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Integrated Tools for Decision Aid in Sustainable Forest Management

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Integrated tools for decision aid in sustainable forest management

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ABSTRACT

The central objective of this project is to develop an integrated set of tools designed to guide forest manager's decisions in a manner that will improve forest sustainability. This goal will be attained by implementing informational and decisional methods that will help managers consider and evaluate the different uses of the forest (wood harvesting, biodiversity, the local economy of forest communities, etc.) at the early stages of forest management scenario design. Informational aspects comprise 1) information gathering (GIS layers, remote sensing images, field data, ecological mapping), 2) information processing yielding useful management data (spatial analysis, SYLVA II forecasting, etc.), 3) multicriteria decision making procedure design (choice of criteria, implementation of Promethée method), and 4) encapsulation of processed data and methods in a software package that can be directly used by forest managers. Most of the milestone objectives have been met: the integration of multiple data layers (an online catalog of data and metadata is now available: www.unites.uqam.ca/FERLD, user=ferld, password=uqamuqat), processing of remote sensing images, the analysis of management scenarios pertaining to biodiversity and forest productivity as well as multicriteria evaluation is being completed. First results with SYLVA I were generated and more advanced analysis using of SYLVA II are beginning. Due to budget cuts however, the scheduling of certain tasks was modified: more costly activities, such as software programming, have been delayed but are now being pursued using additional sources of financing (such as from NCE-GEOID).

Data and methods have been developed and tested for the *Lake Duparquet Training and Research Forest* (LDTRF), a 80 square km of forested territory in the Abitibi region, Quebec (79.3 W, 48.5 N), which is part of the *Forest Ecosystem Research Network of Sites* (FERNS). This test area was chosen for its landscape and habitat diversity, representative of the mixed boreal forest, the wide availability of data, and the important collaborative effort between universities, forest companies and the socio-economic environment. Three research groups are presently conducting research projects in the area of the LDTRF totaling over 1 million dollars of investment: the GREFI (*Groupe de Recherche en Écologie Forestière Interuniversitaire*) and the GEIGER (*Groupe d'Études Interdisciplinaires en Géographie et Environnement Régional*), both from Université du Québec à Montréal, and URDFAT (*Unité de Recherche et de Développement Forestier d'Abitibi-Témiscamingue* from UQAT). Moreover, the LDTRF is managed by a mixed comity composed of two forest companies (Tembec and Norbord), hunting

and fishing associations, and the *Municipalité Régionale de Comté* (an administrative entity regrouping neighbouring municipalities). This comity is also responsible of designing the management plan, which has been completed in January 2000.

ACKNOWLEDGMENTS

This project received support from different organisations. Financial support was mainly provided by the Network of Centres of Excellence on Sustainable Forest Management since April 1997. Also, our team is part of an NCE-SFM integration project which is also financed by the Network which aim is to achieve a joint implementation of individual team contributions at the decision level.

This project also benefits from synergies with industrial and institutional partners. Our main partner is the *Lake Duparquet Training and Research Forest* (LDTRF) who helped us considerably by providing numerous data layers, some of which result from years of research, and by providing consulting time of its manager, Brian Harvey. Moreover Tembec and Norbord representatives who sit on the LDTRF management committee have provided insight on the industrial point of view of forest management.

Complementary funding was received from different organisations in support of research activities that brought further support for the current project. Both LDTRFF and Québec University in Abitibi-Témiscamingue financed an ongoing project to support the implementation of a stakeholders dialogue table and its decision making process.

Natural Resources Canada provided part of the salary of the programmer Martin Deschênes though its Science and Technology program.

The Algonquin First Nation community of Long Point (Winneway) has contributed to a feasibility study to implement our proposed research framework, including ecological mapping, GIS capabilities, and multicriteria decision support system, according to traditional ecological knowledge. They envision better forest management practices and relationships with forest companies.

Finally, the Geography Department at Université du Québec à Montréal gave us full logistic support and dedicated a part-time professional (Bertrand Touchette) to our project for technical support (hardware and software).

INTRODUCTION

Profound changes have occurred during the recent years in the forest industry. The emergence of the concept of sustainable development brought about a lot of discussion on the necessary joint consideration of the economical and the environmental criteria as a condition for development. Even more recently, enterprises and institutions have started efforts to implement solutions inspired by the sustainable development principle and based on integrated resource management. Integrated resource management is an approach that can itself be traced back as far as the 19^{th} century but that was essentially developed during the seventies in the field of natural resources. This fairly recent increase in interest over integrated resource management can in part be explained by the fact that it was realised that resources are not unlimited and are sensitive to certain human interventions. Moreover, as natural resources constitute the basis of local economies, resource utilisation conflicts become more and more frequent and call for new approaches. Thus, the Quebec Provincial Government has put forward, as early as 1991, a pilot project for integrated management of the forest resource. Indeed, the Ministère des Forêts, the Ministère des Loisirs, de la Chasse et de la Pêche, and the Ministère de l'Environnement had, at that time, experimented integrated management on two territories: the "Réserve Mastigouche" and the Laurentide region. This integrated management effort aimed at valuing simultaneously all significant forest resources, according to the user needs, in order to benefit from the full potential of the resource. It consisted in evaluating different management scenarios that take into account multiples possible uses in order to choose the best use of all components. That project also experimented with different methodologies in the context of a vast work programme which goal consisted, among other things, in developing decision tools. At project conclusion, important advances had been made, especially on the question of decision processes. However, the pilot project have not answered all implementation questions posed by the forest companies.

