Silva Lusitana, nº especial: 35 - 47, 2004

Large-Scale Planning Address Interior Space Production Three Case Studies from Northern Minnesota

Howard Hoganson*, Joshua Bixby, Susan Bergmann*** and José G. Borges***

* Associate Professor

** Graduate Student

*** Research Fellow

Department of Forest Resources. University of Minnesota, NC Research and Outreach Ctr, 1861 Highway 169 East, Grand Rapids, MN55744-3396, USA

* Associate Professor

Departamento de Engenharia Florestal. Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017 LISBOA

Abstract. Applications of a forest management scheduling model to the forest situation in northern Minnesota added insight on how to better integrate management for ecological and economic conditions. Emphasis was on developing harvest schedules that recognise the value of older forest interior space (core area). Although ownership patterns in northern Minnesota are quite intermixed, results show that most of the gain from improving management schedules to produce old forest interior space can likely be achieved by the larger public landowners through careful spatial planning on their own lands. Simple management rules like cut in larger blocks are not likely to perform well because of lost opportunities to produce more interior space in the shorter term.
Key words: interior space; core area; forest management scheduling; dynamic programming

Sumário. Desenvolvem-se aplicações de um modelo de gestão para solução de um problema florestal em Minnesota. Demonstra-se o potencial deste modelo para integrar perspectivas de sustentabilidade ecológica e económica mediante o desenvolvimento de planos de cortes que reconhece o valor da área de espaço interior de floresta em classes de idade avançada. Apesar da complexidade do mosaico de regimes de propriedade em Minnesota, os resultados evidenciam que as metas relativas à dimensão daquela área de espaço interior poderão ser alcançadas com recurso ao planeamento espacial adequado de áreas públicas. Regras simples de gestão tais como a realização de cortes em manchas de grande dimensão não permitem obter resultados satisfatórios por inviabilizarem a possibilidade de oferecer mais espaço interior no curto prazo.
Palavras-chave: espaço interior; planeamento florestal; análise espacial; programação dinâmica

Résumé. Des applications d'un modèle de gestion forestière sont développées pour une situation de forêt au Minnesota du Nord. On démontre le potentiel de ce modèle à intégrer les perspectives écologiques et économiques moyennant le développement de plans de coupe qui identifient la valeur de l'espace intérieur de forêt plus ancienne. Bien que les modèles de régime

Corresponding author E.mail: hogan001@tc.umn.edu

de propriété au Minnesota du Nord soient complexes, les résultats prouvent que les buts relatifs aux dimensions de l'espace intérieur peuvent être réalisés par une planification spatiale des aires publiques.

Les règles simples de gestion comme la réalisation de coupe en blocs de grande dimension ne permettent pas d'obtenir des résultats satisfaisants pour ne pas offrir plus d'espace intérieur à plus court terme.

Mots clés: espace intérieur; gestion forestière; analyse de l'espace; programmation dynamique

Introduction

Sustainable forest management requires more than just producing a steady supply of timber over time. Forests serve many purposes. Improving and sustaining forest conditions are often primary objectives. Computer models serve as decision support tools for forest managers to help better integrate potentially conflicting economic, ecologic and social objectives. This paper focuses on recent large-scale modelling applications in northern Minnesota to address spatial concerns regarding older forest in Minnesota's forest landscape. The applications focused on how harvesting activities might be scheduled over the landscape so that older forest might be sustained over time and arranged in large enough patches (blocks) to be effective for wildlife habitat and natural ecological processes. A related objective was to examine the potential gains from better coordinating forest management across state and federal ownership boundaries to help better achieve ecologically-based spatial management objectives.

In forest management planning, spatial arrangement of the forest is a relatively new concern that is difficult to define precisely and difficult to model directly in forest management scheduling models. Forest management scheduling models have a long history of use in the US, focusing on efficient and effective ways to sustain timber harvest flows over time. Recent applications have added emphasis on also sustaining environmental conditions such as targets related to the desired mix of forest cover types and stand age distributions. Addressing specific spatial arrangement characteristics of the forest is difficult in management scheduling models because spatial arrangement considerations involve interdependencies between specific site-level decisions for the vast majority of the many stands in a typical forest. These interdependencies are thus far more complicated than interdependencies related to broader forest-wide goals like those for sustaining overall timber flows or overall forest cover type.

