ANALYTIC HIERARCHY PROCESS APPLICATION FOR MULTIPLE PURPOSE FOREST RESOURCES MANAGEMENT BUDGET ALLOCATION IN DURANGO, MEXICO

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ABSTRACT

A very important aspect of natural resources management is determining optimal budget allocation to satisfy the needs and aspirations of multiple stakeholders. This is especially the case in developing countries like Mexico where budgetary funds are in short supply. There has been an increasing debate in Durango, Mexico, for example, about determining the most efficient way of allocating a budget for multi-purpose forest management. The debate has been triggered by a growing number of interests and stakeholders, which in addition to optimal timber production, have the desire to improve environmental conditions, water resource development, range and other non-timber resources production, and to provide better amenity values and expanded recreational opportunities. CONAFOR (COmisión NAcionale FORestal), the Mexican agency in charge of allocating funds to promote sustainable forest resources development, has been implementing four national programs: developments of *forest resources, tree plantations, non-timber products,* and *water resources.* In addition to these programs, the forest resources management decision-making process involves four interest groups and six management objectives independently connected in a hierarchical framework. Accordingly, the most suitable multi-objective/multi-criterion decision-making (MODM/MCDM) technique for optimal allocation of scarce budgetary funds among the four natural resources development programs is the Analytic Hierarchy Process (AHP). The two programs that receive the most funds are *forest resources development* and *water resources/ environmental services development*. In this way, the AHP can be used to optimally distribute scarce financial resources among competing programs to improve regional economic development and better satisfy the needs of various interest groups.

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Keywords: Multi-objective forest management; CONAFOR; forest budget allocation; Mexican community forestry; *ejido*; utility model

1. Introduction

In the past, Mexican forest management decision-makers and consultants focused their allocation of funds primarily on agroforestry-related resource management activities. The intention was to support forestland farming communities who depended on timber production, cattle grazing and crop farming for their livelihood. Recently, however, there is a growing interest among stakeholders on improving other land-based goods and services such as environmental protection, water production, natural resources conservation, as well as promoting biodiversity, and cultural and recreational values. This in principle is multi-objective forest resources management. In this regard, the concept of multiple-use forestry is being revised by Mexican federal and local governments to more efficiently allocate scarce funds. The revision entails adopting a forest resources management approach that incorporates the views and aspirations of multiple, some of them conflicting, stakeholders. Such stakeholders in a forest ecosystem management may include community and individual landowners, the logging industry, wildlife enthusiasts, forest-related resources managers, non-government organizations (NGOs), the general public, and federal and local institutions (Tecle et al., 1995, 1998; Jenkins, 2005; Niemela et al., 2005; Hossain & Robak, 2010).

A considerable portion of the necessary funds for managing Mexican natural resources comes from the National Forest Commission (or CONAFOR which stands for its Spanish equivalent acronym). CONAFOR is a relatively recent Mexican federal agency created by a Presidential Decree on April 4, 2001. Its main objectives are to promote efficient forest management and restoration activities and to enforce and monitor sustainable forest development policies. To achieve these objectives, CONAFOR has recently been engaged in projects that increase forest stock levels. The projects include development of plantation forestry and improved management of native forests, improvement of landowner's resource management skills, development of forest system management for non-timber products such as resins, oregano and mushrooms, and rewarding landowners whose efforts have improved water quality and environmental protection (Perez-Verdin et al., 2011). For instance, recently combined federal and state funds equivalent to US $4.1 million were issued in the budget to support 1,200 projects in the state of Durango, Mexico (see Figure 1). The aims of the projects were grouped into nine categories: (1) managing timber, (2) developing plantation forestry, (3) increasing non-timber products, (4) expanding recreational opportunities and ecotourism, (5) protecting water quality and quantity, (6) enhancing environmental quality, (7) fostering skilled manpower development, (8) providing technical assistance, and (9) reducing operational costs.

