Forest level projections

Based on the short comings of the wood supply model used in the 1982 exercise, the intervening years were used to develop a new model called FORMAN (Wang et al, 1987). It was well tailored to New Brunswick forest conditions and made more realistic forest dynamic assumptions. It still however required aggregation of stands into classes.

Spatial configuration

The lack of location-specific detail continued to flaw the process. In an attempt to compensate, the GIS was used to spatially allocate FORMAN's class-based harvest schedules and stand harvest maps were generated. It remained, however, to develop an operationally acceptable harvest block schedule from these maps — an arduous manual process. The important result was translation of a harvest schedule, designed at the management planning level, into a map format that had direct relevance at the operational level.
By the end of this second revision of management plans the process was much better understood by all parties and important strides had been taken to make planning assumptions better reflect reality. One major shortcoming however was that the process was almost fully geared to problems of sustaining fibre supply. Little or no accounting was made for multiple use, especially with regard to sustaining wildlife habitat. This item would be the focus of considerable development over the next 5 years.

The current state of New Brunswick management planning

The management plans being developed for 1992 are the most sophisticated to date. Most notably, there are requirements that Licensees incorporate wildlife management in their plans by providing for deer habitat and habitat for fauna that frequent mature forest.

Land base description

GIS was used extensively to more accurately describe the available land base. This was done by digitizing land base restrictions (i.e., restricted from a harvesting perspective) and overlaying them with the forest to report the area of covertypes within restrictions. These restrictions included:

(i) Riparian Buffers: To reflect reality, historical average buffer widths by watercourse type on a Licence-by-Licence basis, were determined and applied to all Crown watercourses within the Province.
(ii) Deer Yards: Identified Deer Wintering Area Management Units were digitized.
(iii) Legal Reserves: Ecological Areas and Sugar Bushes were digitized.
(iv) Inaccessible Areas: Topographic maps were used to identify areas of excessive slope that would not be harvested. These were subsequently digitized.

Stand growth forecasting

For 1992, computerized growth models were developed that simulated the establishment, growth and decline phases of stand development using plot data from forest stands. These empirical models were not intended to give definitive yield projections but, as in 1987, were intended to guide users in their development of yields.

Forest level projections

Primarily to accommodate specialized harvesting techniques required to enhance and maintain wildlife habitat, the FORMAN wood supply model was upgraded (FORMAN+1 and FORMAN+2, Vanguard, 1991) to allow for 2-pass, shelterwood and true uneven-aged management.

Spatial configuration

For the majority of Licensees, the GIS-based approach used to develop 1987 harvest schedule maps will be used again in 1992. Three Licensees, however -- J.D. Irving Ltd., Fraser Inc. and Juniper Lumber Ltd. -- will employ a spatial wood supply model. These companies are participating in the FORMAN 2000 project at the University of New Brunswick and will use the GISFORMAN model in developing and testing wood supply strategies. As the name implies, GISFORMAN is an extension of the original FORMAN but differs in two important ways:

(i) the model produces forest forecasts based upon stand-level information as opposed to stand aggregate information; and,
(ii) by accessing a topologically structured database, the model mimics harvest blocking and adjacency delay in developing and testing harvest strategies.

The future of management planning in New Brunswick

Table 1 summarizes the development trends that have been discussed above. Clearly there has been a trend toward sophistication of the procedure, particularly in terms of:

(i) more accurate descriptions of the nature of stand growth and yield;
(ii) incorporation of multiple use into the planning process; and,
(iii) maintenance in the planning effort of the spatial characteristics of the forest.

These trends are likely to continue and be evident in the 1997 planning effort. Because of its cyclical nature there has been a tendency for the stakeholders to focus on the problem only once every 5 years. The increasing complexity has caused these stakeholders to realize that the process is important to the future well being of the Province and requires commitment of staff and resources on a continual basis to ensure that plans adequately reflect the goals and objectives of forest management.

Consistent with this trend, will be a shift from DNRE leadership in planning to leadership by Licensees. This shift is healthy and consistent with the primary intent of the CLFA, i.e. that licensees be responsible for management and that DNRE be in the position of setting objectives and monitoring performance.

New Brunswick has been fortunate in that this level of forest management planning experience has attracted considerable expertise to the Province. Not only is there considerable interest in research on the subject at the university level but there are now several consulting firms in the Province that have developed marketable skills in the area of GIS and wood supply modelling.
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<td>• GISFORMAN allows true spatial modelling</td>
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<td>• general Lic. use of 1987/ procedure</td>
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<td>• manual blocking</td>
<td>• 3 Licensees develop blocked schedules from GISFORMAN</td>
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Table 1: Trends in forest management planning in New Brunswick between 1982 and 1992. (adapted from Erdle and Frame, 1991)

At the heart of the planning exercise is an up to date forest inventory. While the New Brunswick inventory has been updated on an annual basis for cuts and burns, the unharvested inventory will be more than 10 years old by the time the next management plan revisions are due in 1997. Consequently innovative procedures are currently being investigated to determine ways of updating this inventory and at the same time maintaining the investment in the updated information in the existing database.

**Lessons learned**

The New Brunswick experience is neither unique nor perfect. It has demonstrated, however, that management planning on a forest-wide basis can be taken beyond a theoretical exercise and the lessons learned to date may prove useful to others contemplating similar initiatives:

(i) Nothing as complex as the New Brunswick forest management planning process could be implemented error-free. However, waiting for perfection only results in inaction. This has been an underlying, though not specifically stated principle driving the New Brunswick forest management planning effort. As Samuel Johnson said "nothing will ever be attempted if all possible objections must first be overcome".

(ii) The success of the Arc/Info geographic information system at DNRE is due in large part to the Crown Lands and Forest Act. Had it not been for the legislated mandate of the Province to provide Licensee managers with up to date information on the Crown forest for planning purposes, it is doubtful that the system would be in use today.

(iii) The process is complex and constantly changing. Not only do standards change but goals, objectives, rules and guidelines change. Couple this with changes in staff and soon there is a process understood by few and mistrusted by many. To avoid this situation there is a need to simplify the complexity without taking away the need for input by the forest managers. The first step in this process is thorough documentation of the procedure followed by the possible development of knowledge-based computerized tools that prompt managers for input and guide them through strategy development.
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B4 Fire applications

Tracking suppression resources via an Australian fire management system: in principle and in practice
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Evaluating spatial strategies of wildfire prevention with a GIS
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The application of GIS technology for forest fire management planning
Bryan Lee et al., Forestry Canada, Edmonton, AB, Canada
Tracking suppression resources via an Australian fire management system: in principle and in practice

Judith A. Beck and Stephen R. Kessell
Department of Geographic Information Systems
School of Computing
Curtin University of Technology
GPO Box U1987
Perth, Western Australia 6001

Abstract

A geographic information and modelling system has been developed in Western Australia to support the management of logistics during wildfire suppression, concomitantly with simulation routines that support an appreciation of fire behaviour. This work details the design, structure and use of generic routines that support the tasks of planning and tracking suppression resources, giving due consideration to critical financial, managerial and organisational constraints which have governed the development of this system.

Textual information that details a particular suppression resource is associated with an icon that categorises it visually. Mobile resources can be positioned at their work location with the click of a mouse. The provision of a simple, visual summary is interpreted readily, and functions as a valuable incident briefing tool.

The utility of this system, which operates on personal computers, lies in its ability to integrate fire behaviour, suppression, plant, personnel, environmental, historical and cultural features in a manner useful to fire controllers.

Introduction

A Wildfire Incident Management System (WIMS) is being developed to support decision making during wildfire control. The system, the inception of which is detailed elsewhere (Beck 1989, 1990, 1991; Kessell 1990; Kessell and Beck 1991), can be conceptualised via its two primary functional components: fire spread routines are used to simulate the spatial development of a forest fire over time; and resource management routines are used to deploy, track and query suppression resources for a particular event.

The development of decision support systems for fire management must consider the special objectives of the organisation at hand, and the development of this system has been governed by the financial, managerial and organisational constraints of the Western Australia Department of Conservation and Land Management (CALM). During the Cyclone Alby emergency in 1978, when 92 fires developed in State forest over a three hour period (Underwood et al. 1985), it was extremely difficult to consider all values at risk, to identify suppression priorities and to track the whereabouts of allocated resources. With the development of WIMS, CALM seeks to improve the safety, efficiency and effectiveness of suppression efforts under extreme circumstances such as those presented by Cyclone Alby.
The majority of WIMS is PC based, because phone, electricity and main-frame computer operations cannot be guaranteed during adverse situations in Western Australia. Hence, each installation must be self sufficient with respect to data and software.

In order to ease the transition from a manual to an automated decision support system, design strategies have concentrated on incorporating concepts from as many of CALM's manual systems as possible. For example, the Western Australian forest fire behaviour tables (Sneeuwagt and Peet 1985) provide the basis for fire behaviour predictions. A fire growth model, which is a hybrid between cell and vector based perimeter spread algorithms such as those developed by Kourtz and O'Regan (1971) and Anderson et al. (1982), employs weather inputs, geographic information and the Western Australian fire behaviour tables to predict the temporal and spatial development of a fire.

The resource allocation and tracking routines of WIMS have incorporated concepts from two of the manual systems that CALM uses for logistics management. These two manual systems are namely the Fire Resource Management System (Hamilton 1988, Rawet 1990), which employs colour coded cards to depict allocated resources such as personnel, plant and equipment; and, the Situation Board, which is used to map the physical infrastructure and depict the whereabouts of deployed resources with colour coded magnets.

The Department of CALM has also developed a computerised Resource Inventory System, which is known as RESIN (Rawet 1991). RESIN is a simple, data base management application, which has been developed in DBase, that is used to maintain current listings of available fire control personnel, plant, vehicle and equipment resources. Hence, this system could be used as a basis for resource management in WIMS.