At the same time, the Canadian Council of Forest Ministers had elaborated a list of criteria and indicators for sustainable forestry management. These inspired the new forest legislation of Quebec. Moreover, many enterprises have initiated processes of environmental certification similar to the criteria and indicators.

Forest management is also at the centre of land related stakes for local communities. Some preoccupations are also discussed with First Nation communities. Forest management that is solely based on the value of wood products is being questioned because of its apparent non sustainable nature, particularly at the local level. Forest management must therefore take into account the diversity of uses it supports (wood production, recreation, hunting and fishing, etc.) and its ecological, cultural and aesthetic functions (related to the hydrological cycle, to biodiversity, culture, landscape quality, etc.). This outlines the need for more and more negotiated decision processes. Stakeholders will thus have to find a common ground on which to resolve conflicts.

The various sustainable forestry planning practices each rely on a particular subset of information (forest inventory data, socio-economic data, locally calibrated yield prediction equations, etc.) and make use of specialised tools: forest harvest planning software (such as Sylva), geographic information systems, remote sensing, statistical analysis, etc. Integrated resource management approaches wish to bring together the different aspects of planning and also include public consultations at the early stages of management scenario design.

At least three kinds of problems follow from this approach: information processing, methods integration and balancing the needs of different interest groups. Solutions to these problems call for the development of a unified approach to information, methods and policy management.

The general objective of this project is to offer decision support tools to forest managers concerned by harvesting or inhabited forest projects in the context of sustainable management. The first specific objective is to develop general purpose multi-stakeholders modelling tools allowing systemic environmental management of forest long term (25 years) landscape planning scenarios according to a multicriteria decision support system that relies, among other things, on an ecological reference framework used as a basis for technical studies pertaining to landscape planning potential and constraints. The second specific objective aims at developing a spatial information management system integrating GIS and remote sensing data that will serve the purpose of managing, processing, and analyzing spatial data describing the study area. The third and last specific objective consists in the integration of information and tools stemming from the two first specific objectives to assemble a decision support system for forest management. It also aims at offering a unique user-friendly interface to provide an efficient software tool for the environmental evaluation of systemic forest landscape planning scenarios.

Data and methods are developed and tested for the *Training and Research Forest of Lake Duparquet* (TRFLD), a 80 square km section of inhabited forested territory in the Abitibi region, Quebec. This test area was chosen for its landscape and habitat diversity, representative of the mixed boreal forest, the wide availability of data, and the important collaborative effort between universities, forest companies and the socio-economic environment. This partnership provides favourable conditions for the methodological development put forward by this project because the ecologist and environmental point of views of researchers on forest management can be confronted directly to the managers opinion on the same matters. The stakes relative to forest company survival in the context of finding a rare resource (accessible forest) and of increasing global competition are explained by the stakeholders themselves. Other planned projects in the region will further reinforce these collaboration. A “dialogue table” (*table de concertation*) is also started working recently as a consequence of our research work.

SUMMARY OF DATA ANALYSIS AND MANAGEMENT APPLICATIONS

Since our work directly targets decision making for forest management, we deemed more useful to present the summary of data analysis and the management applications in the same section to avoid redundancy. Specific items relating to management applications are clearly identified in the text that follows.

Ecological Reference Framework

Methodology

The ecological reference framework has been developed and used in different contexts since 1967 in Québec Province as well as at the international scale (Jurdant *et al*., 1972; Jurdant *et al*., 1977). It is recognized in the scientific literature as a useful tool for forest management (Gerardin and Ducruc, 1990). It is thus an accepted fact that ecological classification (typology) and mapping of forest sites must be based on a global approach in which the physical variables of the environment play a decisive role, an approach related to the concept of landscape ecology. Even if ten years ago the authors (Gerardin and Ducruc, 1990, p.19) mentioned that “In spite of the huge areas already mapped, attempts to integrate such an information in the forestry practice have thus far proven inconclusive”, we can say now that the ecological reference framework is slightly penetrating the forest management practice (Beauchesne, 1994; Beauchesne, 1995; Guay, 1999).

Ecological mapping being a dynamic research field and a growing practice, significant progresses are continuously been made on the methodological side such as cartography at higher levels of resolution like natural provinces and regions (Ducruc, Li and Bissonnette, 1995; Li *et al*., 1994), integration of hydrosystems and watersheds (Lajeunesse *et al*., 1997), better knowledge of the appropriate scale to delineate forest management units for Forest Agencies (Beauchesne *et al.*, 1998), and integrated decision aid system for the Outaouais region (collaboration with our team, Falardeau, 1998), ecological mapping of Waswanipi Model Forest (Ministère de l'Environnement, 1999) and gap analysis for conservation issues (Côté, 1998), etc.