Old forest interior space

Old forest interior space was the spatial measure used to address spatial objectives for this study. Interior space can be conceptualized as the interior area (or core area) of a homogeneous forest patch. A buffer area surrounds interior space, protecting it from outside influences. The specific definition of interior space depends on a number of factors including requirements on the specific conditions necessary for the core area, and the required width and composition of the surrounding protective buffer. For this study emphasis was on older forest interior space that has a core area with stand ages of at least 75 years and a surrounding buffer that is 45.7 meters (150 feet) wide with trees at least 35 years old. These figures are based on the extended rotation guidelines by the Minnesota Department of Natural Resources (1996) and on averages between suggested distances from riparian areas (GREEN, 1995; DARVEAU *et al.*, 1995).

The interior area of a forest patch often involves multiple stands. In fact, larger blocks (patches) are generally more efficient at producing interior space because a smaller proportion of the patch is used for providing the required surrounding buffer area. Interior space is a useful measure because it also takes into account the geometric shape of forest patches. Irregular-shaped patches tend to have relatively less interior space per unit area because of relatively more patch edge requiring buffer.

Seven different types of interior space were recognized, one for each of seven ecological classifications (landscape ecosystems) recognized by the USDA Forest Service for the Chippewa National Forest in their current forest planning process. Five of these seven ecological classes are primarily upland areas and two are primarily lowland areas. Each landscape ecosystem has developed under a different rate of natural disturbance with different successional pathways for each of its current forest cover types. Similar to the way that specific timber product flows are valued and tracked explicitly in a forest management scheduling model, interior space flows were valued and tracked for each landscape ecosystem in all scenarios modeled. The specific value assumed for interior space was a key difference between scenarios.

Roads can subdivide a forest and impact interior space production. Clearly, buffers are needed between interior space and large developed roads. For smaller roads, the appropriate assumption is less clear because the forest canopy can remain closed under narrow forest roads. For this study it was assumed that all forest roads impact interior space with 150-foot (45.7 meter) buffers required between any road and any old forest interior space. Roads recognized included all roads open to motorized travel within the Chippewa National Forest proclamation boundary.

The test cases

As indicated above, a major objective was to explore how detailed site-specific forest management scheduling tools might be used to help better integrate environmental and economic objectives across public ownerships. The intent was to build off of the detailed baseline modelling work done by the USDA Forest Service and explore the potential gains from better coordinating management planning across ownerships to address spatial considerations related to the production of old forest interior space. Three test cases were used to examine potential gains from coordinating management of USDA Forest Service lands with Minnesota Department of Natural Resources (DNR) lands to produce older forest interior space. The study area was comprised of Minnesota DNR managed lands in Itasca and Cass County and USDA Forest Service lands within the Chippewa National Forest. Approximately 302,000 hectares were modelled with 224,000 in federal ownership and 78,000 in state ownership. One case considered just Minnesota DNR lands, another used just the USDA Forest Service lands and the third case considered both of these two ownerships together. All three cases used multiple runs of the University of Minnesota's DPspace forest management scheduling model to examine trade-offs between timber production and interior space production. For each case, model runs varied only in terms of assumed values for old forest interior space. In effect, by placing higher values for older forest interior space, one is simply placing more emphasis on interior space production compared to timber production. Timber stumpage prices were assumed to be constant over time and equal to average prices received by the Chippewa National Forest in 1998. Considerable detail was included in tracking timber volume and values for 13 timber product classes: large red & white pine logs, small red & white pine logs, jack pine logs, spruce logs, hardwood logs, aspen pulp, hardwood pulp, balsam fir pulp, spruce pulp, tamarack pulp, pine pulp, cedar and firewood. Management cost estimates were those used by the USDA Forest Service and included sale administration costs, and a wide range of stand establishment and stand treatment costs that vary by forest cover type and treatment option. A 100-year planning horizon was used with ten 10-year planning periods. A four percent discount rate was used to compare net returns with all costs and revenues expressed in real terms (net of inflation).