The dynamic allocation routines of WIMS are used to track the whereabouts of resources that have been deployed for a particular event. These modules can be integrated with any data base management applications that has been programmed in DBase or Clipper. Textual information that details a particular vehicle, plant or piece of equipment can be associated with an icon that categorises it visually. Mobile resources such as tankers, bulldozers and aircraft can be positioned at their work location with the click of a mouse. Plant, vehicle and equipment resources can be affiliated with the individuals responsible for them, and icons can be interrogated for personnel or equipment details.

**User interface**

WIMS does not incorporate digitising or Boolean map algebra routines of a typical GIS. An emergency situation is hardly the time to begin to collate forest type, fuel quantity, cadastral and cultural details. Instead, WIMS is expected to compliment a corporate GIS, which functions to capture, maintain and manage the geographic information that is relevant to fire management. Facilities have been developed to transfer geographic information between WIMS and commercial GISs such as ARC/INFO or INTERGRAPH.

WIMS has been designed to incorporate whatever geographic information and suppression resource details are required in order to meet the needs of a given organisation. In effect there are two operating levels of WIMS. Low level system manager routines are used to define the structure of geographic and suppression resource information for a particular installation. The general user, on the other hand, is able to access this information as required, and uses the system to forecast, monitor and document the progress of events.

**System management level**

System management routines are used to define, for example, the geographic information that is available, the mapping patterns that will be used to depict a particular theme value. These routines are also used to define the data bases that will contain plant, vehicle and other suppression resource details, as well as the icon images that will be used to depict a particular suppression resource.

This design framework has been provided so that ownership preferences can be incorporated dynamically. State headquarters can establish standard data bases, to which region or district installations can add. Hence, a degree of user ownership and responsibility can be established for each installation.

It is at the system management level that an icon is defined (Figure 1). The data structure of an icon is defined first, and its image is established subsequently.

Up to twelve characters are used to distinguish one icon from another by name. The mobility of an icon is then established. A general user can place a mobile icon using a mouse to drag it to the desired location on the background map. Locational coordinates are then updated automatically. If an icon is static, however, the general user cannot alter its locational coordinates. For example, most suppression resources would be mobile icons, whereas point features such as rare and endangered flora and fauna would be static.

Next, the relevant data base file is selected from a point-and-shoot menu, which lists all of the available data base files. In Figure 1, for example, a data base (WWVEH.DBF) that contains vehicle information has been identified. In this case, all vehicle details are maintained in one data base file, and the system manager needs to distinguish between icon types on the basis of the vehicle type field (VTYYPE). A record in the data base file is said to be a HEAVYDUTY icon if its vehicle type field is equal to "HD". Hence, the system manager can
create different icons to depict a heavy duty, a bulldozer, a car, or a light patrol unit, for example.

The whereabouts of each icon is stored in two fields that define its x (Easting Field) and y (Northing Field) locational coordinates. These must be integer fields, and are intended to store Australian Map Grid (AMG) coordinates.

Equipment, plant and vehicles have people who are responsible for them. Hence, a HEAVYDUTY icon can be linked to a PASSENGER record, in the data base which contains staff details (WWSTAFF.DBF). It should be noted that locational coordinate fields are compulsory for an icon, but they are not required for an icon link. Further, several records of a designated link type can be affiliated with a particular icon. For example, a number of people can travel in a particular vehicle, and it's up to the general user to link a particular vehicle with its passenger details, interactively.

Next, the icon image is created. Up to 20 drawing elements such as circles, boxes, lines and triangles, are combined to define an icon's image. Elements are drawn in the active palette colour.

The set up for a given installation of WIMS need only be established once, and perhaps modified from time to time as required. Anyone using the system management routines must be familiar with the data base management application and its data structures, hence the system manager is expected to be relatively computer literate.

General user environment

The general user need not be concerned with data base structures or GIS. In this environment, WIMS is used to create a visual situation report, an example of which is given in Figure 2. A base map, at the user's choice of scale, is used to depict the general surrounds of an incident; for example, district boundaries, roads and waterways can be superimposed on a map of any available data theme. In Figure 2, major and minor roads are depicted on an elevation map.

WIMS can be used to perform a number of tasks: for example, suppression resources can be allocated; a geographic location can be queried for attribute details; an icon can be queried for data base details; and search facilities can be used to locate a particular vehicle.

Figure 1a. The system management routines of WIMS are used to design the structure of an icon.
Figure 1b. The system management routines of WIMS are used to design the image that categorises it visually.

Figure 2. The general environment allows a user to track suppression resources, as they are allocated to a particular incident. The Query option can be used to examine the data affiliated with a particular icon.
Several steps are involved in tracking suppression resources via WIMS. The Allocate option is used select a particular icon type and record from a point-and-shoot menu, and drag it to its work location using the mouse. Links can then be created to affiliate a resource with the person(s) responsible for it, and the location of an allocated resource can be altered with the Move command. A user cannot deploy a resource twice, hence, if an icon or link record has been allocated, a user cannot re-deploy that resource until the icon has been recalled or the link has been broken. Icon queries present data base details, and a user can step through information that has been linked to an individual resource. A search filter can be used to identify those point features whose icon records or links adhere to user specified field criteria.

It should be noted that a record must exist in the data base if it is to become an icon or link. WIMS has not been designed to allow for the addition, deletion, or modification of a data base. One of the primary functions of a good data base management application is to ensure that the data is checked on the way in; WIMS would have to incorporate an infinite number of tailoring facilities at the system management level in order to provide suitable data management routines from within. Similarly, resource reporting facilities would have to cope with providing endless report format options.

Data base management and report writing tasks are more appropriately carried out by the data base application, where they can be tailored to meet the needs of a particular organisation. Instead, WIMS allows a user to invoke a number of data base management applications from within. In fact, any executable program can be run from WIMS, provided there is sufficient memory available to load and execute the child process.

**Discussion**

In practice, the suppression tracking routines of WIMS are not apt to replace the current manual T-board systems, such as the Fire Resource Management System (Sneeuwjagt and Vear 1987; Hamilton 1988; Rawet 1990), that are used for logistics planning. Establishing icon and data relationships interactively may be tedious, although key stroke requirements are reduced by applying point-and-shoot techniques, which allow a user to select relevant details from an established list. Details that are not available in the local data base have to be keyed in anew, and this could prove to be rather time consuming during events that involve substantial resources from external agencies.

One alternative to positioning individual resources manually, would be to update their locations automatically using Global Positioning Systems. This is not apt to be economically viable for the Department of CALM. Such a tactic might be cost-effective if the use of aircraft in remote suppression operations were more prevalent than they are currently in Western Australia.

The value of the suppression resource tracking component of WIMS lies in its ability to integrate any local data base readily. Static, intelligent point features can be used to locate and detail rare and endangered flora and fauna, archaeological sites, suppression hazards or any other feature that merits due consideration during suppression planning. In Australia, the ecological impacts of fire suppression activities are of increasing concern, and this type of information will only be considered in suppression planning if it is available readily.

There are many reasons why WIMS has been implemented on a cheap, portable, stand alone system platform. Personal computers no longer pose the speed and memory limitations they once did, and they are not dependant on, but can work in conjunction with, main-frame systems.

The is a more important reason for maintaining a relatively low level of technology in geographic information, modelling and decision support systems such as WIMS. Although the capabilities of GIS implemented on sophisticated graphics workstations helps communicate information, the "pretty pictures" generated by the technology may present a false lure about the credibility of the information depicted (Burrough 1986, 1990).

This is especially relevant in the case of modelling the temporal and spatial development of a fire, where modelling and data weaknesses are apt to be prevalent. The mathematical modelling techniques that are used to simulate fire spread (see, for example, Kourtz and O'Regan 1971; Anderson et al. 1982) have the potential to introduce bias or error, which is a direct result of the simulation process and is distinct from that associated with input parameters (O'Regan et al. 1976; Richards 1990; Feunekes 1991).

Rather than focus on the technology per se, the introduction of WIMS in March 1992 will stress limitations in the prediction models and data. If simulation outcomes are to be applied effectively, a "license to drive" can only be granted to user's who have a sound knowledge of fire behaviour. For these user's, WIMS will foster their knowledge, as well as structure and support the decision making processes critical to wildfire management.

**Literature cited**


Evaluating spatial strategies of wildfire prevention with a GIS

Yue Hong Chou
Department of Earth Sciences
University of California
Riverside, CA 92521

Abstract

Effective management of wildland fires relies more on prevention than on suppression because preventive treatments cost much less than suppression measures. While suppression efforts demand immediate attention and quick-response actions, decisions on preventive treatments are harder to make unless their cost-effectiveness can be accurately evaluated. This paper presents the use of GIS to evaluate alternative spatial strategies of prescribed burning. The evaluation of a spatial strategy is based on two criteria: the fire danger of the entire district and the spatial pattern of fire occurrence probability. Eight spatial strategies of prescribed burning for the Idyllwild quadrangle of the San Bernardino National Forest were evaluated and the most cost-effective strategy identified.

Introduction

Wildfires are most controllable when they are small. Those fires that escape the initial attack of suppression forces cause substantial damage to natural resources and property, and, occasionally, loss of life. As a fire grows in size, both the damage it may cause and the cost to control it increase exponentially. Therefore, effective wildfire management requires a management plan based on which possible spatial strategies of preventive treatments can be evaluated. As critical localities of great fire danger are identified in the management plan, fire managers are able to make timely decisions on launching initial attack should a fire occur. More importantly, the management plan can be used to set the priority of possible proposals of preventive measures such as prescribed burning.

Prescribed burning is the application of fire to wildland fuels under certain conditions of weather, fuels, and topography that specific objectives can be accomplished safely (Green 1981). When carefully planned, prescribed burning can be much more cost-effective than suppression.