The ecological reference framework (Ducruc, Li, Gerardin 1995, pp.5-8) is based on two major concepts: a hierarchical and holistic approach to the environment, and the ecosystem considered as a spatial entity. Ecological mapping calls upon several level of resolution; the upper level conditioning the lower levels. Mapping the territory therefore is done from the upper level to the lower one, from the global to the local. Whatever the level of resolution, the territory is mapped by segmentation. The mapping delimitation focuses on natural units at the surface of earth and is derived from stable physical variables analysis. The maps units are heterogeneous and each level of resolution determines its own heterogeneity. The natural units thus defined have permanent boundaries, at least at the human time scale; the dynamic elements (vegetation, wildlife, land-use) are mapped within stable the aforementioned ecological limits. Mapping is based on the study of satellite images and conventional aerial photographs, studied by, stereoscopic analysis predominates. This analysis leads to the delimitation and morpho-topographic definition of cartographic polygons. This mapping delimitation is then used for field sampling stratification.

Training and Research Forest of Lake Duparquet

The ecological mapping of the *Lake Duparquet Training and Research Forest* (LDTRF) was conducted by Richard Boivin (Ph.D. student in the project). Those data and maps as well as pre-existing ones are available on the TRFLD web site (www.unites.uqam.ca/FERLD). It provides a spatial framework for forest planning and will thus be a useful tool for next TRFLD forest management plan. This ecological maps are also used to teach courses related to the DESS in sustainable forest management (graduate program jointly implemented by Québec University components of Abitibi-Témiscamingue -UQAT- and of Montréal -UQAM-) such as the course on ecological mapping and environmental impact assessment).

Other contributions

Stemming from our collaboration with the Québec Ministry of the Environment, three other territories were under investigation. The ministry provided us with ecological maps for three different projects related to the use of ecological mapping for forest management.

Management application #1. The first project was in the Outaouais region, on the MacLaren management unit in the south part of the wildlife reserve of Papineau-Labelle. A new photo-interpretation of spatial units (at the topographic unit level of resolution) was made to analyze environmental impact of forest management practices (see Lacroix-Turgeon, 1999). This study sheds light on the utility of the ecological reference framework for spatial analysis at the operational level. A “potential management units” map was produced as a synthesis of four ecological interpretations (soil susceptibility to water erosion, and to machine-induced gullying, soil carrying capacity for machinery, forest fertility potential). Different harvesting techniques, including common and alternative ones, were evaluated on their theoretical impacts on the environment. A multicriteria decision aid tool (here the Prométhée method) was used to compare them. The decision maker can thus make a rational technical choice knowing the improvement on the quality of the environment (better practice). The choice made by foresters were confirmed as a good one. The use of horses to extract trees from the forest can also offer a good opportunity to decrease environmental impacts.

Management application #2. The second project was in the Québec region, in collaboration with Scieries Leduc. The existing ecological maps (from the district unit level of resolution to the topographic unit one) were completed with the hydrosystems mapping (see Guay, 1999). A methodological framework based on ecological information has thus been designed to improve forest road planning in management units. This leads to decrease both environmental impacts and costs. Four terrestrial interpretation maps were derived from the ecological maps and a multicriteria approach: slope, drainage works, road foundation bed and the “borrowing buffer” (*banc d’emprunt*) and one hydrosystem interpretation for trout hatcheries. First, primary, secondary and tertiary road networks are manually traced from the interpretations. They are then evaluated and compared using environmental and economical criteria. The case study showed the economical benefits as well as the environmental benefit of the road traced according to the ecological maps compared to the existing road networks for the same region. The complete research is available as a master thesis at UQAM's library or upon request directly at GEIGER. A CD-rom presents the GIS built for this project (see figure 1).

