Forests **2010**, *1*, 99-113; doi:10.3390/f1030099

OPEN ACCESS

forests

ISSN 1999-4907

www.mdpi.com/journal/forests

Article

A Forest Management Process to Incorporate Multiple Objectives: a Framework for Systematic Public Input

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Received: 6 July 2010 / Accepted: 30 July 2010 / Published: 30 July 2010

Abstract: A multi-objective forest management process employing mathematical programming and the analytic hierarchy process has been developed for systematically incorporating public input. The process was tested as a "proof of concept" for four values and five stakeholders in Crown License 5 in New Brunswick. The impacts of tradeoffs among various weighting schemes were evaluated. Analyses of stakeholders' expected satisfaction were conducted for each scenario. The forest management implications of different weighting methods are discussed.

Keywords: multi-objective forest management; systematic public input; mathematical programming; analytic hierarchy process

1. Introduction

Achieving sustainable forest management (SFM) requires identification of all the important values that should flow from a forest over time [1], but determining the appropriate set of forest values is a challenging task given the conflicting demands of different interest groups in society. Public involvement in forest management (FM) processes is proposed or required by most forestry jurisdictions in Canada, presumably in order to help ensure that public values are factored into the goals of forest management. However, it can be argued that no comprehensive methods to fully incorporate public input in FM planning processes have, as yet, been instituted. Furthermore, current forestry planning tools and approaches do not appear to be amenable to actively integrating public values into FM planning processes in most forestry jurisdictions in Canada. For instance, New Brunswick's Protected Natural Areas Act of 2003 (http://www.gnb.ca/0078/publications/OurHeritage-e.pdf) requires the establishment of local advisory committees to be involved in the management of each protected area. However, it is not clear how public values or preferences are actually incorporated into FM planning processes. Although, arguably, the public forests in provinces like New Brunswick are being managed sustainably with respect to timber and environmental values, processes or techniques to integrate diverse public values into provincial FM processes are not well developed.

Forest management (FM) processes all over the world have evolved over the last few decades from a single resource-based paradigm to one that emphasizes multiple objectives [2]. This has led to the application of multi-criteria decision support methods and tools, which are considered appropriate for addressing multi-objective forestry problems [3]. There are a number of methods/techniques to integrate multiple criteria/objectives into FM planning processes. One approach is to construct a single objective-based optimization model by combining several objectives having fixed or varying weights into a single aggregate function [4]. Solutions are obtained by optimizing the weighted sum of the objectives by which the trade-offs among the objectives can be determined. Unfortunately, the problem with this method is that determining appropriate weights for the objectives is difficult [5]. Moreover, the weights of the objectives are often determined by a team of experts without properly considering the opinion of stakeholders [6]. Another approach is to optimize one objective (having absolute preference over other objectives) while keeping the others as constraints in the model in a parametric fashion. However, determining trade-offs among all objectives simultaneously is difficult or impossible using this approach. As a result, its application is limited in multi-objective forest management (MOFM) planning processes. An alternative, yet promising, approach is called Interactive Decision Map (IDM) where decision makers (DM), at each iteration, progressively articulate their preferences for alternative solutions based on the tradeoffs between competing objectives [7,8]. The advantage of this approach is that it allows the DM to drop infeasible solutions and achieve the best compromise solution(s). However, a major drawback of this approach is that it requires a lengthy and active engagement of all the DMs. Finally, it is possible to calculate efficient/optimal Pareto frontiers for competing objectives where it is not possible to increase the value of one objective without compromising the value of another [9]. Calculating the Pareto efficient frontier can help DMs to understand the tradeoffs between objectives and to identify a feasible solution space. However, for larger MOFM problems with multiple DMs (each of which values all of the objectives but to different degrees) in a non-idealized decision environment, it is not clear that defining and using the Pareto frontier would provide enough valuable information to be worth the considerable computation time [8] and stakeholder involvement it would require. Applying this method to MOFM problems often results in numerous non-dominated Pareto-optimal solutions, which does little to further the decision-making process and, ultimately, to select one for implementation.

Historically, two optimization techniques have been widely used for multi-objective natural resource management: (1) multi-objective linear programming and (2) goal programming (GP) [10,11].