While technology in prescribed burning has been well developed (Emrick and Adams 1977, Green 1981), little has been done regarding the evaluation of spatial strategies. A spatial strategy is one that addresses the issue of location. In terms of prescribed burning, a typical spatial strategy is one that specifies the locations where prescribed burning will be applied. For managing a large district of wildlands under a limited budget, the capability of evaluating spatial strategies is particularly important because preventive treatments must be planned effectively.

In previous studies (Chou et al. 1990, Chou 1992), GIS procedures were developed for constructing probability models of fire occurrence and, according to such models, delineating the distribution of critical zones of fire danger. This paper presents the empirical application...
Figure 1. The Idyllwild 7.5-minute Quadrangle, San Jacinto Ranger District, San Bernardino National Forest, California.
of those procedures to the evaluation of eight spatial strategies of prescribed burning in the Idyllwild 7.5 minute quadrangle of the San Bernardino National Forest, California (Figure 1).

**Setting spatial strategies**

In the ecological database of the study area, fires that occurred between 1911 and 1984 were coded (Figure 2). Geographic units were defined by topographic characteristics such as slope aspect and slope gradient (Figure 3). Using the TIN package of ARC/INFO (Environmental Systems Research Institute 1987), the GIS employed in this study, the digital elevation models (DEM) of U.S. Geological Survey (1987) were converted into triangulated irregular networks which were then used for generating geographic units of homogeneous topographic characteristics. Figure 4 shows 200-meter contours generated from the triangulated irregular networks.

The distribution of fire occurrence probability is constructed from the logistic regression model (Wrigley 1976) such that

\[
P_i = \frac{\exp(U_i)}{1 + \exp(U_i)}
\]

(1)

where \( P_i \) denotes the probability for a major fire to occur in the \( i \)-th geographic unit. Formally, the quantity \( U \) of the model is specified as:

\[
U_i = \beta_0 + \beta_1 \text{AREA} + \beta_2 \text{ASPECT} + \beta_3 \text{SLOPE} + \beta_4 \text{ROAD} + \beta_5 \text{BUILD} + \beta_6 \text{ROTATION} + \beta_7 \text{RAIN} + \beta_8 \text{TEMPERATURE} + \epsilon
\]

(2)

where \( \text{AREA} \) is the area of the \( i \)-th geographic unit; \( \text{ASPECT} \) denotes slope aspect; \( \text{SLOPE} \) represents slope gradient; \( \text{ROAD} \), the proximity to transportation, is the distance between the unit and its nearest road; \( \text{BUILD} \), the proximity to man-built structures, is the distance between the unit and its nearest building; \( \text{ROTATION} \) is a fire rotation weight determined by vegetation type; \( \text{RAIN} \) is annual precipitation; \( \text{TEMPERATURE} \) denotes the mean temperature in July; \( \epsilon \) is the parameter for the \( i \)-th variable; \( \epsilon \) is the random error term. Coefficients of the parameters were estimated from the stepwise logistic regression program (LR) of the BMDP statistical package (BMDP 1987).

The probability of fire occurrence must be modified for bare ground and water surfaces. Since major fires are not expected to occur on these surfaces, the probability of fire occurrence should be assigned zero rather than being estimated from the model. For other surface types, the probability is derived directly from the best-fit logistic model. For management purposes, geographical units were classified into three categories by probability of fire occurrence: areas with a probability greater than .60 are labeled high fire-danger zones, those between .60 and .30 are labeled medium fire-danger zones, and less than .30 are labeled low fire-danger zones. Figure 5 shows the distribution of fire-danger zones based on this classification scheme. From this map, we delineated zones of high fire danger and, accordingly, defined eight spatial strategies of prescribed burning. In each strategy, three or four adjacent polygons will be burned. Figure 6 shows the polygons that need to be burned for the eight strategies listed in Table 1.

**Criteria for evaluation**

The effectiveness of a spatial strategy of prescribed burning is evaluated by two measures: the district fire danger index (DFDI) and Moran's I coefficient of spatial autocorrelation.

The DFDI is the area-adjusted average of fire occurrence probability for the entire district, such that

\[
\text{DFDI} = \frac{\sum P_i A_i}{\sum A_i}
\]

(3)

where \( P_i \) is the probability of fire occurrence for the \( i \)-th geographic unit; \( A_i \) is its area. In (3), the numerator is the sum of products of fire occurrence probability and area. The denominator is the total area of the district. A higher level of DFDI implies a greater propensity to burn. In evaluating the effectiveness of alternative spatial strategies, a preferred proposal is one that reduces the DFDI more.

The second measure, Moran's I coefficient of spatial autocorrelation (Cliff and Ord 1981), evaluates the neighborhood effects of fires. Formally, the I coefficient is defined as:

\[
I = \frac{n}{2a} \frac{\sum w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum(x_i - \bar{x})^2}
\]

(4a)

where \( n \) is the number of geographic units; \( w_{ij} \) is the contiguity weight of spatial relationship, which equals one if the \( i \)-th and \( j \)-th geographic units are adjacent to each other and zero otherwise; \( X \) is the study variable, which is the probability of fire occurrence in this study; \( 2a \) is the sum of contiguity weights of all pairs of geographic units, i.e., \( 2a = \sum \sum w_{ij} \).

In general, a positive value of the I coefficient indicates a pattern of positive spatial autocorrelation where areas of similar values tend to be close to one another. A negative I coefficient indicates a pattern of negative spatial autocorrelation where areas of high values tend to be located near areas of low values. When the I coefficient is close to zero, the pattern is considered random.

In terms of fire danger, a clustered pattern of fire occurrence probability is least desirable because it implies a distribution where areas of high burn-propensity are concentrated thereby maximizing the threat of wildfire holocausts; a scattered spatial pattern is preferred because it separates areas of high burn-propensity into isolated patches. In a pattern of negative spatial
Figure 2. Fire activity between 1911 and 1984.
Figure 3. Geographic units defined by topographic characteristics.
Figure 4. Topography of the study area.
autocorrelation, each parcel of high fire danger is surrounded by parcels of low burn-propensity, thus the chance for a wide spread, uncontrollable fire is minimized. In evaluating spatial strategies of prescribed burning, the strategy resulting in a lower value of the I coefficient is preferred.

The cost of a strategy consists of two factors: total area to burn and proximity to roads. In general, a larger area costs more to burn than a smaller area. Also, burning areas that are closer to roads is cheaper because it is easier to transport crew and equipment.

**Evaluating spatial strategies**

The effectiveness of a spatial strategy was evaluated according to both DFdi and Moran’s I. The DFdi was calculated for each of the eight strategies listed in Table 1. Based on DFdi, the DFdi of the original map, RDDFI, is defined as the degree to which a strategy can reduce DFdi from the pre-burned state. Therefore, for the strategy k,

\[ \text{RDDFI}_k = (\text{DFDI}_k - \text{DFDI}_o)/\text{DFDI}_o \]

Also, EDFDi is defined as the effect of the strategy in reducing DFdi, relative to the strategy of maximum RDFFI among m alternative strategies, such that

\[ \text{EDDFI}_k = \text{RDFFI}_k / \text{MAX RDFFI}_m \]

Likewise, Moran’s I coefficient was calculated for each strategy and defined EI as the effect of a strategy in producing a more desirable (scattered) pattern, relative to the minimum of this measure, such that

\[ \text{EI}_k = 1 - (\text{I}_k - \text{MIN I}_o)/\text{MIN I}_m \]

Finally, the effect of a specific strategy, Ek, is defined as the product of EDFDi and EI such that

\[ E_k = \text{EDFFI}_k \times \text{EI}_k \]

The calculated E indices for the eight strategies are listed in Table 1. According to this measure, the sixth strategy which will burn polygons 763, 774, 803, and 844 is most effective in reducing the overall fire danger of the district and producing a more desirable spatial pattern.

The cost of a spatial strategy is determined by the total area to burn and proximity to roads. It is well-known that the relationship between area and cost is nonlinear, i.e., it costs less than twice as much to burn an area twice as large. For this reason, the cost in terms of area, CAREA, is defined as the square root of the area to burn, relative to the maximum of this measure, such that

\[ \text{CAREA}_k = (A_k / \text{MAX } A_m)^{1/2} \]

Likewise, the cost in terms of proximity to roads, CROAD, is defined as the square root of the average distance to a nearest road, relative to the maximum of this measure, such that

\[ \text{CROAD}_k = (\text{ROAD}_k / \text{MAX ROADS}_m)^{1/2} \]

Finally, the cost factor for each strategy, C, is derived from the product of CAREA and CROAD such that

\[ C_k = \text{CAREA}_k \times \text{CROAD}_k \]

The calculated C indices for the eight strategies are listed in Table 1. According to this measure, the second strategy which will burn polygons 257, 344, and 404 is most costly and the eighth strategy which will burn polygons 919, 948, 955, and 977 is least costly.

To take into account both effectiveness and cost in evaluating spatial strategies, the measure of cost-effectiveness, E/C, is defined as the ratio of E to C. The calculated E/C indices for the eight strategies are listed in Table 1.

Based on the E/C measure, the fifth strategy is most cost-effective while the second strategy is least cost-effective. Accordingly, the highest priority of prescribed burning should be assigned to the fifth strategy.

**Conclusion**

To effectively manage wildland fires in a large district under a limited budget, one must evaluate the cost-effectiveness of all possible management plans and set the priority of alternative spatial strategies. It is important to realize that not all prescribed burns are desirable, and that certain alternatives could be less expensive yet more effective. Although some prescribed burns may be important locally, if they are not located and scheduled according to a well-designed, full-scale district management plan, the expensive efforts of prescribed burning may simply create a situation of potential fire disaster in the future.