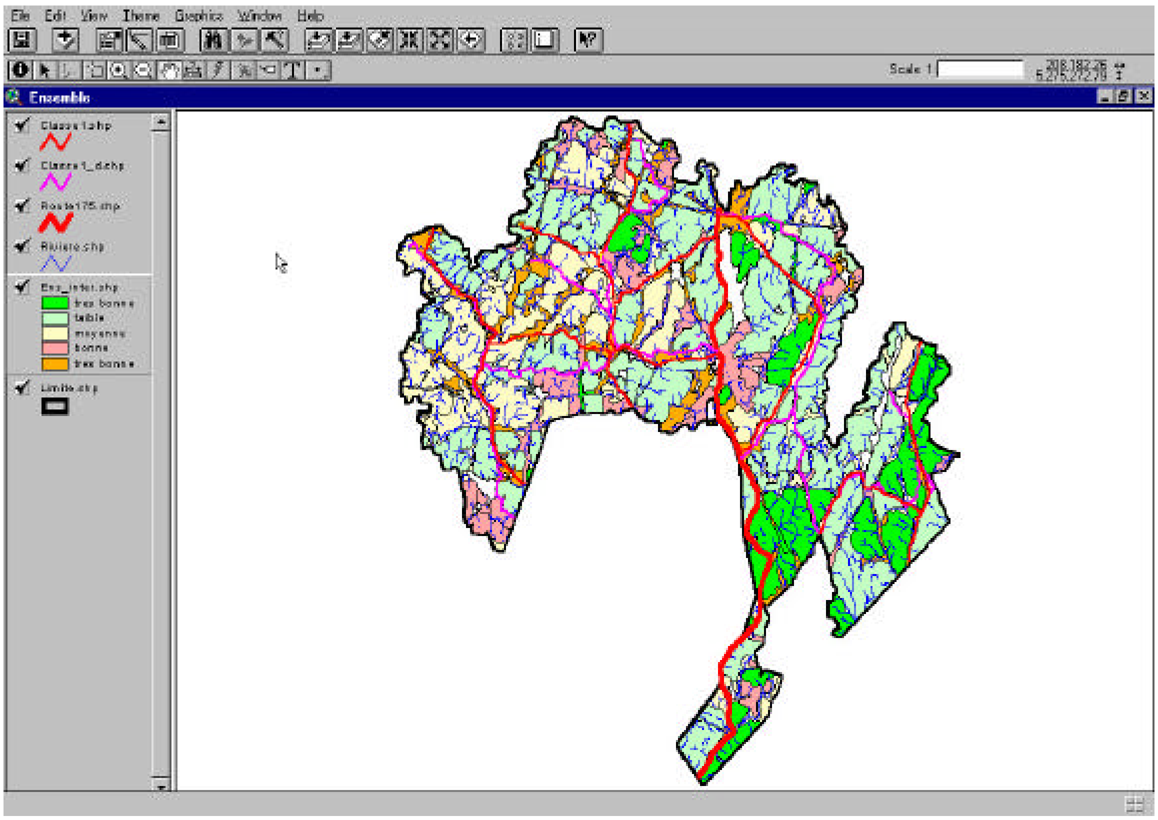


Figure 1 – Ecological interpretation for forest road planning.

***Management application #3* -** The third one was in the natural region of middle Saint-Laurent plain (B02 region), in collaboration with an ad hoc ministerial committee working on network of protected areas at the province level. The ecological reference framework at the natural region level of resolution was completed with a cartography of hydrosystems and with complementary sources of information appropriate to evaluate the need for protected areas (see Larouche-Boutin, 1999). This research concentrates on necessary data to built a territorial information system (TIS) designed to evaluate and complete the Québec network of protected areas representing ecological diversity. The TIS is based on the ecological reference framework (fundamental physical information: geology, topography, hydrography, geomorphology) augmented with biotic and land use data. Complementary themes have been identified, justified and described with available information sources. The theme selection is based on data availability, data format and content quality. Themes were refered to the ad hoc ministerial committee for approval. The important themes are respectively: land use and land occupation, major infrastructures, the existing network of protected areas, sites of ecological interest, the vegetal cover, fauna, endangered and vulnerable species, and climate.

Geospatial data integration

Long term sustainable development of the forest is best achieved by considering the different uses of the forest (wood harvesting, biodiversity, survival of communities, etc.), and thus by merging various information sources describing the territory (harvest plans, intervention technology, biodiversity assessment, watershed modelling, forest fire susceptibility, landscape aesthetics, First Nations way of life, etc.), and by taking into account environmental concerns at the early stages of forest management scenario design. Many valuable databases have been created in the past years on forested regions. However, these databases are often poorly documented and difficult to obtain. This is why the focus of geomatics is shifting from digitising to documenting and diffusing standardised information. Our objective in these matters was to document the GIS data layers that were gathered for the purpose of multicriteria evaluation in such a way that their contents will still be understood in the future, and such that any researcher of student can easily comprehend the information of each layer. Moreover, our goal was to provide the easiest way to access the data and metadata so that research opportunities and efforts are not hindered by difficulties in obtaining the data and its description. We have thus created a Web site on which the data and metadata can be consulted and downloaded. Access to this datawarehouse is provided through a sequence of thematic classification (e.g. “Vegetation”, “Anthropic”, “Hydrography”, etc.), sub-themes, and lists of data layers. An overview of the data layer is provided by rapid-display black and white samples of the layer, and through an interactive Java program that allows zooms and pans of complete raster and vector data layers, although trough a slower display. The data can be downloaded in Esri’s Arcview shapefiles format with attributes in dBase files. The metadata is mainly composed of the layer description, the list of attributes, and the signification of attributes codes, which is otherwise often lost when data is past from one person to another. The Web site can be consulted at : www.unites.uqam.ca/FERLD (the user name is "ferld" and the password is "uqamuqat"). New data is being added regularly. Throughout this data dissemination effort, our goal was to assemble an easily maintainable datawarehouse. The process of putting new data layers on the server could be slowed by the fact that writing new metadata and publishing it on a Web site is not a straightforward task. For this reason, we have developed a program that runs on Arcview to automate this task using Esri's Avenue language. When new data is created, the provider of these data only has to fill in a digital form. The Java program updates the metadata database and automatically creates a new version of the Web pages (automatic HTML code generation) reflecting the changes that have been made.

Decision process

Methodology

The multicriteria approach constitute a decision making method. Its objective is to provide tools to decision makers to allow for rapid progress in problem solving in the context where more than one point of view must be considered (Gouvernement du Québec., 1998c). Results concerning the contribution of multicriteria approaches (Maystre, Pictet and Simos, 1994; Martin, St-Onge and Waaub, 1997; Côté and Waaub, 1999) show that they offer a scientific basis for informed decisions while giving the advantage of taking into account stakeholder's values and of not dismissing the political dimension related to the necessary negotiations in complex processes. A group decision making procedure based on PROMÉTHÉE (Brans, Macharis and Mareschal, 1997) was recently elaborated and tested in the context of watershed management (Martin, St-Onge and Waaub, 1997). This multicriteria approach is inscribed in a process of negotiating stakes in a collaborative environment. It constitute a promising approach as it facilitates the participation of intervening parties and the grouping of technical studies in a framework of multiple options analysis, for example the general purpose use of the land (Joerin, 1998). Following are our contributions concerning multicriteria decision aid.