GP, in particular, has been extensively applied to multi-objective FM planning. Goal programming is designed to minimize the weighted sum of the deviations of each goal from its target. If all goals can be met exactly, then the objective function value is zero. In GP, goal deviations may be weighted equally (based on normalized weightings), or they may have different weights (based on preferential weightings). Goals with higher preferential weights are favored over those with lower weights. Using GP, decision makers strive to achieve the desired goal levels as closely as possible by minimizing the deviations from the goals while, at the same time, the impacts of stakeholders' preferences (in terms of different weighting schemes) on the achievement of various goals can be explicitly examined. Since the pioneering work of Field [12], extensive research has been undertaken using GP in natural resource management. Chang and Boungiorno [5] used GP to develop a multiple use FM model for Nicolet National Forest in Wisconsin. They applied a preemptive GP (where goals are ranked by their importance and the higher ranked goals are achieved first followed by the lower ranked goals) without considering stakeholders' preferences. Van Kooten [13] developed a GP model for land-use planning on Vancouver Island in British Columbia to achieve timber and non-timber objectives. However, the goal-weighting process used in this study was not explicit and mathematical modeling was not used to determine the trade-offs among various objectives. Among other studies, Balteiro and Romero [14] and Bottoms and Bartlett [15] developed GP models for MOFM situations. Both studies were designed to quantify trade-offs among different objectives to select the best management solution(s). The former study used both equal and unequal weights for all objectives in the GP model and the latter used a combined method of both GP and LP. Despite the potential usefulness of GP for FM decision-making processes, the application of GP is not very common in forestry jurisdictions, including in New Brunswick.

2. Objective

The objective of this study was to design and develop a defensible and feasible MOFM process for public forests in New Brunswick using GP and LP that explicitly incorporates multi-stakeholders' preferences in the development and evaluation of alternative solutions. As a "proof-of-concept" study, this objective could be considered achieved if the proposed technique:

- was able to efficiently incorporate multiple stakeholder preferences using methods that have been previously proven;
- employed readily available data and tools in the development of alternative solutions;
- enabled the decision-maker to evaluate the impacts of trade-offs among various weighting methods and stakeholder preferences on the acceptability of alternative solutions.

The primary evidence for the validity of the "proof-of-concept" would come from the application of the proposed MOFM method to the forest management of a particular License area (Crown License 5) in New Brunswick, Canada. Note that the scope of this study did not incorporate a methodology for soliciting preferences from multi-individual stakeholder groups, which is itself an important area worthy of investigation. Rather, the assumption is made that the representative preferences for each multi-individual stakeholder group are solicited in some manner external to the MOFM process that is the focus of this study.

3. Methods and Results

The objective of this study was accomplished by: (1) designing and administering a questionnaire for the forest manager of License 5 in order to obtain information regarding the forest management objectives for the forest, as well as his "best guess" of the forest value preferences of significant stakeholder groups; (2) designing and developing a weighting system suitable for goal programming using the analytic hierarchy process, a mathematical method for measuring preferences for diverse criteria in order to compare alternative decisions [16], to transform stakeholders' preferences into measurable weights; (3) determining targets of the goals using linear programming in a timber supply model (in Woodstock^{TM}); (4) formulating a GP model by modifying the existing timber supply model of License 5 and using the data from steps 2 and 3 as input to the model; and (5) evaluating the results of the GP model with four forest management scenarios: equal preference, individual stakeholder preference, group average preference, and weighted average preference scenarios.