The recent development in GIS technology has made it possible for wildfire managers to evaluate possible spatial strategy of prescribed burning. Using a GIS, we can establish an ecological database which incorporates data of fire activity, type and age of vegetation, topographic characteristics, weather conditions, human structures, and existing preventive treatments. From the database, a logistic model of fire occurrence probability can be constructed. The distribution of fire occurrence probability can be mapped by calibrating the best-fit model of fire occurrence, which then allows for the identification of critical zones of fire danger. Different spatial strategies can be evaluated effectively and a comprehensive management plan can be obtained.
Figure 5. Classification of geographic units by fire danger.
Figure 6. Eight spatial strategies of prescribed burning.
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The application of GIS technology for forest fire management planning

Bryan S. Lee
Forestry Canada
Northern Forestry Centre
5320 - 122 Street
Edmonton, AB, Canada T6H 3S5

David J. Buckley
TeTeC, GIS Division
Suite 210 - 1430 Florida Avenue
Longmont, CO, USA 80501

Mark Kressin
IBM Corporation
Federal Sector Division
6300 Diagonal Highway
Boulder, CO, USA 80302

Abstract

In recent years Canadian forest fire management agencies have become more dependent on decision support systems for planning and real time decision-making. In particular, the integration of GIS technology and expert systems has become increasingly important for realistic modelling of forest fire potential and fire behaviour situations. However, to date few operational systems have been successfully implemented in an effective and cost-efficient manner. The Intelligent Fire Management Information System (IFMIS), developed by Forestry Canada, is one exception.

Following on the design and principles of IFMIS, a prototype was developed using several different GIS software offerings to evaluate the feasibility and issues related to implementing a fully operational GIS forest fire preparedness planning tool. Specific models were developed using typical GIS toolkit functions and application programming interfaces (API) to address basic fire management concerns. These applications utilize weather, forest inventory, fuels, base map, and topographic data in a real time integrative fashion. A range of different application scenarios were developed to address fire preparedness planning requirements including fire weather modelling, fuel table modelling, fire behaviour prediction, fire detection and the deployment of initial attack resources. Both the Canadian Forest Fire Weather Index System (FWI) and the Canadian Forest Fire Behaviour Prediction System (FBP) were incorporated as the platform for all empirical modelling equations.

This paper presents the results of the prototype, including a review of the issues related to integrating GIS technology and expert systems techniques in a manner consistent with fire management methodologies and requirements. An emphasis is placed on the opportunities for customizing commercial GIS software using industry-standard toolkits. Of particular concern is the issue of temporal data. This involves both historical fire data and time-sequenced fire growth predictions. Methodologies will be described that afford both regular monitoring of fire potential as well as real time prediction of fire behaviour. Examples will be presented including a real time demonstration if time permits.
B5 Harvesting operations

Integration of silvicultural record keeping and geographic information systems
Robert Kennett, Reid, Collins and Associates, Vancouver, BC, Canada

GIS-based strategic planning at MacMillan Bloedel Limited
Brad Whitehead et al., MacMillan Bloedel Limited, Nanaimo, BC, Canada

Elements of management for tracking forest planning in Quebec with the aid of GIS
Gilles Arsenneau et al., Université Laval, Sainte Foy, PQ, Canada

Probability based spatial-temporal modelling for natural forests: sampling techniques, model development, accuracy assessment, and residual evaluation
Kim Lowell, Université Laval, Sainte Foy, PQ, Canada
Integration of silvicultural record-keeping and geographic information systems

Robert Kennett, RPF
Reid, Collins and Associates
A Division of H.A. Simons Ltd.
503-425 Carrall Street
Vancouver, B.C.
V6B 2J6

Abstract

Conceptually, silvicultural record-keeping is an ideal application for Geographic Information Systems. Silvicultural activities are spatial in nature, are linked to other thematic layers such as forest inventory, and contain descriptive attribute data. However, implementation of a silvicultural record-keeping system within the framework of a GIS is not a straightforward task due to the nature of the data.

This paper examines the motivation for silvicultural record-keeping and outlines some of the problems that may be encountered when integrating silvicultural information into a GIS. A conceptual framework for development of a record-keeping system is also presented.

Introduction

Geographic Information Systems have been used to maintain forest inventory information for a number of years. More recently, GIS has been used in other forestry applications. One application that is attracting greater attention is silvicultural record-keeping systems.

Traditionally, silvicultural records have been maintained either in a manual filing system, or in a non spatial computerized database system. However, there are three characteristics of silvicultural records that make them ideally suited to implementation within a GIS framework.

First, silvicultural activities are spatial in nature. They take place on polygonal areas of land that are defined in the real world with areas and locations. Second, each activity has descriptive attributes (e.g., species, number of trees planted, etc.) associated with it.

Finally, silvicultural information is linked with other thematic layers in the database. For example, forest inventory information (species, stocking, quality) is dependent to some degree on the silvicultural activities that take place. Also, the actual treatments that are performed are a function of other parameters such as slope, aspect, elevation, biogeoclimatic zone, and susceptibility to insects and disease.

While the concept of a GIS-based silviculture record-keeping system is not complicated, its actual implementation can be extremely complex due to the regulatory environment and the variety of silvicultural treatments that can be applied to a single area.

This paper examines the motivation for developing a GIS-based silvicultural record-keeping system, outlines the problems associated with such a system, and suggests a framework that may be used.
Motivation for silvicultural record-keeping system

There are several reasons why forest companies are becoming more interested in implementing a GIS-based silvicultural record-keeping system. The most important of these reasons is the ever increasing reporting requirements of the provincial government. These requirements result from the method by which forest land is administered in British Columbia. Ownership of the majority of forest land is retained by the government, with forest companies harvesting the timber from this land under a variety of administrative tenures. These tenures usually require reforestation to the "free-to-grow" state following harvest. There may also be provisions in the tenures for incentives to carry out more intensive silvicultural activities such as thinning and fertilization.

As a result, the most common question asked by our clients when discussing record-keeping is "Can it do MLSIS reports?" MLSIS, or Major Licence Silvicultural Information System, is the mechanism used to report silvicultural activities on Crown lands in British Columbia. This system consists of standardized reports and maps that are submitted three times per year for harvesting operations, and four times per year for silvicultural operations. These reports and maps require maintenance of accurate information concerning silvicultural activities, and usually involve a staff member going through the files for several days to complete the requirements.

In addition to the MLSIS reports, each licencee must submit an annual report to the Ministry of Forests describing the operations (including silviculture) that have taken place during the previous year. A computerized record-keeping system is a very valuable tool for preparing this report.

Along with the requirement for reporting to government agencies, there are also other external as well as internal reporting requirements that must be satisfied. One of our clients reports that questionnaires relating to silvicultural costs and treatment areas were received from the Canadian Pulp and Paper Association, Council of Forest Industries, and Ministry of Forests last year. Internally, managers often need to know the questions such as how many hectares were planted last year, and how much did it cost? These questions may be required because of traditional accounting and budgeting processes, or because the public and special interest groups are starting to raise these types of questions more frequently. Usually, the managers need the answers "yesterday" which implies that the information must be readily at hand.

The third reason that forest companies implement silvicultural record-keeping systems is that they can assist in the planning of work programs for the future. For example, foresters need to know how many hectares of land will be planted next year, and where the planting will be located so they can determine budgets, organize the planting contracts, and check on accessibility.

Another reason for implementing a record-keeping system is to provide better forest management through the process of learning from past successes and failures. At times, it has seemed that success was measured by the number of wheelbarrows it took to carry their completed field survey forms. A wealth of information was collected but it was difficult to use because it couldn't be easily accessed. As professionals, foresters are constantly trying to improve their knowledge and performance. If accurate, easily accessible records are maintained it is possible to answer questions like "What combination of treatments and physical factors make certain plantations perform above average? Can they be duplicated elsewhere?"

The dollars spent on silviculture by governments and companies represent a significant investment. One company has used the following analogy to emphasize the need for GIS-based silvicultural record-keeping systems:

"If a company were to take the money it spent on silviculture and invested in the stock market, the shareholders would want to know the status of that investment. Why wouldn't we treat our investment in silviculture any different from an investment in the stock market?"

Finally, the different working environment of today provides a motivation for maintaining computerized record-keeping system. The work force is much more mobile now than it used to be, with the result that there are frequent staff turnovers. It is no longer possible or acceptable to allow staff members to retain the knowledge in their heads or in a filing system that only they understand.

Requirements of a GIS-based silvicultural record-keeping system

Several fundamental concepts must be emphasized in order that a GIS-based silvicultural record-keeping system can be successfully implemented in a real world situation.

The system must be developed with an open design that will allow the system to be easily modified as new types of treatments are incorporated into the silvicultural prescription and the reporting regulations change. Changes in reporting regulations may require only a change in report formats; however in some cases they may require new data to be collected and thus stored in the database.

One of the advantages of computerized database systems is the amount of information that can be stored. Unfortunately, it is not often realized by the user that there is a cost in terms of system complexity and management that is associated with these great volumes of data. Decisions regarding which data and at what level of detail is to be collected must be made in advance.
An often heard response to this is “Well, you never know... someone might want to know that” which usually results in a system full of data that is never accessed. A good rule to follow is that if you cannot identify and document a particular need then the data should not be in the system. If a future need for this data arises, there should not be a difficulty in incorporating it into the system if an open and flexible design is used.

Problems associated with implementing a GIS-based silvicultural record-keeping system

As discussed in the introduction, maintenance of silvicultural activities is an application that appears to be ideally suited to implementation within the framework of a GIS. However, there are a number of characteristics of silvicultural activities that make successful implementation of a GIS-based system difficult.

First, there are many different types of activities that can take place within a forest company's operating area. For example, typical silvicultural activities might include site preparation, regeneration, brushing and weeding, regeneration surveys, free-to-grow surveys, juvenile spacing, pre-commercial thinning, commercial thinning, pruning, and fertilization. Each one of these activities has a different set of descriptive attributes that must be maintained. For example, site preparation attributes might include the method, cost, and degree of disturbance created. On the other hand, regeneration attributes may include species, type of stock, seedlot, planting density, seedling quality, and cost. For this reason, it is impossible to store the attributes for all activities in a common database table, which requires that a thematic layer must be created for each different activity type.