The study area is one of the areas in Minnesota with the most intermixed public ownership. It contains 302,000 hectares of forest land in approximately 92,000 management units with approximately three-fourths of the area (and units) in federal ownership (Chippewa National Forest). Land classifications from the current USDA Forest Service planning effort in Minnesota helped define the range of possible management treatment options for each management unit. Specific site-level characteristics considered were the ecological class (as described above), visual quality class, management area class, riparian class, and sensitive species class.

Applications were extremely data intensive utilizing DNR stand level inventory data, associated GIS maps, and much of the management data recently developed as part of the USDA Forest Service planning process in Minnesota. Much of the focus in a forest management scheduling model is on how specific management treatment options can be assigned to site-specific management units to best achieve forest-wide economic returns while also achieving broader forest-wide environmental objectives. Management units are assumed to be homogenous at all times. For this study each management unit was either an individual stand or substand. Substands were created to recognize riparian areas within stand boundaries, thus allowing those areas to be managed differently than the parent stand. Here, management units will be referred to as stands realizing that some are substands. Treatment options for individual stands differed in terms of type of silvicultural treatment, timings of harvests, type of reforestation activities after harvest, and the type and timing of silvicultural treatments for future rotations. Seventeen different silvicultural treatment types were considered including new types designed to help change aspen stands to other forest cover types through partial cuts and management of the understory. The "no treatment" option recognized natural succession with successional rules describing forest cover type and age changes that vary by ecological land classes. Options to convert stands to other forest cover types at the end of the first rotation added substantially to the number of treatment choices for most stands because a host of options for managing the second and subsequent rotations are associated with each possible first rotation length.

Modeling process

The modeling process used two forest models: (1) Dualplan based on methods developed by HOGANSON and ROSE (1984) and (2) DPspace based on methods developed by HOGANSON and BORGES (1998) and BORGES *et al*. (1999). Dualplan addresses the aspatial impacts of forest-wide constraints involving even-flow timber objectives and age distribution and forest species mix targets. Dualplan results are key inputs to DPspace, the model where spatial considerations are integrated in the management scheduling process. The strength of Dualplan is its ability to decompose the forest-wide problem into parts to address each stand separately while still taking into account the forest-wide aspatial constraints. Most of the effort in Dualplan is to search for good estimates of the marginal costs (shadow prices) associated with each of the forest –wide constraints. Once good estimates are found, optimal solutions can be determined for the overall model formulation just by summing the results over all stands. Shadow prices represent the marginal cost of the constraint level for its corresponding forest-wide constraint. Shadow price estimates can be valuable information to decision-makers. For example, for a constraint that requires at least x hectares of old white pine in decade 10, the associated shadow price is an estimate of the cost of increasing that constraint level to $x+1$ hectares.

Shadow price estimates from Dualplan are used in DPspace to recognize the impact of the forest-wide constraints on site-level decision options. This study used Dualplan shadow price estimates from a model run for the USDA Forest Service Chippewa National Forest. The focus of that run was primarily on timber production with forest-wide constraints added to sustain timber harvest flows over time. Ties were not made directly with specific alternatives developed for the USDA Draft Forest Plan (USDA FOREST SERVICE, 2003)

A key step in the analysis process involved the development of a new GIS map layer that identifies how management decisions at the stand level are interdependent. This layer identifies all areas of the forest capable of producing interior space, and for each of these areas, identifies which stands influence that area in terms of its potential to produce interior space. This map layer is based on the simple concept that for any specific location in the forest to produce interior space, it will be influenced by all stands within the assumed buffer distance required for producing interior space. This new map layer we refer to as the map of influence zones where each zone representing a unique area in that it is influenced by a unique combination of stands in terms of its ability to produce interior space. Influence zones that involve only one stand are in the center area (core area) of that stand. For the study area involving both federal and state ownerships with 91,000 management units, there were over 239,000 unique influence zones. To recognize that areas within influence zones are not all necessarily in the same condition (or state) at different points in time, each influence zone is subdivided into subzones based on the parent stand in which they are located. For a given subzone, it produces interior space when it meets the age requirements for interior space and all other subzones in that influence zone meet the requirements for producing interior space buffer. For the test case that used both state and federal lands, over 732,000 subzones were modelled explicitly over the ten decades in the planning horizon.