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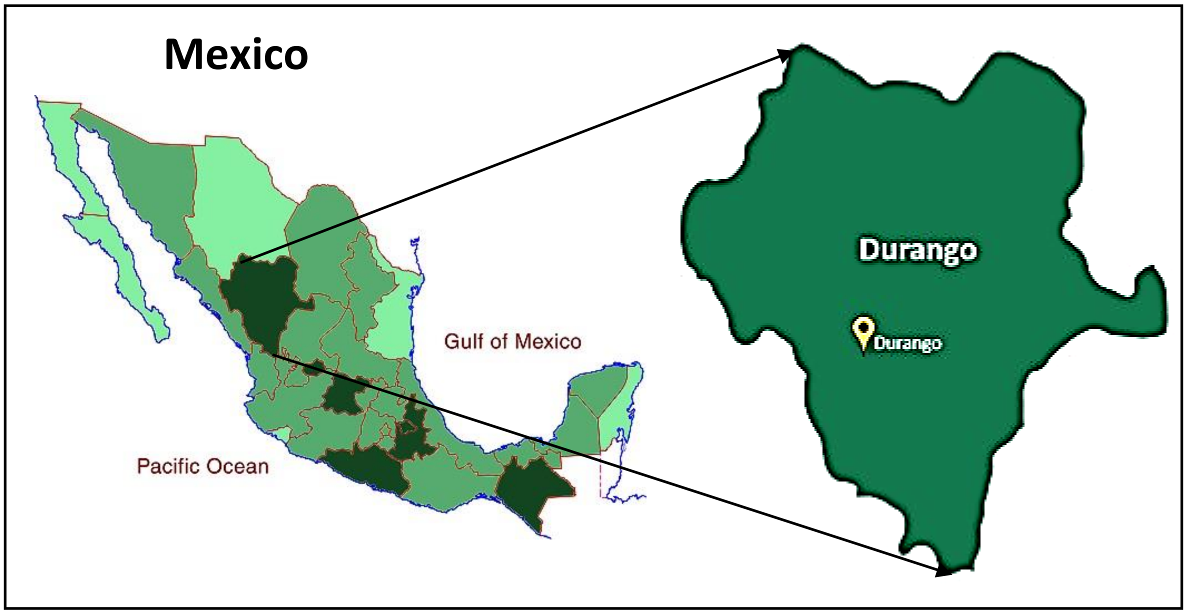

Figure 1 Location of the State of Durango in Mexico (Rhoda and Burton, 2010)

Allocating a budget to such a complex problem consisting of different resources with non-commensurable values, and involving numerous interested parties some with incompatible and conflicting objectives like those stated above is a multi-objective problem (Tecle et al., 1995; Zanakis et al., 1995; Schmoldt et al., 2001a, 2001b). Such a problem tends to become more complex as it usually involves evaluating the performances of numerous alternative management programs using a set of criteria to arrive at the most preferred decision outcome(s) (Tecle & Duckstein, 1994; Duckstein & Tecle, 2002; Vaidya & Kumar, 2006). In the problem under study, the alternatives are the varying *ejido* forest management budget allocation levels, and the preferred outcome is the most optimal budgetary allocation to achieve the various management objectives that can produce the most satisfying mix of forest resources products and services.

In general, there are numerous types of multi-objective/multi-criterion decision-making (MODM/MCDM) techniques that have been used to solve various types of multi-objective problems (Tecle, 1992; Tecle & Duckstein, 1994; Triantaphyllou, 2000; Duckstein & Tecle, 2002; Hajkowicz & Higgins, 2006; Vaidya & Kumar, 2006; Moseley et al., 2009; Sadeghi et al., 2012; Mardani et al., 2015). A typology of the many different available techniques is summarized in Duckstein and Tecle (1993a), while their solution approaches are described in Duckstein and Tecle (1993b). There are many MODM/MCDM techniques that have specifically been used to analyze and solve varying types of multi-objective forest resources management problems (Kangas, 1992; Tecle et al., 1995, 1998; Kangas et al., 2001; Jenkins, 2005; Krcmar et al., 2005; Niemela et al., 2005; Phua & Minowa, 2005; Hajkowicz & Higgins, 2006; Balteiro & Romero, 2008; Ananda & Herath, 2009; Balteiro et al., 2009; Šporčić et al., 2010; Šporčić, 2012, to mention some). Very few of these problems involve costs and budget allocations in multiple objective forest resources management projects; yet, to the best of our knowledge, this study is the only one specifically dedicated to optimally allocate scarce budgetary funds to a multi-objective community level forest resources management

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(Kangas, 1992; Tecle et al., 1998; Balteiro et al., 2009; Chiou et al., 2009; Poff et al., 2010, 2012; Bradford & D'Amato, 2012; White & Bordoloi, 2015).