Further complicating the problem described above is the fact that it is necessary to examine the different types of activities together. Foresters often ask questions such as “Which areas of land were planted in 1985 and have had free-to-grow surveys completed?” Therefore, it is not sufficient to create individual thematic layers for each of the different activity types. Rather, a resultant layer composed of the overlay of each of the different activity types must be created.

This requirement for a resultant thematic layer presents the second major problem in implementing a GIS-based silvicultural record-keeping system. Different silvicultural activities are seldom carried out on exactly the same area of land, with the consequence that many valid resultant polygons, and even more invalid “sliver” polygons are created. Figure 1 shows how these sliver polygons can be created.

The valid resultant polygons present problems in ensuring that the correct attributes are stored with each one. Although most GIS systems supposedly handle this aspect automatically, very few actually make it easy to implement. Because silvicultural records are dynamic in nature, it is necessary to recreate the overlays each time a new activity takes place.

The invalid sliver polygons present an even more complicated question. When is a sliver polygon not a sliver polygon? Is it 0.5 hectare, 0.25 hectare, or 1.0 hectare? An appropriate answer is that the data should only be kept down to the level at which the resource is managed. The difficulty is that there is a reluctance to “throw out” this “data”, even though it will never be used at an operational level. Also, the elimination of the slivers must be consistent so that the same database is created if the overlay process is repeated.

The third problem associated with implementing a record-keeping system is that the same type of activity can occur to the same area of land more than once. For example, plantations often fail and it is necessary to replant all or part of the area originally planted. If the regeneration activity type is treated as a single thematic layer, it becomes very difficult for a system to distinguish and keep track of the two individual activities, particularly if the two activities are not entirely coincident.

A fourth problem of integrating a silvicultural record-keeping system into a GIS database is the procedure by which the forest inventory thematic layer is updated. When a cutover area becomes “free-to-grow”, the inventory database is updated. However, inventory polygons are based on homogeneity of factors such as species, age, and height. Areas within a cutover area may have received totally different treatments to achieve the “free-to-grow” status, but may have identical stands from an inventory perspective. Thus, the process of converting from silvicultural records to inventory must be capable of undertaking the generalization necessary to create these homogeneous polygons, while also maintaining a record of the individual treatments that created them.

This last problem raises another issue. To what degree does a silvicultural record-keeping system also become a history record-keeping system? If part of its purpose is to maintain a record of the history of a given area of land, should it also maintain a history of previous forest types and treatments? This may not be a serious problem where clearcutting and long rotation ages are prevalent. However in situations where partial cutting is used or in tropical plantation forestry where effective rotation ages can be as short as 5 years, it will be a significant issue in terms of data management and data volumes.

A final problem, at least for developers of a GIS-based system, is the need to create a solution that will work for more than one client. In this way, development costs can more readily be recovered, and the purchase price for the end-user reduced. Unfortunately, there is no standardization of GIS software or database software between users. Furthermore, the reporting regulations are different in each jurisdiction and the types of activities, as well as the individual attributes recorded for each activity always seem to be unique for each user.
FIGURE 1

CREATION OF SLIVER POLYGONS THROUGH GIS UPDATE PROCEDURES.

ORIGINAL GIS LAYER
A = ORIGINAL CUTBLOCK

SILVICULTURE ACTIVITY UPDATE
A = NATURAL REGENERATION
B = PLANTING

UPDATED GIS LAYER

SILVICULTURE ACTIVITY UPDATE
A = STAND TENDING

UPDATED GIS LAYER WITH POTENTIAL SLIVER POLYGONS
Suggested framework for implementing a GIS-based silvicultural record-keeping system

The intent of the framework proposed below is to promote discussion and exchange of ideas for successful implementation of a GIS-based record-keeping system. It is not intended to present the best solution to the problems described above, or even to solve all of these problems.

The basic administrative unit used in the system is the cutblock, or opening. Each cutblock entered into the system has a unique identifier, and all silvicultural activities are referenced to a specific cutblock. Each activity that takes place within the cutblock must be assigned a unique number or other identifier in order to facilitate activities of the same type occurring in the same opening.

The attribute data is stored in a series of related database tables: "master table", "base data table", and individual "activity data tables". Figure 2 shows the three types of tables and linkage to the graphic database. In this example, there are seven polygons, three of which (124, 137 and 139) contain standing timber and have had no silviculture treatments; thus they have no reference in the silviculture database. The remaining four polygons are formed as the result of harvesting and silvicultural activities. Polygon 231 is formed from a single opening (A112), while polygons 232, 233 and 234 are formed from a second opening (A143) and the subsequent silvicultural activities.

**FIGURE 2**

**SILVICULTURE ATTRIBUTE TABLES.**

<p>| MASTER TABLE |</p>
<table>
<thead>
<tr>
<th>POLYGON#</th>
<th>OPENING#</th>
<th>ACTIVITY1#</th>
<th>ACTIVITY2#</th>
<th>ACTIVITY3# ...</th>
<th>AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>231</td>
<td>A112</td>
<td>R012</td>
<td>S005</td>
<td>...</td>
<td>10</td>
</tr>
<tr>
<td>232</td>
<td>A143</td>
<td>R014</td>
<td>S003</td>
<td>...</td>
<td>11</td>
</tr>
<tr>
<td>233</td>
<td>A143</td>
<td>R014</td>
<td>S003</td>
<td>...</td>
<td>8</td>
</tr>
<tr>
<td>234</td>
<td>A143</td>
<td>R014</td>
<td>S003</td>
<td>...</td>
<td>8</td>
</tr>
</tbody>
</table>

<p>| BASE DATA TABLE |</p>
<table>
<thead>
<tr>
<th>OPENING#</th>
<th>ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A112</td>
<td>NW 375 10 ha ...</td>
</tr>
<tr>
<td>A143</td>
<td>N 360 33 ha ...</td>
</tr>
</tbody>
</table>

<p>| REGENERATION TABLE |</p>
<table>
<thead>
<tr>
<th>ACTIVITY#</th>
<th>ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>R012</td>
<td>FIR 1978 10 ha ...</td>
</tr>
<tr>
<td>R014</td>
<td>PINE 1979 25 ha ...</td>
</tr>
</tbody>
</table>

<p>| STAND TENDING TABLE |</p>
<table>
<thead>
<tr>
<th>ACTIVITY#</th>
<th>ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>S003</td>
<td>HAND 1990 10 ha ...</td>
</tr>
<tr>
<td>S005</td>
<td>SPRAY 1979 10 ha ...</td>
</tr>
</tbody>
</table>
The master table forms the linkage between the spatial database and the attribute tables. There is one record in this table for each of the resultant polygons formed during the overlay of the various silvicultural activity themes in the spatial database. The actual attribute data that is stored in this table consists of:

- area
- pointers to the activities that have taken place on the polygon in question

The base data table contains attribute information that applies generally to the entire cutblock, and is relatively static over time. Therefore, only one record per cutblock is required. Typical types of attributes that are stored in this table include:

- total cutblock area
- slope
- aspect
- elevation
- biogeoclimatic zone
- administration (forest region, district, tenure, etc.)

The activity data tables contain the descriptive attributes for each activity. The different specific silvicultural activities can be grouped into general categories of treatment types for which there are similar attributes that must be stored. For example, "REGENERATION" is a general activity type, and specific activities that occur within this general type may be planting, natural regeneration, seeding, fill-in planting, and coppicing. Each of these specific activities contains similar attributes such as species, stocking, etc., and can therefore be grouped together into one attribute table called "REGENERATION".

Through this process of grouping into general activity types, it is possible to reduce the number of different activity attribute tables required to approximately six, including:

- denudation
- site preparation
- regeneration
- surveys
- brushing/weeding
- stand tending

There is one record per activity within the cutblock, and that record is entered in the appropriate general activity table in the list above. The specific attributes that are entered for each activity will vary with the general activity type, but there are some fields that are common to all types.

Some examples of these include:

- specific activity name (e.g., planting, natural regeneration)
- activity identification number
- date
- actual or planned
- area (from field traverse)
- cost

There are a few things to note with regard to the actual attributes stored for each activity. First, the activity can either be planned for some point in the future, or have already happened. In this way, reports can be generated that will outline proposed future silvicultural programs. The process of assigning future activities may be automated to a certain extent (e.g., surveys of some description usually follow regeneration), but some manual assignment and checking by a forester is also required.

Second, the area for the activity is entered by the user based on a field traverse or some other measure, rather than being calculated by the GIS system. The reason for this is that unless a more precise method than digitizing (e.g. coordinate geometry) is used to enter the boundaries of the activity, the area calculated by the system will not be the same as that calculated when the activity takes place due to the inherent error involved in the transfer and table digitizing operations. Furthermore, there will likely be areas that are significant from the regulatory point-of-view and which add nothing to the graphic information stored in the GIS. Examples of these areas might be small wet areas in a large clearcut that were not planted. Also, removal of sliver polygons will alter the area if it is calculated by the GIS. Therefore, the only way to ensure consistency on the reports submitted to the government is to use an entered area based on the field traverse. The areas calculated by the GIS would be used for any analysis or ad hoc queries involving overlays of different activities.

The above paragraphs have defined the general database structure of the record-keeping system. To be integrated into the GIS environment in a manner that can be used efficiently, some additional requirements must be met.

First, the silvicultural records and the tools necessary to maintain them must be accessible within the GIS environment. At the simplest level, this means that an import/export routine should not be required to move attribute data into and out of the GIS. The database management system (DBMS) should be directly accessible from within the graphics environment of the GIS, to facilitate attribute updates and queries without moving in and out of different programs.

Equally important, both the GIS and DBMS should implement the concept of relational database structures and database views. Because the complex nature of silvicultural records requires the attribute data to be stored in several different tables, but queried as if it were
one table, simultaneous access to related records in different tables is required. Most database management systems support this concept, but very few GIS packages are able to take advantage of this functionality within the graphics/query environment.