Each test case was subdivided into a series of overlapping subproblems. Four steps were used for defining the subproblems:

1) Major roads and large lakes were used to divide the study area into eleven subforests of roughly similar size. These breaks in the landscape subdivide the study area into subsets that are independent in terms of the potential for producing interior space.

2) For each subforest, the interior space interdependencies of management decisions between component stands are defined by the influence zone information. Influence zone interactions were tabulated to determine independent subsets of stands within each subforest. These subsets are referred to as subdivisions.

3) For each stand, management treatment options were analyzed in detail to reduce the number of treatment options considered for it in the spatial model. Emphasis was placed on not eliminating any treatment option for a given stand that could potentially be optimal in the spatial model. Trimming rules used detailed spatial characteristics of each stand in terms of its potential impacts on the decision outcomes for nearby stands. Summaries of the influence zone data were important information used in this step.

4) For each subdivision, a series of dynamic programming formulations were developed using overlapping subproblems with most stands included in multiple subproblems. Each subproblem represented an area that could be easily formulated into a dynamic programming model that recognizes spatial interdependencies. Using overlapping areas helps overcome problems associated with interdependencies that involve stands in different subproblems (HOGANSON and BORGES 1998, BORGES *et al.*, 1999).

The third step in this process was key for making practical application possible for problems as large as those considered in this study. In Dualplan, most polygons had hundreds of potential management options. Defining a workable number for the spatial model is somewhat subjective. It did not become an issue because it was found that numerous options could be trimmed from the spatial formulation without sacrificing any loss in terms of mathematical optimality. It was found that after trimming options no stand had more than 32 potentially optimal options, and on average, options could be reduced to approximately 4 per stand. This average actually varied very little over a wide range of potential values assumed for interior space.

Table 1 summarizes the modeling decomposition process used for test cases. Formulations were developed using two different-sized subproblem-size guides based on an estimate of the maximum number of nodes needed for any single stage of the dynamic programming formulation for the subproblem. These limits were used only as guides because the size of the DP formulation for a subproblem varied between scenarios depending on the number of stand treatment options necessary to consider for each stand for the specific scenario. Computation times varied substantially with almost 2 hours needed for the largest formulation using a Dell Precision Workstation with a 1.4 Ghz processor. If computation time was a major concern, solution times could be reduced by tailoring the specific DP formulations for the specific scenario.

Model results

For each of the three study areas, multiple scenarios were used to examine the impact of a range of values for interior space on timber production levels. For all scenarios, older-forest interior space values were assumed to be constant over time. Six scenarios were analysed for the test case involving both federal and state lands and four scenarios were examined for each of the test cases involving a single public ownership. Study results suggest that

1) With good planning, concerns about providing older forest interior space is likely more of a short-term problem than a long-term one. Figure 1 and Figure 2 show interior space production over time for two of the larger landscape ecosystems for the test case using both state and federal ownerships. With all but the lower values assumed for interior space, results show interior space levels rising over time. It is in the earlier time periods where interior space levels tend to be lowest. Spatial arrangement of the forest received little consideration in past forest planning efforts so it is perhaps not surprising that forests are not all that well-suited for producing large blocks of old forest today. In the short-term, conditions cannot change rapidly. Obviously one cannot start from scratch to produce large patches of old forest very fast. But with new planning tools one can plan ahead to help better control the future spatial arrangement of the forest. Planning ahead is not simply long-term planning to plan long-term actions. Rather, it involves adjusting today's actions that impact the spatial arrangement of the forest in the future. With higher values assumed for interior space and by planning ahead, gradual gains in interior space levels are possible over time (Figure 1 and Figure 2).