3.1. Step One: Forest Manager Questionnaire Survey

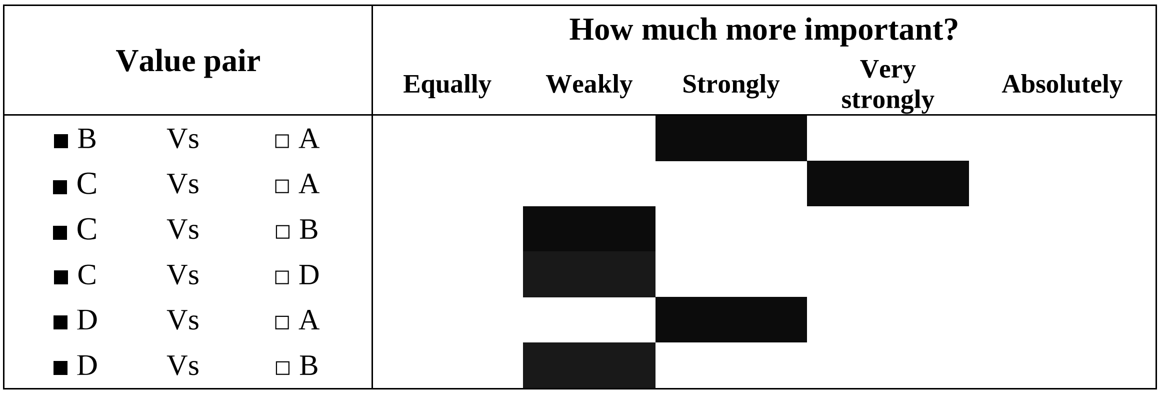
The objective of this step was to acquire information from the forest manager of Crown License 5 concerning his expectations of the preferences of major stakeholders concerning forest values. For this purpose, a questionnaire survey [17] was developed comprising five questions around three main categories. The Category-1 questions were designed to collect information on the order of preferences of five different stakeholder groups (the provincial government, local communities, recreational groups, environmental groups and the licensee company itself) in Crown License 5 to develop a MOFM plan. The Category-2 questions were designed to acquire information about the forest management objectives or constraints for License 5. The Category-3 questions were designed to determine the measurable weights from the expected relative forest value preferences of the stakeholder groups using the analytic hierarchy process (AHP). As noted above, no survey of the actual stakeholders was undertaken. Instead, the manager was asked to guess the relative preferences that each stakeholder group would have for four major goals or values (e.g., timber, employment, old spruce-fir habitat (OSFH), and scenic beauty) of the FM plan. In order to reduce the potential for bias, the forest manager was given a 'unitless' scale from which to choose the preferences for each forest value in relation to the others to be used in pair-wise comparisons in the AHP. Note that the choices regarding stakeholders and forest values for this study were arbitrary, though reasonable for the situation. Any stakeholder group that could be surveyed, and any values whose attainment could be measured as outputs of the forest management planning process could have been used.

3.2. Step Two: Weight Determination Using Analytic Hierarchy Process

The objective of this step was to translate the forest manager's best guess of the relative preference of each stakeholder group for the four FM goals into measurable weights by applying the AHP, employing an adaptation of the methodology described by Smith and Lantz [18]. The AHP made it possible to assign weights to this ranking of predefined forest values [16]. A "goal-weighting matrix" was formed by making pair-wise comparisons using a five-point scale (having numerical preference scores of 1, 3, 5, 7, and 9 for stated preferences of equal, weak, strong, and very strong respectively) to determine the weight of each goal. In this study, the value of a preference score to a given goal varied from 1 to 9, where 1/1 indicates equal importance, 3/1 weakly greater importance, 5/1 strongly greater importance, 7/1 very strongly greater importance, and 9/1 absolutely greater importance. The following describes the procedure using the predicted preferences of the Environmentalist group of stakeholders.

Task 1: Enter the subjective preferences of the Environmentalist group (as simulated by the forest manager) for the four FM goals (e.g., timber, employment, old spruce-fir habitat (OSFH), and scenic beauty representing letters A, B, C, and D in Figure 1). According to this group's (simulated) preferences, B is preferred to A, C is preferred to A, B and D, and D is preferred to both A and B. More specifically, according to the level of importance, B (checked) is strongly more important than A, C (checked) is very strongly more important than A, C is weakly more important than both B and D, and D (checked) is strongly and weakly more important than A and B respectively.

Figure 1. Simulated preferences of the Environmentalist group.



Task 2: Convert the preferences to numerical values and sum the column elements (see Table 1). Here, B is 5 times more important than A (since B is strongly more important than A); C is 7 times more important than A (since C is very strongly more important than A); and D is 5 times more important than A (since D is strongly more important than A); By summing the column elements for A (second column in the table), the total value in Column A became 18.00 (1 + 5 + 7 + 5). In a similar way, the total values for columns B, C and D were measured.

Table 1. Weightings derived from the simulated preferences of the Environmentalist group.

Values	A	B	C	D
A	1	1/5	1/7	1/5
B	5	1	1/3	1/3
C	7	3	1	3
D	5	3	1/3	1
Total	18.00	7.200	1.808	4.533

Task 3: Divide each element by its column total. Averaging each row provides the normalized priority weight for the corresponding value. The highest number under the priority column indicates the highest preference.