Best compromise between logging and biodiversity conservation at the regional scale

The proposed approach (figure 2a) used in the work of Boivin and Waaub is based on ecological mapping, resource analysis using SYLVA model for yields, cost-benefit analysis, and biodiversity evaluation and on multicriteria decision aid.

Outranking multicriteria approach has been used to compare strategic planning forest scenarios. Data involved are information on criteria, magnitude of differences, decision makers preference structure. One important advantage is the insensitivity to scaling effects, another one is the possibility to aggregate conflicting criteria. The PROMETHEE software was chosen. It uses a performance table crossing information on criteria (min/max) for each action (scenarios). It computes net flows (ranking of the scenarios) aggregating pair wise comparisons.

In a multi-stakeholders analysis, several weight sets (here two) take into account specific stakeholder value system. Here, two weight sets were used: one giving equal importance to all criteria, and one focusing on biodiversity. Sensitivity analysis can be performed either on weights or criteria evaluation.

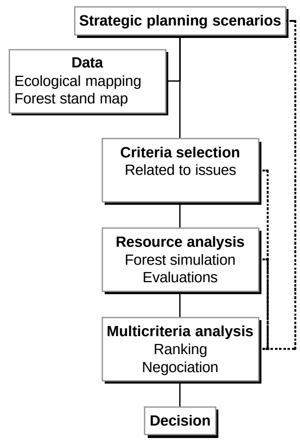
Management application #4. The following question was raised: What strategic planning scenario constitutes the best compromise between logging and biodiversity conservation (figure 2b) at the regional scale? The study area is the management unit 082-02 (3 860 km^2) which includes the LDTRF.

Five scenarios were tested:

- Intensive forestry (ligniculture)
- Extensive forestry (logging without forest treatment)
- Intensive forestry and conservation (25%)
- Extensive forestry and conservation (25%)
- Do nothing (let forest age)

Proposed scenario evaluation approach

a)



b)

Scenario 1.	Coniferous	Mixt	Deciduous	Total
Regeneration	13.7	5.5	7.6	26.8
Young	21	6.9	13.6	41.5
Mature	2.2	21	8.4	31.6
Total	36.9	33.4	29.6	100

Scenario 2.	Coniferous	Mixt	Deciduous	Total
Regeneration	10.3	5.7	8.8	24.8
Young	26.1	10.1	15.6	51.8
Mature	0	16.26	7.1	23.36
Total	36.4	32.06	31.5	100

c)

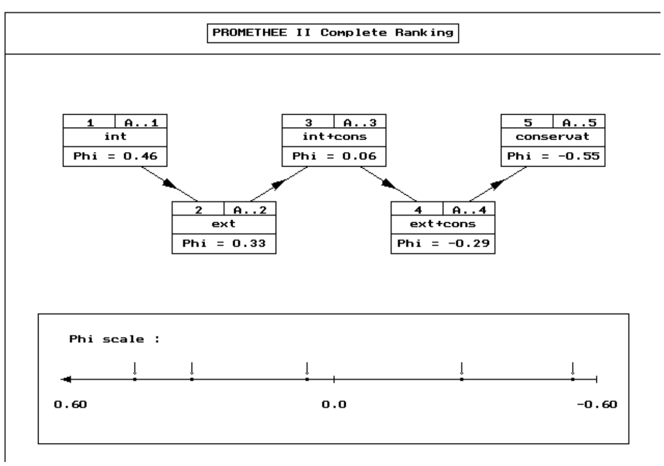


Figure 2 – a) proposed scenario evaluation approach, b) percent area covered by different combinations of age and composition for two scenarios, and c) scenario ranking.

Economic criteria are based on SYLVA simulation (see figure 2c on cost-benefits results) and include revenues: coniferous: $45,08/m3, Birch: $24,75/m3, Aspen: $27,24/m3, and costs of logging, transportation, light scarification, phytocides, manual plantation, and forest roads.

Ecosystem biodiversity (see figure on biodiversity) at regional scale is based on SYLVA simulation (120 years) with three vegetation types (Coniferous, mix, deciduous: birch and aspen) and three evolution states (Regenerating stands (0-20); Young stands (20-60); Mature stands (60+)). Stating that balancing vegetation types and evolution states is targeted, we compute the absolute difference between the percent area of each type and state and the 33,33% target.

The following comments can be made on the preliminary results. Intensive forestry with sustainable yields gives good results on biodiversity (targeting evolution states equilibrium: the 33% rule). We might consider a longer turn over period as suggested by Bergeron's works on natural disturbance regime. Those results are also preliminary because they do not take into account the full array of criteria that should be considered for real IRM.