2) Although simple management guides like "harvest today in larger patches" is one way to increase patches of older forest in the very long term, it is a very simplified guide and potentially quite detrimental in the short-term. Such a guide would tend to destroy large patches of forest that are potentially very important for producing older forest in the shorter term. Patches of older forest can be produced in a variety of ways over the long-term. Effective and efficient strategies likely involve a variety of harvest block sizes with analysis likely key for identifying good spatial and temporal strategies that fit well with existing landscape patterns.

3) Coordinating management across large public ownerships to help produce older forest interior space may not be as important as some might expect. Effective comprehensive planning for each large ownership is likely much more important. With the buffer distance assumed for this study (45.7 meters), most of the gains from better landscape management on public lands can be gained simply through better detailed

planning and analysis by each ownership. For the study area considered, by far most site-level spatial interdependencies impacting interior space production involve single ownerships. With 45.7 meter (150 foot) buffers, over 96 percent of the federal and state land capable of producing interior space involves both ownerships (Table 2a), 179,846 hectares of 185,695 hectares. With larger buffer widths, interactions between the large public landowners increase, but even with 300 foot buffers, over 93 percent of the area capable of producing interior space is in single ownerships (Table 2b) – - 113,279 hectares of 120,763 hectares. With larger buffer widths, substantially smaller areas of the forest are capable of producing interior area and the interactions of decisions for specific areas generally involve more stands.

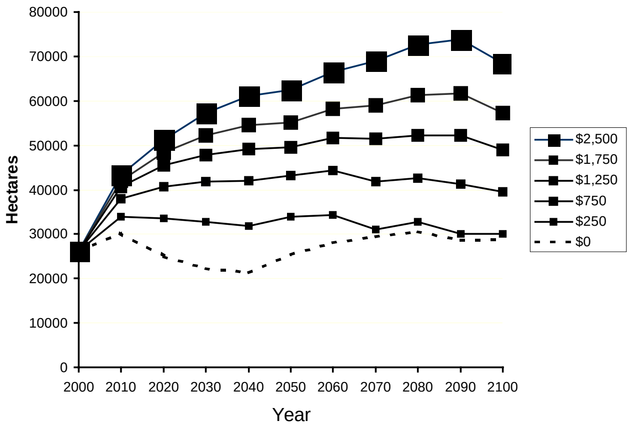

Figure 1 - Production of old forest interior space in the Dry Mesic Pine Oak landscape ecosystem for alternative old forest interior space values ($ per hectare per decade)

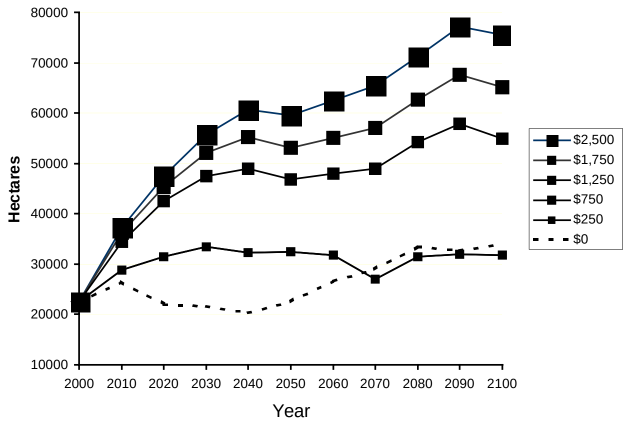

Figure 2 - Production of old forest interior space in the Boreal Hardwood Conifer landscape ecosystem by decade for alternative old forest interior space value assumptions ($ per hectare per decade)

Table 2 - Total influence zone area by number of stands making up the influence zone for the three cases: State, Fed and Both. Differences in area between the Both test case and the sum of the separate analyses (State + Fed) show the maximum potential gains in interior space from coordinating management across ownerships

a) 45.7 m (150-ft) buffer

Number of Stands	Potential interior space (hectares)							
	State		Fed		State + Fed		Both	
	Area	Count	Area	Count	Area	Count	Area	Count
1	19,641	7,342	46,042	21,418	65,684	28,760	65,684	28,760
2	21,910	14,942	55,998	47,250	77,908	62,192	80,640	65,779
3	7,001	16,103	18,382	48,473	25,383	64,576	27,492	70,577
4	1,906	9,042	5,158	26,489	7,064	35,531	7,782	38,962
5	654	4,786	1,721	13,692	2,375	18,478	2,565	19,917
6	275	2,484	708	6,698	983	9,182	1,044	9,783
7	85	1,028	213	2,497	298	3,525	323	3,785
8-10	51	710	95	1316	146	2026	160	2201
>10	2	43	3	52	6	95	6	103
All	51,527	56,480	128,319	167,885	179,846	224,365	185,695	239,867