For example, by dividing each element in row A (1, 5, 7, and 5) by the corresponding column total of A (18.00), three values were found viz. 0.0556, 0.2778, 0.3889, and 0.2778 (see Table 2). In this case, the normalized priority weight for A is 0.051 ((0.0556 + 0.2778 + 0.3889 + 0.2778)/4).

Table 2. Normalized weightings derived from the preferences of the Environmentalist group.

Values	**A**	**B**	**C**	**D**	Normalized priority/weight (∑ = 1)
A	0.055556	0.027777	0.0785398	0.0441208	0.051
B	0.277778	0.138888	0.1841814	0.0734612	0.169
C	0.388889	0.416666	0.5530973	0.6618133	0.505
D	0.277778	0.416666	0.1841814	0.2206044	0.275

The steps mentioned above were applied to this research to determine the priority weight of each goal by each stakeholder group (see Table 3). However, the preferences of the stakeholder groups were not checked for internal consistency, a problem that can occur regardless of the source of the preferences when the AHP method is used (for a discussion of the problems of AHP and how these might be identified and rectified using eigenvalues and consistency coefficients, see Saaty, [16]). A thorough analysis of the internal consistency of the forest manager's estimates of the stakeholders' preferences was beyond the scope of this research project. However, if the proposed methodology is to be used in an actual exercise that involves 'live' stakeholders and that depends upon more certain knowledge of their actual values, then checking for internal consistency of the preferences would be advisable. Note that an IDM approach (mentioned in the introduction) may also be applicable since it would allow us to choose goal targets directly from stakeholders (through comparisons of the tradeoffs between competing objectives) rather than asking them for their preferences for each goal. However, the IDM approach is more suitable for a situation where it would be possible to have the "live", ongoing involvement of all stakeholders.

Table 3. Preferential weights of all stakeholder groups determined by the AHP.

Goal	Stakeholders' preferential weights (normalized to 1.00)				
	Licensee	NB Govt.	Local communities	Recreationists	Environmentalist
Timber	0.642	0.290	0.106	0.047	0.051
Employment	0.218	0.540	0.449	0.093	0.169
OSFH	0.093	0.105	0.121	0.199	0.505
Scenic beauty	0.047	0.065	0.324	0.661	0.275

3.3. Step Three: Linear Programming Modeling

The objective of this section is to perform modeling by linear programming (LP) in order to determine the maximum possible values that could be achieved for each of the four goals over an 80-year planning horizon based on an existing timber supply model of Crown License 5. The original timber supply model (actually implemented in 2002) was modified to formulate LP and GP models for this research (see Hossain [17] for details of the original and modified models).

Some constraints used by the Licensee were removed from the original timber supply model for two reasons: (I) they had been added to the original model for operational rather than policy reasons (for example, to meet the silvicultural budget constraints stipulated by the government), and (II) they might tend to over-constrain the model and thereby cloud the results of this research. For these reasons, all silvicultural constraints were removed from the original timber supply model in order to develop the LP and GP models for this study. The area of OSFH constraint was also removed since it was one of the goals of the multi-objective models. Thus, the constraints removed from the original model were: plantation area, commercially thinned area, spacing area, pre-commercially thinned area, and area of OSFH. Other constraints (e.g., medium wintering deer habitat, severe-wintering deer habitat, mature pine area, mature cedar area, mature jack pine area, mature spruce area, and buffer volume constraint) were retained to satisfy government requirements. A non-declining yield constraint was added to the model to prevent any reduction of timber supply over the planning horizon and a constraint ensuring that the growing stock in the final inventory was greater than or equal to the average of the last fifteen periods was imposed.