GIS and multicriteria decision aid

The development and testing of basic GIS multicriteria decision aid methods was assigned to two masters student (Eric Labrecque and Marie-Ève Ferland). ***Management application #5.*** The first project consisted in testing the use of parcimonious multicriteria methods for planning for the development of a five year plan for forest harvesting. By parsimonious, we mean methods that can perform an analysis using common datatypes (namely the 1:20,000 topographical and ecoforest maps available in Quebec), an easy interface, and a simple model that requires minimum tuning. Using criteria such as stand age, height and density, and distance from rivers, lakes and road systems, we produced maps of the most appropriate harvest locations. Criteria weighting was simulated (based on a literature reviews and current practices) for four different groups: a forest company, owners of "pourvoiries", conservationists, and the Quebec's Natural Resource Ministry (from weights and criteria proposed in Gouvernement du Québec, 1998). Four proposed harvest maps were thus produced showing three levels of harvesting possibility using 1990 forest data. Interestingly, recent cuts performed by Norbord between 1990 and 1995 -Norbord is the forest company that had cutting rights on the LDTRF prior to its cession to UQAM and UQAT-, whose precise delimitation was established from a 1996 Landsat image, corresponded closely to the "high" level of the harvesting possibility of the multcriteria map created using “industry” weights. Results can be found in Labrecque (2000). Mr. Labrecque now works in geomatics at CAE Electronics Ltd in Montreal. Although he has only been marginally financed by NCE-SFM, his work was determined by our NCE project objectives, and he was able to use resources stemming from this project (data and expertise).

Management application #6. The second objective was to use a similar GIS multicriteria approach to address the issue of conflicting land usage between forest companies and trappers. Building on the work of Eric Labrecque, Marie-Ève Ferland is evaluating present and potential conflict using different approaches. First, she digitised the trapping lines from information collected from the five trappers that operate entirely or partly in the LDTRF study area. This information will be useful in guiding management operations in the next five years in the management area of the LDTRF. The objective is not necessarily to avoid cutting near or on trapping lines, but rather to minimise damage by informing trappers of upcoming operations so that the traps can be salvaged. The other part of the study consists in identifying high potential alternative areas for trapping of particular species. Potential habitat maps for half a dozen trapped species are being created using a simple GIS multicriteria method (weighted sum of attributes). Data from criteria selection and weighting was obtained from the literature, regional fauna experts, and from the trappers themselves during interviews. Marie-Ève Ferland will submit her thesis in April of 2000. She was recently hired by Geomat International (Montreal) to work in GIS. Although she has only been marginally financed by NCE-SFM, her work was determined by our NCE project objectives, and she was able to use resources stemming from this project (data and expertise).

Advisory committee of the LDTRF

Management application #7. J.P. Leblanc of UQAT and J.P Waaub are currently working on a research project aiming at defining socio-economic criteria for the use in a multicriteria analysis design to assist sustainable management of the LDTRF. This study includes a public consultation and the creation of an advisory committee.

Remote sensing

Remote sensing is used since the beginning of the century to conduct forest inventory, and, in a general way, to acquire land information useful for forest management. The launch of orbital remote sensing platforms in the last three decades has however not replaced the use of conventional aerial photography for high precision forest mapping (scale of 1:20,000) due to the unacceptable level of error in species and height/density assessment obtained from SPOT and Landsat platforms, mainly because the rather coarse resolution of the images (20 – 30 m) provided by these sensors. The recent announce of the launch of high resolution satellites (one meter, or less, in panchromatic mode, four meters, or less, in multispectral mode) has thus generated new hopes for satellite remote sensing. These new orbital platforms were initially planned for 1997 the first one (IKONOS) was launched in September of 1999. The first usable images with leaved hardwoods will be available in summer of 2000. For this reason, our ongoing research focuses on the simulation of very high resolution satellite images, based on aerial digital image data, in order to test image processing algorithms, in preparation for the utilisation of high resolution satellite images. Our research program also includes automated digital terrain model analysis, to derive ecological information (such as drainage), which will be useful for predictive vegetation mapping and the identification of species composition of forest stands, from 4-meter resolution multispectral imagery.

Recent advances in aerial laser altimetry now make height imaging possible, i.e. the generation of sub-meter resolution digital terrain models (DTMs) of both top of canopy and underlying terrain, with high horizontal and vertical accuracy (Flood and Gutelius, 1997). Basal area, volume and biomass (Nelson *et al*., 1997) as well as accurate mean stand height estimations (Naesset, 1997) have been obtained using in many case only one-dimensional profile data (instead of two-dimensional image data). Laser altimetry data was acquired on June 28th 1998 for a three square km subset of the LDTRF study area in image mode. The high density of laser hits on the canopy provided a height dataset in which individual points (laser spots corresponding to the places where the beam has hit the canopy) are separated on average by a distance of approximately 1.5 m, thus allowing for the estimation of individual tree heights, and, in many cases, the visualisation of crown shape. These point height estimates where interpolated to create two DTMs, respectively for the top of canopy and the ground. The latter was subtracted from the former to produce a tree-only height DTM made of 50 cm pixels. An ongoing study funded by NSERC aims at automatically extracting tree and stand height from these data. The masters project of Martin Couture, one of our NCE financed student, consisted in developing a method to automatically identify tree species composition using a combination of laser and optical imagery. The method consisted in masking all non-tree vegetation by keeping only laser pixels having a height over five meters. The corresponding pixels on the optical 50 cm multispectral imagery were classified using spectral signatures and a standard maximum likelihood classifier. The resulting grid was post-processed by assigning a unique species to individual groups of contiguous pixels representing individual trees of clump of trees. Results show that this method, however data intensive, is far more precise and accurate than conventional Landsat based species identification. The masters thesis of Martin Couture, which is officially submitted, is currently under evaluation. Mr. Couture was recently hired by CAE Electronics Ltd in Montreal as a geomatics expert.