Finally, a smooth process for creation of the resultant polygons, rationalization and removal of sliver polygons, and automatic linkages between the resultant polygons and the appropriate attribute records must be implemented. Most GIS vendors will tell you that this is "no problem", but in practice developing a mechanism that does not break down when you get into a real world situation with real world data is not straightforward.

**Possibilities for the future**

The framework described above is based on working within the limitations set by most GIS software packages today. However, there are significant breakthroughs being made that should allow implementation to proceed more smoothly.

Perhaps the most encouraging development is the trend toward supporting the concept of "one-to-many" relationships between the spatial and attribute databases. This process, illustrated in Figure 3, greatly simplifies the mechanism by which several different activity attribute records can be related to the same polygon in the spatial database.

Another very positive development is the trend towards transparent linkages to a variety of relational database systems by the same GIS package. This will make it far easier for developers of applications such as silvicultural record-keeping to support multiple hardware and software platforms, resulting in enhanced product quality for a reduced price.

Also very encouraging is the trend by GIS vendors to take advantage of the advanced features built into most DBMS systems, including relational structures, views, and input screens. This tighter integration of the DBMS into the GIS environment can only result in more user friendly applications that make it far easier to maintain a valid, consistent database.

**Conclusions**

Although the implementation of a GIS-base silviculture record-keeping system is quite complex, many of the difficulties that have been outlined in this paper can be overcome through careful planning and through close cooperation between the users and the developer. Above all the developer must understand the user's needs and the users must also have a thorough comprehension of their own requirements and priorities.

The current focus of GIS development and integration with database management system capabilities is extremely positive as it can only lead to easier and less restrictive application development.

**FIGURE 3**

**MANY-TO-ONE AND ONE-TO-MANY FILE RELATIONS**
GIS-based strategic planning at MacMillan Bloedel Limited

Peter J. Kofoed
MacMillan Bloedel Limited
Woodlands Services Division
Nanaimo, BC V9R 5H9

Glen A. Jordan
Faculty of Forestry
University of New Brunswick
Fredericton, NB E3B 6C2

Brad T. Whitehead
MacMillan Bloedel Limited
Woodlands Services Division
Nanaimo, BC V9R 5H9

Abstract

MacMillan Bloedel Limited, like many Canadian forestry companies, is no stranger to long-range strategic forest planning, nor GIS technology. However, it has only recently begun to apply GIS in strategic planning. This paper documents the company’s initiatives and experiences to date. It begins with a review of the company’s simulation modelling approach to wood supply analysis (forest estate modelling) during the 1980s. The review pays particular attention to difficulties associated with lack of location-specific resolution. The paper follows with a discussion of two recent company initiatives in applying GIS in forest modelling. In the first, a grid-based approach is introduced and offered as a better alternative to vector-based approaches. In the second, a start has been made on incorporating spatial constraints, including adjacency conditions, in the modelling process. The paper concludes with an indication of future plans that include combining features of the two initiatives.

Key words: GIS, forest modelling, wood supply, strategic planning.

Introduction

A forest management challenge:
MacMillan Bloedel (MB) faces two forest management challenges common to the British Columbia Coastal forest industry. First, forests are increasingly being managed for a wide range of values. How can strategic plans be developed that are consistent with operationally integrated resource management? How may the trade-offs between options be objectively examined?

Second, the coastal industry faces the transition from virgin forest areas known as old growth to a different forest on previously cut-over areas known as second growth. Old-growth timber is large, high valued, changes slowly and occurs in large undeveloped blocks. Second-growth timber is smaller, lower valued, grows rapidly and occurs in a pattern of developed stands. For MacMillan Bloedel operations, the timing of the transition varies from now through to several
decades in the future depending on logging history. The challenge is to plan the transition recognizing differences (including spatial elements) between the two forests.

To meet these challenges requires recognition of the location of different forest conditions and their relative positions. This paper describes MB's recent action and outlook on GIS-based forest planning.

The first section briefly describes current forest level modelling at MB, including recent developments. It is noted that spatial identity is lacking. Discussion details the need for location-specific resolution in the planning process and then describes the foundation for such analysis—MB's GIS-based forest inventory. In the following section, two recent initiatives in spatial analysis are discussed. In the first, which began as an introduction for MB in strategic forest-level spatial modelling, discussion centers on adoption of a raster data structure. The second initiative focused on impacts of spatial constraints on harvest scheduling at the drainage level. The final section describes MB's desire to combine elements of these two initiatives and to expand their use.

Recent strategic forest modelling experience

Since the signing of Tree Farm Licence agreements in the 1950s and 1960s, MB has been involved in strategic forest-level analysis. The demand for such analyses and their complexity has increased dramatically. This parallels society's increasing concerns for a wide range of forest values and the continuing transition to the second-growth forest. It also reflects the increasing amount of forest information and computing power, and development of analytical procedures. Initially, analysis was for explicit calculation of Annual Allowable Cuts (AACs). Starting in the early 1980s emphasis has turned to examining the long-term timber supply impacts of forest management scenarios, particularly landbase and silvicultural options. MB's current inventory projection simulation model named FEM has proved useful for comparing such options. A major focus has been to improve the silvicultural mix between operational reality and strategic analysis. This is being achieved through application of a powerful in-house yield model (Y-XENO) and development of regeneration models based on field experience. While FEM does utilize the stand-level forest inventory data that is stored in MB's ARC/INFO GIS, it does not directly recognize the location and relative positioning of forest conditions. In larger analyses stand-level data is aggregated into strata.

Development of spatial resolution in strategic-forest planning is required to meet the planning demands of the 1990s.

Many operational harvest constraints for protecting non-timber values are location specific. These include leavestrips (greenup of cutover before harvest of adjacent blocks), special management of riparian areas depending on fish values and of forage areas adjacent to deer winter ranges and local rate-of-cut restrictions for visual and hydrologic reasons. FEM indirectly allows for these concerns by requiring additional inventory to be available for harvest. These allowances are not site specific and so may be adequate in some areas but not in others; strategically the timber may be there but operationally may not be available for harvest. There is need for a more effective link between strategic and operational levels of planning.

Spatial information is required to integrate the different spatial resolutions of forest management and basic inventory units (i.e., stands). Management prescriptions (e.g., harvest blocks) ultimately target areas that are aggregates or divisions of forest conditions and do not follow stand boundaries necessarily. This relationship between management prescriptions and the stand inventory differs between undeveloped (not roaded) old-growth areas of larger stands and the general second-growth pattern of developed smaller stands.

Mapped schedules (e.g., wildlife areas, timber harvest, silvicultural treatments) strengthen the links between strategic and operational planning. Forest management strategy is more effectively communicated to operations through maps and feedback of operational reality is encouraged through editing of the mapped schedules (manually or by computer). Such feedback loops may be repeated as desired. This process is not available with FEM when run in strata mode (aggregations of stands) as stands contributing to managed strata can be identified only indirectly.

In summary, forest level analysis must include spatial recognition to improve "on the ground" reality in strategic analysis and to effectively communicate strategic objectives to operational planning. More specifically, there are three main concerns. The first is to include the impacts of adjacency constraints in strategic analysis, in the determination of harvest levels and of forest management strategies. The second is to examine harvest blocks in a flexible manner. Harvest blocks are often not tied to stand boundaries and their size and shape may change as planning proceeds. Procedures are required for grouping and partitioning stands into harvest blocks where they are not explicitly defined. The third concern is to provide mapped harvest and treatment schedules, with the ultimate objective of allowing for interactive editing of schedule maps displayed on a computer monitor.

A GIS-based inventory is of course the key to improving the exchange of the right information between strategic and operational planners. MB first started its GIS-based forest inventory in 1979, but like many companies who began early in the game it has been a long tough road and only in the last few years has the inventory been readily available for analytical processing. Even then a large portion of MB's inventory is based on low intensity sampling. Although adequate for strategic
planning, it has limitations for site specific operational planning. MB manages approximately 1.5 million hectares of land on the coast. The forest inventory is stored in an ARC/INFO GIS that runs on a series of networked Sun workstations. Inventory revisions are run on an annual basis, providing current information for planning. Gradually, non-timber resource information (deer winter ranges, biodiversity corridors, viewsheds, fishery values, etc.) is being added to the system, enhancing the ability of the GIS to provide the information for “total forest” planning.

Recent initiatives in GIS based strategic planning

There have been two recent initiatives for including spatial resolution in strategic planning. The first, a forest-level approach, has been valuable to MB for introducing concepts and procedures and for providing a data structure useful for our spatial planning needs. It is discussed below under the heading “Forest Level Spatial Data Structure”. The second initiative, run at a sub-forest unit level (e.g. a drainage), focused on the impacts of spatial constraints on harvest schedules. It is discussed under the heading, “Drainage Level Spatial Constraints”.

Forest level spatial data structure

New Brunswick research and development efforts (Jordan and Erdle, 1989; Baskent and Jordan, 1991) provided ample evidence that a GIS-based approach to forest modelling, by maintaining geographic distribution of timber inventory, makes it possible to incorporate operational realities such as harvest blocking and leafstrips in strategic planning and to produce prescriptions/schedules in mapped form. Not only is a truer assessment of future wood supply assured but the likelihood of long-term strategic plans being implemented at the operation level is greatly improved.

The spatial model developed in New Brunswick, however, turned out not to be directly applicable to MB's forest circumstances. The model is stand-based, and forms and schedules harvest blocks by collecting neighboring stands into economically harvestable concentrations of volume (see Figure 1). Built around the ARC/INFO GIS the technique relies heavily upon the topological relationships created by this vector-based GIS and works best with highly fragmented forests, i.e., ones with small stands. While this model would be applicable for MB's second-growth areas, it is inappropriate for a forest that also contains extensive areas of uniform timber type, like MB's old-growth areas. In this latter circumstance, stands would have to be partitioned in order to form harvest blocks and leafstrips. Techniques for doing this with vector-based GIS would be tedious at best, and impractical at worst. This necessitated development of a new spatial modelling technique at MB.