The FM goals were measured in terms of specific indicators. The indicator for the timber goal was total timber (m^3) harvested (both softwood and hardwood) over the planning horizon (16 five-year planning periods). The employment goal was calculated from the total number of work hours required for all FM activities (e.g., timber harvesting, planting, commercial thinning, transportation, and primary wood processing activities in the mill). The OSFH goal was the sum, for all periods, of the area (ha) of forests 65–185 years of age conforming to the definition of old spruce-fir habitat according to the original timber supply model. Incorporation of forest scenic beauty into an MOFM process requires that scenic beauty be defined in terms of stand characteristics [19]. While several studies have been undertaken to predict scenic beauty as a social value, the indicators used to define it are somewhat arbitrary. Sheppard *et al*. [20] have used cut area size and regeneration age and height as quantitative indicators for scenic beauty and/or aesthetic value of forests according to Sustainable Forest Initiative (SFI)™ standards. Brown and Daniel [19] have found that mature and even-aged stands were aesthetically pleasing to visitors to the forest. Buhyoff *et al*. [21] have reported that, in southern pine stands in North Carolina, although stand scenic beauty was correlated with stand age, stem size and basal area, only stand-age seemed to have a significant relationship with stand scenic beauty. Since stand age was found to be the dominant factor affecting scenic value of forests in the studies described earlier and no documented research was found that defined scenic beauty in terms of stand characteristics in Canada, stand age was used as a surrogate measure of scenic beauty in this research, with stands between the ages of 20 to 100 years considered to be "scenically beautiful".

Four LP models for the License were developed using Woodstock™ (Remsoft 3.27 version) and the MOSEK LP solver. In addition to the model using the same objective function as was defined in the original timber supply model (maximize total harvest of timber over the 80 year planning horizon), three other models for the same planning period were created that used other objective functions: (1) maximize total employment, (2) maximize total scenic beauty area, and (3) maximize total area of OSFH. First, the timber goal was maximized without regard to other goals subject to the constraints described previously. In the subsequent models, each other goal (e.g., OSFH, employment, and scenic beauty) was maximized without regard to other goals, all subject to the same constraints. The outcomes of all LP models, shown in terms of total values of each goal when they are maximized in isolation over the 80 year planning horizon, are presented in Table 4. These values were used as goal targets in the goal programming model.

3.4. Step Four: Goal Programming Modeling

The intent of this step was to perform goal programming to identify multiobjective solutions based upon different weighting schemes. The GP model was formulated using the outcomes obtained from LP models (see Section 3.3) as the goal targets. Before adding preference weightings, all goals were normalized to ensure that the value of deviations from targets for each goal would be equal when the goals themselves were equally preferred. This was done by adopting a modified version of the process developed by Balteiro and Romero [22]. A detailed description of the goal normalization process can be found in Hossain [17]. The normalized weight of each goal obtained from this process is presented in the second numeric column in Table 4.

Table 4. Maximum total output and normalized weights of each goal in LP modeling over the 80 year planning horizon.

Goals	Maximum total output of each goal	Normalized weights
Timber (m^3)	10,223,481	1
Employment (work-hours)	2,641,528	14.28
OSFH (ha)	415,168	16.39
Scenic beauty (ha)	807,005	26.31

The goals were then weighted under four weighting schemes: equal preference, individual stakeholder preference (ISP), group average preference (GAP), and weighted average preference (WAP). In the equal preference scenario, all the objectives were given equal preference, regardless of the preferences of the various stakeholders, so each of the four goals had a weight of 0.25. The GAP and WAP scenarios were developed to imply consensus among the stakeholder groups. In the GAP scenario, the preferential weight of each goal was determined by averaging the weights (determined by the AHP) across the stakeholder groups. This scenario was developed to examine how the achievement of a goal could be impacted when a combined value of the preferences of all stakeholder groups is considered regardless of their size. In the WAP scenario, the preferential weight of each goal was modified based on the number of people represented by each group. The rationale for developing the WAP scenario was to investigate how the FM decision-making processes could be influenced when stakeholders' preferences are affected by the size of the stakeholder groups. In the ISP set of scenarios, the preferential weight of each stakeholder group, as determined by the AHP, was applied to determine the preferred solution of each individual stakeholder group.

In order to elicit the final weights (or penalty points for not achieving goals in GP) to be attached to each goal, we implemented a multiplicative aggregation process [22] between the preferential weights (obtained from AHP) and normalized weights (obtained from goal normalization). In all FM scenarios (e.g., equal preference, ISP, GAP, and WAP), the final weight for each goal was determined by multiplying the preferential weight with the normalized weights. The weightings used are presented in Table 5.

Table 5. Final weight of each goal under GAP, WAP and ISP scenarios.