Ecological factors such as topography and drainage determine in an appreciable way the spatial distribution of tree species of the boreal forest. Several studies have shown the positive effect of combining spatial ecological data to remote sensing images classification. However, few approaches could clearly separate the influences of stable ecological characteristics from those of disturbance and the succession history. We developed a method which initially consists in developing models giving the probability of occurrence of seven common species of the boreal forest according to variables derived mainly from a digital elevation model (DEM) produced by interpolating the contour lines of a 1:20,000 map. These logistic regression models were developed according to the data of the forest inventory map and then applied to derivatives from the DEM (slope, slope position, etc.) in order to produce a raster map for each species. The probabilities of occurrence per pixel were introduced in the form of prior probability into a maximum likelihood classification of a Thematic Mapper image. The results of this classification constitute an marked improvement over those resulting from a classification which does not take ecological factors into account. The work described here was carried out by Samuel Alleaume, who finished his masters in June of 1999. Mr. Alleaume is back to his home country, France, where he is currently on a short list of candidates for a GIS/forest job at CIRAD (*Centre International de Recherche en Agronomie pour le Développement*) in Montpelier. He presented his work at the Natural Resource Modelling conference in Halifax in June 1999 A paper (Alleaume and St-Onge, 2000) will be presented in April of 2000 to Remote Sensing of Environment.

Software development

Management application #7. The use of numerous data layers and the recourse to complex processing methods demands that a complex set of tools and data be assembled, and that the utilisation of these be facilitated in order for the planners to efficiently reach decisions. We are currently developing and test a decision support system based on digital geographical data and on a regrouping of different existing software packages under a unique accessible interface. This system will be mainly composed of a geographical information system (GIS) and a multicriteria analysis package. Implementation of the decision system will require analysing spatial data to evaluate the score for each criteria as a function of location (e.g.: wood yield per stand, impact on biodiversity, etc.). At the same time, the different users of the forest will be consulted to establish different management scenarios and to evaluate these using a multicriteria multi-stakeholders approach. The integrated set of tools under development is intended for use by non-experts in geomatics and MCDM techniques, such as forest managers, using an approach similar to that of Martin and collaborators, 1997. Two aspects of this decision aid system pertaining to spatial information are critical: 1) the use of up-to-date precise information and 2) the accessibility of this information.

The objective of the GIS-MCA tool is to offer a platform for elaborating and testing forest management scenarios in the same environment used to browse, query and analysing geospatial data. The GIS-MCA should have the following properties:

- impose minimal royalty fees on its potential customer,
- be easy to use, and usable in focus group sessions,
- be interoperable and not limited to one GIS format,
- allow for distributed development between different teams,
- be able to make use of computer programs that already exist.

A custom interface is being developed using Visual Basic and ESRI's MapObjects (figure 3), thus allowing for Rapid Application Development (RAD). All access to data is carried through a handles provided by meta-data. These meta-data contain the usual descriptions but also provide lay-man aliases for data themes (“topography”, “forest stand map”, etc.), data layers, attribute names, and attribute codes. Therefore, an inexperienced user can browse data easily. Data access and basic processing is done through MapObject (GIS software components) and

OGDI (an emerging Canadian GIS interoperability standard). This combination is helpful in making use of existing software (MapObject) without imposing a certain "brand" (ArcView vs MapInfo, IDRISI vs SPANS, etc.) since an OGDI enabled application can read most common formats and perform on-the-fly projection conversions. The metadata is local because it is developed for a specific user or project. However, the data for that user might be in part very specific, and thus would reside on the client's computer, or more general (topographical maps, Statistics Canada, etc.). Thus an access to distant databases is necessary. All of this is however transparent to the user because data access is carried out though the metadata. Specific algorithms (multicriteria analysis, etc.) are encapsulated in DLLs or OCXs and call by the main Visual Basic program.