As an alternative, the company turned to a raster (or grid) data structure. In simplest terms, a raster data structure would capture the geographic distribution of forest conditions by dividing the entire forest up into a regular grid of cells of specified size (dependent on desired resolution). Beyond the inherent simplicity of the raster data structure, its flexibility in forest modelling is significant. By providing a spatial resolution finer than stratum or stand-level detail, it effectively integrates the different spatial resolution of inventory (stand based) and management prescriptions (e.g. harvest blocks). With equal ease, aggregation and partitioning of forest conditions in strategy testing and evaluation is possible (see Figure 2). By permitting this level of location-specific resolution a raster-based approach promises to improve the quality of information exchange between strategic and operational planners.

Since the ARC/INFO GIS lacks a raster processing capability, MB technologists had to "simulate" a raster data structure with ARC/INFO point coverages. The point coverages are created by first generating a regular grid of points and then executing a point-in-polygon overlay with stand-based forest inventory coverages. Each point in the resultant point coverage is assigned a stand type and development information as well as a series of empty attributes for bookkeeping during simulation and for recording intervention schedules that result.

As more layers of data are added to the GIS (non-timber resources, harvesting systems, etc.) the attribute list for the underlying grid cells will expand but the concepts for creating and processing them will remain the same.

Map results, such as harvest and planting schedules, may be generated following a simulation run by executing an ARC/INFO procedure.

Drainage level spatial constraints

In a separate initiative FEM has been adapted to examine a number of spatial harvest scheduling constraints. Several drainages under MB management have received a lot of attention and planning effort because of concern about non timber values. Mapped harvest blocks and roads were added for one of these drainages, providing a set of test data for development of planning procedures.

This development has been vector based. Basic polygons are parts of stands divided according to overlapping harvest blocks and non timber concerns such as viewsheds, biodiversity corridors and harvesting the profile. Each basic polygon's description includes identification of harvest block, viewshed, etc.

A number of overlapping timber harvest constraints are recognized. These include adjacency, rate-of-cut and harvesting the profile. A common adjacency constraint is leafstrips (greenup) in which areas adjacent to a
Figure 1. Using the topological relationships maintained by a vector-based GIS, a spatial model is able to group immediately adjacent stands into "pseudo-blocks" of maximum size (from Baskent and Jordan, 1991). In this example the maximum block size is 80 hectares. In subsequent scheduling, the same topological information may be used to prevent harvest of adjacent stands for a period of time sufficient to permit greenup.
Figure 2. Using a raster-based GIS, a spatial model forms "pseudo-blocks" by grouping adjacent cells, orthogonally as well as diagonally, until a maximum block size (80 hectares in this example) is reached. In subsequent scheduling, harvesting of adjacent cells (and cells up to some minimum distance) may be prevented for some period of time to permit greenup.
harvested area cannot be harvested until the initial area has greened up. The greenup period is often between 8 and 15 years depending on objective and site index. To plan a harvest schedule with greenup constraints it is necessary to know which harvest blocks are adjacent to one another. Adjacency information is developed within the GIS and passed to the Forest Level model.

The rate-of-cut (harvest) may be restricted on a local area basis to protect visual values or for hydrologic concerns. For example, a drainage is divided into a number of viewsheds which vary in visual quality objectives and corresponding rate-of-cut constraints. For each area the constraint is defined as the maximum percentage of area below a defined age.

The intent of a harvest-the-profile constraint is to match in some way the harvest description with the inventory description. For example, there is a desire to harvest according to the distribution of areas by harvesting system within the inventory. If ten percent of the inventory is mapped for long-line systems then it is required that ten percent of the harvest area over a ten-year period is also by long-line systems. To examine the rate of cut and profile constraints it is necessary to identify constraint areas (e.g., viewshed and profile component) for each basic polygon. Again, this is developed in the GIS and passed in the data file to the model.

Initially the main concern was to determine whether there was a feasible harvest schedule given the overlapping constraints. The second question was what impact do different combinations of constraints have on possible harvest levels? The procedures proved useful, showing for the test case, the existence of possible harvest schedules and the harvest volume impacts of the constraints. Further, harvest schedules are readily mapped by passing the harvest output file back to the GIS. Mapped output assists with checking of reasonableness and comparing options. The GIS data base and adjacency information is being used to improve the link between operational reality and strategic planning.

The next stage, underway now, is to add more engineering rationale and to add economics to the harvest scheduling process. In harvest volume terms there may be a number of feasible schedules. Which is preferred? Also, what are the trade offs between planning scenarios? The first question is important to forest engineers. The second is important input to planning policy.

Even in this situation of defined harvest blocks and adjacency relationships the usefulness of a raster data base structure was evident. Many planning problems may be solved by partitioning polygons while retaining locational identity. For example, a small viewshed includes part of a single harvest block. If the block is harvested all at once the viewshed rate of cut constraint is broken. Dividing the harvest block into two smaller harvest blocks may provide an acceptable harvesting alternative while retaining the visual values. This is most easily accomplished with a system of grid cells.

Where to next?

The spatial constraint accounting system and the raster data structure will be brought together. This will be facilitated in the latest version of ARC/INFO by a noteworthy new raster processing capability (called GRID) based upon Dana Tomlin's map algebra (Tomlin, 1990).

Procedures have been developed on relatively small forest areas. It is necessary to expand the results and the analysis to major blocks (or working circles) within a management unit. For some applications it may be sufficient to use a number of drainage analyses to provide a basis for indirect rules in the larger analysis (similar to the additional inventory requirement in FEM mentioned above). The advantage is reduced complexity in the larger analysis. For other analyses, a more direct expansion of spatial modelling to larger areas is required. Of particular importance is the need for such tools to objectively compare forest management scenarios for policy analysis. What are the trade offs in terms of timber values and non-timber values? Does another option make more sense?

Spatial modelling has the potential to greatly assist the process of formulating twenty-year plans. Data concerns are less limiting than for short-term operational planning where site specific detail is important. The modelling process provides a framework for defining harvest constraints and attaching financial information. This is used to identify feasible harvest schedules and to compare options. Further improvements to this planning process include outputting mapped schedules and encouraging engineers to edit and feed them back to the analysis. These relatively detailed twenty-year plans will be included as the first portion of longer term forest planning analyses to ensure consistency between the two time frames.

Mapped harvest blocks and roads were available in the test area used for the analysis of spatial harvest scheduling constraints. This level of planning detail is not available for all areas. The raster-based data structure provides the flexibility required to develop procedures for simulating harvest blocks by aggregating and/or partitioning stands. Harvest blocks produced in this way may then be mapped to obtain feedback from forest engineers.
Summary

Use of GIS based strategic forest planning is essential for MB to meet the challenges of managing the forest for a wide range of forest values and for planning the transition from the old-growth forest to the second-growth forest.

In particular, recognition of site specific locations is required to examine the impacts of spatial constraints, provide flexibility for handling different spatial resolutions (e.g., stands and harvest blocks), and to produce maps. These features improve the links between operational planning and strategic planning, communicating operational reality to strategic planning, and a better awareness of strategic plans to operations.

The tools for effective forest-level spatial modelling are coming together. MB has a GIS-based forest inventory for its management land base. Recent work has shown that a raster data structure is most useful for our spatial planning needs. Routines are being developed to examine the impacts of location specific constraints on harvest schedules. The next task is bringing this work together and expanding its use to larger geographic units.

References


Elements of management for tracking forest planning in Quebec with the aid of GIS

Gilles Arsenneau
Kim Lowell

M.S. Student and Professor, respectively
Universite Laval
Industrial Chair in Geomatics
Faculty of Forestry and Geomatics
Pavillon Louis-Jacques Casault
Cite Universitaire, Ste-Foy
Quebec, CANADA G1K 7P4
Office: (418) 656-7998
Fax: (418) 656-7411

Abstract

(This is an English version of a paper written in French for presentation (in French) at the Canadian Conference on GIS to be held in Ottawa, Ontario in March 1992.)

One must optimize the use of GIS to perfect one's knowledge of a forest territory. By implementing a spatial-temporal model to track forestry operations, one would like to create a tool to encourage the use of time in forest management and minimize unexpected surprises when actual operations are realized. Presently, there is very little integration of information in the planning process for forestry operations and exploitation. However, the management of this information is now possible with greater ease. During planning, one must identify how to integrate in the decision process the impacts of forest interventions on the ecosystem. To better exploit the potential of a GIS, it is necessary to store the pertinent management information that constitutes the knowledge base. In summarizing descriptive information about forest management operations, we can increase the precision of our knowledge about the dynamics of the forest.

Introduction

With the advancement of a technology such as GIS, we have reached a point where it is necessary to question the practices of an earlier age of forest management. The capacity for management and interpretation of forestry data can now be more easily realized.

Presently, we must develop and integrate a variety of forestry information required for the planning, control, and tracking of forest activities. The problem is more critical now that forest resources of high quality are rarer and the management of the mixed forest, as is the case in Quebec, is more difficult.

Presently, strategic forest planning is conducted with a data base that corresponds to a tactical level — that is, a relatively coarse knowledge of the terrain. It is our intention to determine if one can modify one's planning methods by utilizing more exhaustive data obtained from previous years. We want to conceive a tool to guide planning and to encourage the use of time-based information in order to minimize the effects of surprises.
One must wonder why we do not compare the volumes forecast for a territory with the volume actually obtained for a given territory. These data, considered with a certain amount of human interpretation, would provide an inventory that would allow us to improve our projections of forest resources. Furthermore, one could utilize these data to model better the reaction of the ecosystem to a given operation. However, our present planning methodology does not permit us to establish the necessary procedures for validation and feedback.