Goal	Final weight of each goal						
	GAP	WAP	Licensee	NB Govt.	Local communities	Recr. groups	Envi. groups
Timber	0.227	0.196	0.642	0.290	0.106	0.047	0.051
Employment	4.241	5.526	3.113	7.711	6.411	1.328	2.413
OSFH	3.343	2.245	1.524	1.720	1.983	3.261	8.276
Scenic beauty	7.208	9.945	1.236	1.710	8.524	17.390	7.235

Goal programming modeling was performed to minimize the weighted sum of deviations of each goal from its target based upon different weighting schemes. Goal deviations indicate the difference between the maximum value of a goal and what could be accomplished with respect to the goal (a description of the goal constraints and the deviation variables can be found in Hossain [14]). The reason to employ GP is that it allowed us to express multiple and conflicting goals in a model to find feasible solutions. Unlike LP, where feasible solutions can only be achieved if the goal constraints are satisfied, GP doesn't require that the goal targets be strictly achieved. The general design of the objective function in the GP is given as:

$$\text{Minimize Z} = \sum_{i=1}^{4} \mathrm{W_i}\ (d_i^+ + d_i^-)$$

where,

d_i^+ = positive deviation of i^{th} goal from its target (i = 1…4)
d_i^- = negative deviation of i^{th} goal from its target (i = 1…4)
W_i = weights of i^{th} goal (i = 1…4)

The goal achievement levels for 16 periods (80 years) under the equal preference, GAP and WAP scenarios are presented in Table 6, while those of the ISP scenarios are presented in Table 7. It is noteworthy that in the GP models in this study, the goal targets and goal achievements were the aggregate measures of each goal over all periods. In an actual situation, it is very likely that constraints would also be set on the minimum achievement of each goal in each period, as well as on the maximum variation in goal achievement between periods. In this "proof of concept" study, however, the only periodic goal that was constrained to be above a minimum was that of OSFH, as had been noted earlier.

Table 6. Total achievement value of each goal in the equal preference, GAP, and WAP scenarios[a].

Weighting schemes	Total goal achievement levels in the GP models			
	Timber (m^3) (10,223,475)[a]	Employment (work-hours) (2,641,520)	OSFH (ha) (415,165)	Scenic beauty (ha) (807,000)
Equal preference	10,133,518 (99.12%)[b]	2,487,181 (94.15%)	72,951 (17.57%)	647,821 (80.27%)
GAP	9,118,488 (89.19%)	2,613,684 (98.94%)	131,656 (31.71%)	709,888 (87.96%)
WAP	9,119,018 (89.20%)	2,615,615 (99.01%)	127,087 (30.61%)	710,294 (88.01%)

[a] Figures in parentheses indicate the goal targets
[b] Figures in parentheses indicate percent of the goal target achieved

Table 7. Total achievement value of each goal in the ISP scenarios.

Stakeholder groups	Total goal achievement levels in the GP models			
	Timber (m^3) (10,223,475)[a]	Employment (work-hours) (2,641,520)	OSFH (ha) (415,165)	Scenic beauty (ha) (807,000)
Licensee	9,793,863 (95.79%)[b]	2,597,025 (98.31%)[b]	84,306 (20.30%)[b]	669,826 (83.00%)[b]
NB Government	9,291,713 (90.88%)	2,640,833 (99.97%)	90,544 (21.80%)	689,120 (85.39%)
Local communities	9,152,874 (89.52%)	2,622,293 (99.27%)	115,597 (27.84%)	707,851 (87.71%)
Recreational groups	7,475,307 (73.11%)	2,226,253 (84.27%)	213,477 (51.41%)	766,294 (94.95%)
Environmental groups	7,999,893 (78.25%)	2,366,572 (89.59%)	219,354 (52.83%)	742,869 (92.05%)

[a] Figures in parentheses indicate the goal targets
[b] Figures in parentheses indicate percent of the goal target achieved

3.5. Step Five: Evaluation of Goal Programming Results

In this step, the multi-objective solutions obtained from goal programming modeling were assessed. Upon analysis of Tables 6 and 7, it was found that the achievement of only one goal, OSFH, varied significantly in terms of percentage of the goal target across the equal preference, GAP, WAP, and ISP model runs. As expected, it was observed that in none of the MOFM scenarios were the individual goal targets completely achieved since the MOFM process requires making trade-offs among individual goals in order to attain a global optimum solution.

The results in Table 6 show how the achievement (total value) of all goals vary under different weighting methods (equal preference, GAP and WAP scenarios). As could be expected, the achievement of employment and scenic beauty is improved in the GAP and WAP scenarios compared to the equal preference scenario simply because the weights of those goals are higher in these scenarios. However, the relationship of weights to final results are not similarily consistent for the timber and OSFH goals. Possible reasons for this will be discussed later.