b) 91.4 m (300 ft) buffer

Number of Stands	Potential interior space (hectares)							
	State		Fed		State + Fed		Both	
	Area	Count	Area	Count	Area	Count	Area	Count
1	6,072	1,933	9,153	5,916	15,225	7,849	15,225	7,849
2	12,168	7,082	25,412	20,668	37,580	27,750	38,771	29,134
3	9,484	11,390	22,058	32,142	31,542	43,532	33,971	47,874
4	4,880	10,518	11,032	28,281	15,912	38,799	17,995	44,003
5	1,932	6,996	4,553	18,411	6,484	25,407	7,506	29,071
6	918	4,246	2,161	11,500	3,079	15,746	3,475	17,754
7	430	2,600	1,076	7,108	1,506	9,708	1,680	10,807
8-10	482	3,873	1,068	9,050	1,550	12,923	1,705	14,182
>10	150	1766	250	2922	399	4688	437	5127
All	36,515	50,404	76,764	135,998	113,279	186,402	120,763	205,801

Results also show how multiple model runs can be used to gain insight regarding the impact of specific assumptions. A comparison of scenario runs shows that by assuming higher values for older forest interior space, much more of it is produced. However, this comes at a cost to timber production (Figure 3). Caution must be exercised in generalizing too much about these trade-offs. Had constraints also been included in all scenarios to also produce older forest, then trade-offs between older forest interior space production and timber harvest levels would not be as dramatic. Had funding and time permitted, more scenarios could have been developed to learn more about the extent to which harvest reductions are caused by valuing older forest itself or by valuing its spatial arrangement. Of importance is to realize that this modeling tool can help in addressing these types of questions.

Clearly the modeling system has enormous potential for better integrating ecological and economic objectives. These objectives are important with potentially much at stake. The modeling system can recognize enormous stand-level detail over very large study areas. Strong ties to optimization modeling helps build confidence in the efficiencies of the coordinated management schedules developed to achieve forest-wide objectives. Once up and running, the model can be applied to numerous scenarios to help learn more about many facets of the management situation ranging from broad forest-wide policies to the potential role of specific new silvicultural treatment options. With its ability to subdivide the problem into small subproblems, the model has the potential to address additional landscape objectives not considered in this study. Management schedules developed for specific scenarios are easily imported into GIS systems that can help in interpreting results or in developing additional spatial statistics.

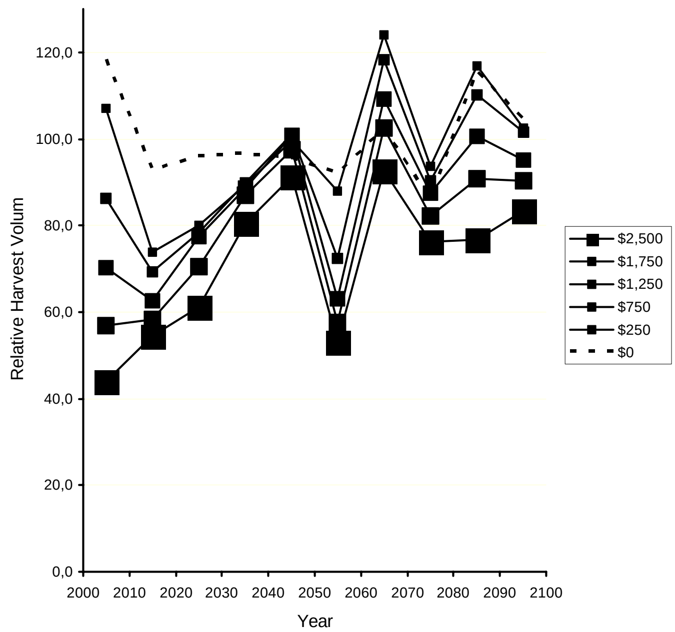

Figure 3 - Relative level of timber production by decade for alternative value assumptions for old forest interior space ($ per hectare per decade). Relative timber production levels are set such that the average production level equals 100 for the scenario that did not recognize interior area values