Between the planning and realization of forestry operations, there are a number of procedures that one must understand and integrate as knowledge. However, it is necessary to know what one wants and how to get it in order to avoid the phenomenon of GIGO (garbage in, garbage out).

Factors of management

One of the principal tasks inherent in forest management planning is monitoring the evolution of the forest. In the province of Quebec, one utilizes the software SYLVA as a tool to simulate forest yield. SYLVA permits one to define yield objectives and the breadth of silvicultural operations for each beneficiary of a forest management contract. However, existing planning techniques make this process difficult. It is necessary to obtain feedback concerning the annual harvest that can be conducted without reducing the forest capital. Moreover, this is necessary for all levels of forest planning.

It is necessary to protect commercial forest stands against the takeover of the forest by undesirable species, maximize the expansion of commercial stands, and accelerate their maturation through a cycle of natural regeneration. The present strategy of forest conservation to achieve these goals must utilize integrated management which considers all forest resources. Furthermore, one would like to conduct forestry operations by minimizing forest interventions and maintaining production. One would also like to eliminate chemical interventions to protect further the environment.

To minimize forest losses, we must protect these resources against catastrophes — namely, insect infestations and fires. In knowing all of the factors which favor these, we must prioritize the most susceptible zones during planning. Specifically, considerable efforts must be expended to minimize the effects of spruce budworm. Finally, to assure adequate wood supplies for the forest industry, we must alter the characteristics of forest stands as a function of expected future industrial needs.

All of these points contribute to promote the implementation of a spatial-temporal model to study the relation between cause and effect.

The conception of such a model has been conducted within the context of supply for a sawlog and veneer mill. This has evolved with the notion of the scarceness of the resource. Furthermore, the sectors of supply for this are the area of mixed-species forest in Quebec. We have had a tendency to manage these zones for either hardwood or softwood. Currently, we want to regard this ecosystem as a different entity — one which is truly mixed. However, this cannot be done without complicating the work of the forest manager.

Methods of planning

Before using Geomatics in forest planning and installing a valid spatial-temporal system, it is necessary to place things within a certain context and to understand better the dynamics of forest planning.

In the province of Quebec, we have divided planning into three steps: the General Plan (for 25 years), the Five-year Plan, and the Annual Plan. For each of these, the data base is the one supplied by the Minister of Forests (MFO) (Figure 1). Each of the planning steps correspond to a Strategic, Tactical, or Operational (respectively) planning level.

A problem is that the forest inventory data from the MFO correspond to the Strategic or Tactical level only, and is not suitable for Operational planning. This is the reason that forest management must be conducted on forest inventories obtained by operation interventions in order to validate projections made before operations commence.

Classification processes

Stratification

It is necessary now to separate the steps of forest management to obtain an Annual Plan closer to reality than the General Plan. The base of all information systems is the reliability of available data. One must, therefore, validate the information on a forest map using ground control points. After one has obtained a certain confidence in the information contained on a map, one moves into the phase of the classification of forest strata. We have identified four general classes of stratum (Figure 2).

1. Inaccessible strata

Within the data base of the MFO, there is a criteria of accessibility (which is based on topographic slope) assigned to each forest stand. However, one must also identify strata located in "inaccessible places" such as ridges, bottomlands, and isolated stands. This identification can be conducted by overlaying topography and elevation information.

2. Priority strata

These are those strata which are susceptible to significant losses of volume if not harvested "immediately." Principally, these include those areas which have been recently subjected to fires or insect infestations,
INTERVENTION PLANIFICATION

GENERAL PLANIFICATION (STRATEGIC)
FOREST TERRITORY ALLOCATED BY CONTRACT (25 YEARS)
CALCULATION OF ALLOWABLE CUT
DÉTERMINATION OF VOLUME TO HARVEST BY SPECIE BY YEAR
DÉTERMINATION OF MAXIMUM ANNUAL CUTTING AREA

FIVE YEARS PLANIFICATION (TACTICAL)
TERRITORIAL DISTRIBUTION BY FIVE FIVE YEARS PLANS
OPERATIONAL TERRITORY DÉTERMINATION
FUNCTION OF ALLOWABLE CUT
FUNCTION OF VOLUME DISTRIBUTION IN TIME
FUNCTION OF THE STATE OF THE ROAD NETWORK

DATABASE (MFO)
FOREST MAP (SCALE 1:20000)
1:50000
STAND TABLE
REGROUPED STAND TABLE
STOCK TABLE
SAMPLE PLOT

ANNUAL PLANIFICATION (OPERATIONAL)
ACCORDING STRATAS RESPONDING TO
HARVEST REGULATIONS
ALLOWABLE CUT
NEEEDS OF THE MILL
ECONOMICAL THRESHOLD

SPATIAL TEMPORAL HISTORY
UPDATING
ANNUAL REPORT
PLANIFICATIONS IMPACTS
FEEDBACK ON THE ALLOWABLE CUT
CONTRIBUTION TO A BEST KNOWLEDGE OF THE TERRITORY

FIGURE 1
FOREST DATA CLASSIFICATION

FOREST MAP VALIDATION

PRODUCIVE STRATAS
YEAR > 50
VOLUME > 50 M³ / HA
SLOPE < 40%
MINIMUM DM3 / STEM FOR PRODUCT
VOLUME / HA / PRODUCT

INACCESSIBLE STRATAS
WAITING STRATAS
PERTURBED
REGENERATED
UNREGENERATED
IMMATURE

PRIORITY 2

PRIORITY 1

PRIORITY 3

REGROUPED STRATAS REVISION

STRATAS CLASSIFICATION

CUT BLOCK OPERATION AREA
spatial correlation and autocorrelation coefficient for locating

STRATAS CLASSIFICATION

OPERATIONAL EVALUATION
SEASON OF EXPLOITATION
MULTIPLE USE CONSTRAINT
PRIORITY ACCORDING TO BUSWORM VULNERABILITY
ECOLOGICAL CONSIDERATION
SPECIE PRIORITY
OPÉRATIONNAL PRIORITY

EVALUATION OF ECONOMICAL THRESHOLD
MEAN COST OF HARVESTED M³ (AMORTIZATION OF THE ROAD COST)

STRATAS CLASSIFICATION
STRATAS SURVEY

FIGURE 2
and where recovery of the area is possible. Secondly, one must identify those areas which are vulnerable to such maladies based on the species, age, and density of the forest stand. Ultimately, it would be useful to utilize ecophysiological information to estimate these parameters. Work is ongoing in the MFO to classify the criteria for vulnerability; results should be known soon. One must then try to integrate these, as much as is possible, into forest planning.

3. Strata in waiting

Regenerating strata

These are those strata which have been subject to (human and/or natural) disturbance and which are regenerating with~hy commercial species. Reforestation work has been effective to eliminate shortcomings in natural regeneration.

Young strata

These are those strata for which the volume and age are not yet sufficient for optimum development. One assigns to them a code indicating the number of years expected before they reach commercial maturity.

Disturbed strata with volume

These are those strata which have been subject to human and/or natural disturbance in the past and whose present forest parameters do not conform to any standard intervention. It is possible that, if no corrective action is taken within these strata, it will require considerable time before they reach an acceptable level of productivity. It is thus very important to exploit these territories “in the near future.”

Disturbed strata without volume

These are those strata which have been subject to human and/or natural disturbance which have not regenerated with commercial species. It is necessary to be able to restore them to productivity “eventually.” These strata constitute an habitual “backlog” of strata that must be restored to production at a relatively high cost.

The Strata in Waiting are those entities for which it is necessary to consider that, if one intervenes within a given sector, these could be integrated into forest planning. The ideal would be to examine the territory with a fine-tooth comb, yet still manage the territory in its entirety. However, to optimize investments, it is preferable to choose those Strata in Waiting for which an appropriate intervention would provide wood during a time of scarcity. Also, choices must be based on ecological criteria and experience in order to identify those sectors which will respond well to prescribed interventions. Still, one will determine the ecological cover and compare this with the planning history. To do this, however, one must have followed management planning and maintained these historic data.

4. Productive strata

These are those strata that provide the wood supply to a factory for the short- and long-term. These are the pivotal strata in the system.

After identifying these strata, we must revise the re-groupment of strata to respond to management needs. The base of all estimates being a sample, we establish our criteria of discrimination on these results. The MFO has already established one regroupment which we must review. The result of this revision will translate into seven classes:

1 - Well-sampled productive strata
2 - Poorly-sampled productive strata
3 - Well-sampled moderately productive strata
4 - Disturbed strata with volume
5 - Disturbed strata without volume which are poorly regenerated
6 - Young strata
7 - Strata in the process of being regenerated

With the stratification process being standardized, one would be able to facilitate management planning with the integration of an expert system. We believe that stratification is a step in which one can define the mechanisms which encourage certainty, and thus formalize the representation of knowledge and provide an appropriate decision tool.

“Experts” use a collection of operational concepts. Each of these corresponds to a node within their heuristic. Possibly we have all of the elements in hand to standardize and “systematize” this step based on an expert system. However, to do this requires one to build a data base in which one can have confidence.

Integration within the “massive forest”

Following this work, one is in a position to start the work in which a GIS is able to help delineate the “Massive Forest” — i.e., relatively large blocks of forest which are able to sustain a harvest. By using a spatial auto-correlation coefficient, we may be able to determine a territorial division (according to a Quad-Trec method) in which certain phenomena — i.e., forest volume — have a tendency to regroup themselves (Figure 3). Instead of examining criteria of contiguity, one would be able to consider minimum distance between forest stands as the criteria of “proximity.”

Furthermore, points on the map could correspond to the centroid of polygons (forest stands), and the value at each point could be considered to be representative of the area and volume corresponding to the polygon.

The area of Massive Forests must consider the Annual Allowable Harvest. It will also be necessary to consider this in order to further research in spatial operations in forest planning, and integrate these into the planning process.