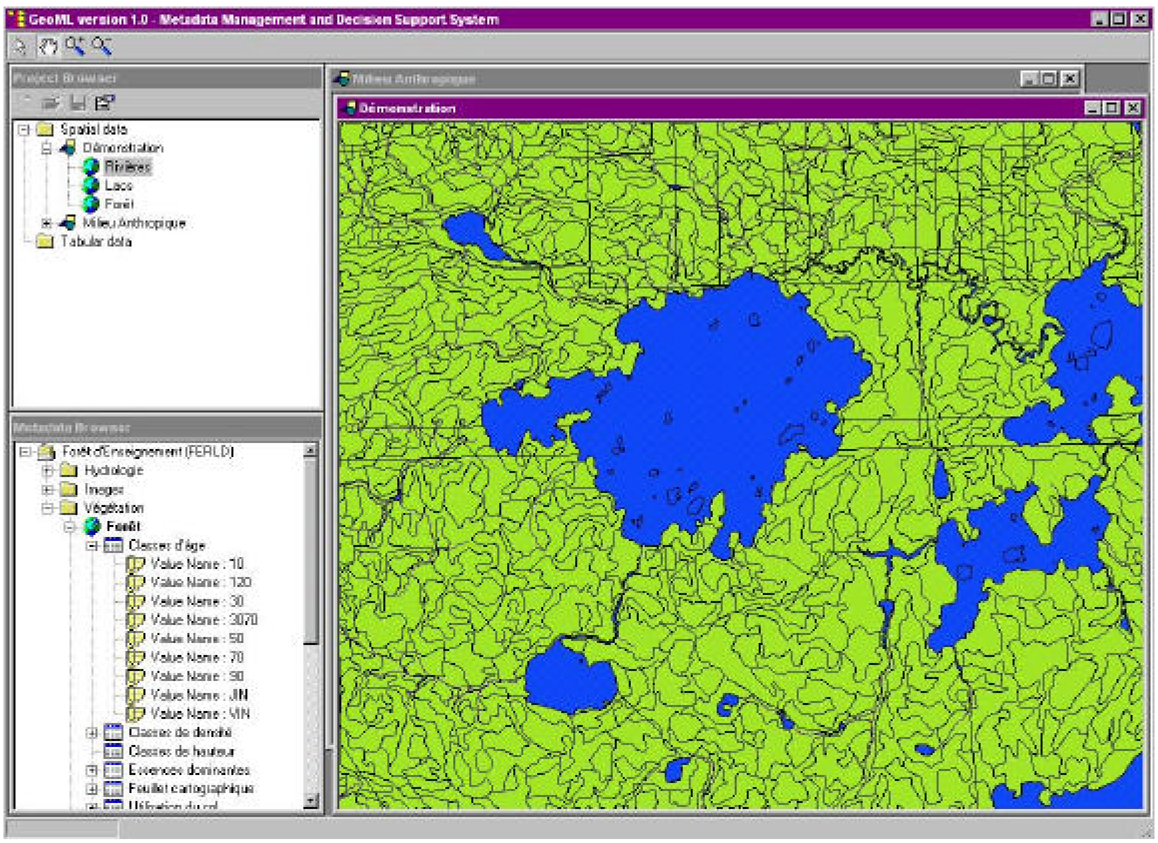


Figure 3 – Screen capture from the software tool showing the metadata tree (lower left) and a map displayed using MapObjects.

Integration project

Management application #8. Our project is also a component of a wider integration project led by C. Messier and L. Bouthillier. This integration project includes NCE-SFM project teams from Quebec and aims at **providing partners with *biophysical indicators of sustainable forest managemen*** *t* that would be useful in their operations in order to ensure the maintenance of biodiversity and regeneration as well as soil and aquatic resources. These indicators were for both planning and monitoring stages of forest management. In early October (Oct.6-7), we participated in a two-day technology transfer workshop with our Industrial Partners (Cartons St-Laurent, Abitibi Consol., and the Quebec Ministry of Natural Resources) in LaTuque, Québec. In this meeting we gave a brief overview of the work being conducted on multicriteria decision making and the associated software. The work we are currently doing will be specifically integrated with that of M.-J. Fortin by connecting multicriteria analysis to landscape modelling software such as LANDIS. This tools will be used to generate the different biologically sustainable scenarios based on the biophysical indicators that have already been presented and those that will continue to be developed this year. The SFM scenarios that are established in LANDIS will be essentially coarse-scale scenarios (landscape level and long-time horizons). Following spatial evaluation the ecologically sustainable alternatives will be fed to the general multicriteria analysis (taking economical aspects into consideration). This process can occur in a feedback loop in which stakeholders (from the public participation forum) request alternative scenario generation.

CONCLUSIONS

The central objective of this project is to develop an integrated set of tools designed to guide forest manager's decisions in a manner that will improve forest sustainability. We have presented methods and tool that are useful in implementing informational and decisional methods that will help managers consider and evaluate the different uses of the forest (wood harvesting, biodiversity, the local economy of forest communities, etc.) at the early stages of forest management scenario design. Important results are hereby summarised.

The usefulness of the ecological mapping approach has been demonstrated for different aspects of forest management, including for elements that relate to cost factors such as forest road construction. We have showed that geodata can be provided by a variety of means, including high resolution remote sensing sources. This geodata can be processed in a variety of ways, including ecological modelling (predictive vegetation mapping by logistic regression) and multicriteria analysis. The breadth of multicriteria analysis also allows for the consideration of socio-economic criteria in addition to environmental criteria. Such analyses have been conducted in different context and confirmed their potential. They will soon be tested with real decision groups such as advisory committees.

Some challenges have yet to be tackled. First, the task of integrating GIS, multicriteria decision making software and ecological modelling is complex but very promising. Our future work essentially aims at bringing these components closer together in order to create a more complete decision tool. Second, the implementation of this tool will have to consider uncertainty associated with the data and models in such a way that decisions are taken according to these uncertainty levels. Finally, the implementation of the decision aid tool in the context of real decision making will have to be made so that their user become accustomed to working with such tools, therefore, a technology transfer or education strategy will have to be studied more closely.

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