In Table 7, which shows the results of the ISP runs where each stakeholder's preferences were used to weight individual multi-objective model runs, it is observed that the relative achievement of each goal in the ISP scenarios is consistent with the relative preferences of the stakeholder groups (as seen in Table 5). Here, the total values of timber, employment, scenic beauty, and OSFH are maximum for the Licensee, NB Government, recreational groups, and environmental groups respectively, since these are the most preferred goals of the stakeholder groups. Conversely, the achievement of OSFH and scenic beauty is lowest for the Licensee, since these are the least preferred goals for that stakeholder. Similarly, the achievement of employment is lowest for the recreational groups, since this is the least preferred goal for recreational groups (Tables 3 and 5).

In terms of deviation of goal outputs (total value) from the targets, the deviation of OSFH output is greatest compared to other goals (82 % deviation from the target; see Tables 6 and 7). One reason of this low achievement could be that the age-range of the occurrance of OSFH is 65–185 years while most harvesting actions are carried out on stands aged 70–170 years, so logically it is difficult to achieve OSFH and timber simultaneously. Given that employment and timber are closely related since most employment comes from timber production, their combined weight would tend to surpass that of OSFH. For instance, in the GAP and WAP scenarios, the combined weights of employment and timber are 4.468 and 5.722 respectively, which are much higher than the weights of OSFH (Table 5). Clearly, this combined weight should exert a negative influence on the attainment of OSFH. However, this does not completely explain why the maximum achievement of OSFH is only 18% of its target in the equal preference scenario.

Upon performing a series of equal preference GP models with minimum OSFH level (total OSFH must be greater than or equal to 125,000; 150,000; 175,000; 200,000; 225,000 and, 250,000 ha), it was observed that the achievement of timber decreased sharply to zero when the OSFH constraint was set to 250,000 ha, implying that after this point the cost of losing timber rises suddenly and dramatically (Table 8). This would be a major reason why the achievement of OSFH is so poor when all four goals are targeted simultaneously; that is to say that after a certain point (i. e. when OSFH is greater than or equal to 250,000 ha) the cost of losing timber (and/or employment since timber and employment are closely related) is so high that the model favours achieving timber at the expense of OSFH. However, given the multi-dimensional nature of the model and the complexity of the forest, it is not possible explain exactly how the trade-offs were made among the goals.

Table 8. Total values of OSFH and timber at minimum OSFH constraints.

Total value of OSFH (ha)	Total value of timber (m^3)	Minimum OSFH constraint (ha)
246,320	7,091,712	OSFH ≥ 125,000
247,792	7,084,528	OSFH ≥ 150,000
249,456	7,078,416	OSFH ≥ 175,000
252,512	7,063,184	OSFH ≥ 200,000
259,744	6,979,712	OSFH ≥ 225,000
315,008	0	OSFH ≥ 250,000

3.6. Step Six: Assessment of Stakeholders' Satisfaction over Goal Achievements

In order to evaluate the acceptability of solutions, it would be beneficial to estimate the level of satisfaction or dissatisfaction that the stakeholder groups might feel for the outcomes associated with a particular solution based upon their preferences. Assuming that over-achieving targets in the ISP models leads to more satisfaction and underachieving the targets leads to more dissatisfaction, three analyses were undertaken based upon the ISP, GAP, and WAP solution sets to estimate the overall satisfaction and/or dissatisfaction (in terms of penalties for not achieving goals) of each stakeholder group. The first analysis was performed based upon the ISP solutions to examine how satisfied and/or dissatisfied the other stakeholder groups would be if the Licensee's preferred multi-objective solution was imposed upon them. For example, the overall level of satisfaction of the NB government was determined by measuring the difference between the achieved values of each goal in the Licensee solution and those values achieved in the NB government's ISP solution (from Table 7), multiplying the difference by the corresponding weights used under the NB government ISP scenario (from Table 5), and finally summing the product value for each goal. Thus, the overall level of satisfaction of NB government when the Licensee's preferred solution is imposed on them was calculated as:

$$(9{,}793{,}863 - 9{,}291{,}713) \times 0.290 + (2{,}597{,}025 - 2{,}640{,}833) \times 7.711 + (84{,}306 - 90{,}544) \times 1.721 + (669{,}826 - 689{,}120) - 1.710 = -235{,}920,$$

where ,

(I) 9,793,863 is the Licensee's timber solution, 9,291,713 is the NB govt's preferred timber solution and 0.290 is NB govt's "value" for shortfalls or overachievements of its preferred solution;