It is also important to understand some of the potential limitations about the model and its applications:

1) Forest management scheduling models are data intensive with success of applications dependent on providing the model with a set of potentially good management treatment options for the individual stands. Some pre-analysis work is likely needed to reduce the number of treatment options considered in the model for each stand. Although this pre-analysis worked well for this study, it may be more difficult when additional spatial measures are also valued or constrained. Heuristic rules for reducing treatment option may then be needed with some concern about potential loss in optimality.

2) By assuming value in producing interior space, many stand-level decisions become quite interdependent. Substantial data preparation work is needed to identify interdependencies explicitly. This process is not fully automated yet.

3) The model itself is fairly technical. It requires a background in forest management, basic operations research techniques, and computer operations.

4) The model currently uses the same buffer distance for all types of interior space. Recognizing multiple distances will require more data pre-processing and will increase model run times. It will also complicate the pre-analysis process done to keep the number of management options at the stand level to a workable number.

5) The model does not address explicitly objectives related to very large patches or specific distributions of patch sizes. Large patch objectives are addressed only by using larger buffer distances for interior space, larger interior space values, or pre-allocating some areas for large patch production by planning period.

6) Although the spatial model is linked explicitly with Dualplan to consider a broad range of potential forest-wide constraints and objectives, the linkage with Dualplan is not developed to the point where it is easy to address the impact that the spatial objectives have on the aspatial (Dualplan) forest-wide constraints. More work is needed on developing a fully integrated system with fully-automated linkages.

7) The model is deterministic. It does not recognize natural disturbances. Clearly, losses from natural disturbances would have some impact on the forest-wide output levels if schedules were implemented exactly as modelled. It is erroneous to assume that the management schedules developed will be implemented precisely over the long term. It is assumed that the planning process is dynamic with schedules updated on a fairly regular basis to adjust to uncontrollable events, changing market conditions and changing values. It is assumed that schedules in the short term would need to be adjusted to integrate responses to natural disturbance events.

Methods have at least been outlined to help overcome these limitations in practice. The USDA Forest Service is currently using the model system to help support their forest planning process in Minnesota. Undoubtedly, more will be learned about the system as more experience is gained.

Acknowledgements

Partial support for this research was provided a Project Sapiens 36332/AGR/2000, with the title "Forest ecosystem management: an integrated stand-to--landscape approach to biodiversity and to ecological economic and social sustainability" funded by FCT, POCTI and FEDER

Bibliography

BORGES, J.G., HOGANSON, H.M., ROSE, D.W., 1999. Combining a decomposition strategy with dynamic programming to solve spatially constrained forest management scheduling problems. *Forest Science* **45** : 201-212.

DARVEAU, M., BEAUCHESNE, L., BELANGER, J. HUOT, LARUE, P., 1995. Riparian forest strips as habitat for breeding birds in boreal forest. *Journal of Wildlife Management* **59**(1) : 67-78.

GREEN, J.C., 1995. *Birds and forests: a management and conservation guide*. Minnesota Department of Natural Resources, St. Paul. 97 pp.

HOGANSON, H.M., BORGES, J.G., 1998: Using dynamic programming and overlapping subproblems to address adjacency in large harvest scheduling problems. *Forest Science* **44** :526-538.

HOGANSON, H.M., ROSE, D.W., 1984. A simulation approach for optimal timber management scheduling. *Forest Science* **30** : 220-238.

MINNESOTA DEPARTMENT OF NATURAL RESOURCES, 1996. *Northeast Region Biodiversity Guidelines*, Workshop Draft 1994, updated 1996, 41 pp.

USDA FOREST SERVICE, 2003. *Draft environmental impact statement: forest plan revision: Chippewa National Forest and Superior National Forest*. Milwaukee Wisconsin. 695pp.