(II) 2,597,025 is the Licensee's employment solution, 2,640,833 is the NB govt's preferred employment solution and 7.711 is NB govt's "value" for shortfalls or overachievements of its preferred solution;

(III) 84,306 is the Licensee's OSFH solution, 90,544 is the NB govt's preferred OSFH solution and 1.721 is NB govt's "value" for shortfalls or overachievements of its preferred solution;

(IV) 669,826 is the Licensee's scenic beauty solution, 689,120 is the NB govt's preferred scenic beauty solution and 1.710 is NB govt's "value" for shortfalls or overachievements of its preferred solution; and

(V) −235,920 is the total level of dissatisfaction of the NB Govt with the Licensee's solution (negative signs indicate overall dissatisfaction).

Similarly, the overall satisfaction levels of local communities, recreational groups, environmental groups with the Licensee's preferred solution, as well as the GAP and WAP solutions were determined and the results are presented in Table 9.

Table 9. Overall satisfaction of stakeholders when the preferred solution of the Licensee, the GAP solution or the WAP solution are imposed.[a]

Stakeholder Groups	Level of satisfaction (or dissatisfaction) with the Licensee's Solution	GAP solution	WAP solution
Licensee	0	−260,017	−260,128
NB Government	−235,920	−153,319	−145,443
Local communities	−480,264	−9,631	−2,794
Recreational groups	−1,497,600	−656,066	−661,319
Environmental groups	−998,621	−311,089	−341,282

[a] Negative signs indicate dissatisfaction

The first column of numbers in Table 9 shows how much the other stakeholder groups (NB government, local communities, recreational groups, and environmental groups) would be dissatisifed if forced to accept the Licensee's preferred solutions. In the second and third numeric columns, it can be seen that even though all stakeholder groups would be dissatisfied with the GAP and WAP scenarios, the levels of dissatisfaction are lower than would be the case if the Licensee's preferred solution was imposed. By analyzing the satisfaction/dissatisfaction results, one can observe that, from the viewpoint of the NB government, the WAP scenario would be the "best" plan simply because it generated less dissatisfaction than the GAP and the Licensee's preferred solutions. For the recreational groups, local communities, and environmental groups, the 'best' plans would be the GAP, WAP, and GAP scenarios respectively. With respect to the measure of dissatisfaction in this research, it would be ideal to compare this method of measuring the acceptability (to stakeholders) of the various solutions with alternative approaches, but no such methods were found in the literature. Nonetheless, the method used here is one way that the results could be analyzed in terms of the anticipated impacts of various preferences upon the expectations of different stakeholder groups.

4. Conclusions

The approach described in this paper employs a framework for systematic public input to FM processes that considers the preferences of different stakeholder groups in identifying solutions. Using a multi-objective forest management (MOFM) process combining LP, GP and AHP, it could facilitate a more explicit form of public involvement in FM planning processes. In terms of the objectives of this study:

- We were able to incorporate multiple stakeholder preferences regarding forest management in a relatively efficient (and explicit) manner in a situation where valid representative opinions were assumed to have been obtained;
- Apart from the aforementioned preferences, this method employed readily available data and tools in the development of alternative forest management solutions. The methods used in this study can be applied to a License level MOFM planning process since they employ existing tools and data that are readily available to a Licensee.
- This method enabled the decision-maker to evaluate the impacts of trade-offs among various weighting methods and stakeholder preferences on the acceptability of alternative solutions.

While this study was based upon data for a specific situation in Canada, the kinds of data and information required should be generally available to forest managers elsewhere. We believe that this approach could help forest managers in situations where they must evaluate the acceptability of a relatively small set of alternative optimum FM solutions from the point of view of other major stakeholders and/or used to identify and negotiate trade-offs. We also believe that this approach could provide useful information to forest managers even when the calculations are based upon their own best guesses of stakeholder preferences, but involving actual stakeholder representatives in the development of solution sets and the evaluation of results would greatly increase the likelihood of identifying acceptable compromises.

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