As noted previously, there are numerous multi-criterion decision-making approaches that have been used to evaluate and solve various types of multi-objective forest resources management problems (Mendoza & Prabhu, 2000; Kangas et al., 2001; Balteiro & Romero, 2008; Poff et al., 2010, 2012; Šporčić et al., 2010; Šporčić, 2012; Tecle & Jibrin, 2014). However, the formulation of the different parts of the problem in an interconnected hierarchical structure makes this particular problem a candidate for evaluation using either the Analytic Hierarchy Process (AHP) or the Analytic Network Process (ANP). But, since the different levels in an Analytic Network Process show interactions and dependence among themselves as described, for example, in Cheng and Li (2004), Ozdemir et al. (2011), Thangamani (2012), Sadeghi et al. (2012), Napoli and Schilleci (2014), and Saaty (2017), the ANP is excluded in favor of the AHP. The latter is so because the different levels in the budget allocation problem are independent of each other to justify and favor the use of the AHP (Leskinen, 2000). The AHP evaluates the multi-objective forest resources management budget allocation problem by incorporating public values to indicate preferences in the decision making process (Saaty, 1977, 1980, 1988, 1990; Schmoldt et al., 2001a; Niemela et al., 2005; Proctor, 2005; Saaty & Vargas, 2006; Ishizaka & Labib, 2011). Furthermore, we found the AHP to be a relatively simple and effective method with an ability to deal with both quantitative and qualitative criteria to determine the most efficient budget allocation for the multi-objective *ejido* forest management problem under consideration.

2. Problem description

In the past, Mexican planners and resource managers rarely focused on developing strategies that strengthen multiple use and sustainable land resource development practices. Hence, federal programs resulted in poor resource management scenarios that jeopardized sustainable development, which eventually led to a decrease in resource productivity and an increase in environmental degradation as stated herewith.

> The lack of a consistent policy to strengthen ejidos [common properties] has grave social and economic implications that result in the degradation of natural resources, which consequently prevents rural communities from making sustainable use of land resources such as forests leading to a decreased quality of life. This creates the vicious cycle of degradation, poverty and poor quality of life. (Semarnat, 2000, p. 43)

Recent changes have improved the management of natural resources by developing new forest policies and their enforcement to promote not only sustainable resource management but also improve important environmental services. These in turn have led

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to improved research, and more efficient decision-making. Such changes are necessary to alleviate the disparities between farmers and forest landowners. Previously, crop farmers received a government subsidy to cultivate their lands, while forest landowners did not receive any funds to help them improve management of their natural resources; instead, they were blamed for the deterioration in land productivity and the poor quality of water coming from the forested areas. To ameliorate the situation, the Mexican government through CONAFOR has decided to manage the *ejido* forest system by developing four different forest resources/service programs to improve and optimize sustainable forest resources productivity. The programs are forest development (FD), plantations development (PD), non-timber products development (NTP), and water resources/environmental services development (WH). Table 1 shows a one year U.S. $4.1 million Mexican government budget allocation to these four different forest resources management programs.

Table 1
A one-year federal budget allocation to manage the four forest resources/service development programs.

Programs	Budget (mill $)	%
Forest development (FD)	2.16	53
Plantations development (PD)	1.45	35
Non-timber products development (NTP)	0.49	12
Water resources/ environmental services development (WH)	0	0
Total	$4.10	100

The main objectives for developing the four different forest resources /services programs are: (1) to promote the sustainability of primarily timber-related products, (2) to improve landowner's resource management skills and (3) to reduce operational costs. Of the four programs, forest resources development (FD) was considered the most important one receiving the largest share of the budget with the largest number of individual projects funded. The plantation development program (PD) was designed to increase forest stocks through establishing new commercial plantations, by producing seedlings and reforesting burned areas and former agricultural or pasture lands. The non-timber products development program (NTP) was not given as much importance as the first two programs, and was meant to focus on the production of items such as oregano and mushrooms and the development of fisheries and improved ecotourism projects. Though these kinds of multiple programs development plans were designed to operate in only six wetter and more forested states of Mexico, the state of Durango was included because of its enormous potential to generate similar products in its temperate and semi-arid forested areas. The fourth program, *water resources/ environmental services development* (WH), was the latest program created by the federal government to protect and enhance amenity values, improve water quality and quantity, increase carbon sequestration, promote recreation, and reduce the pressure on timber-based products. It was not funded during the above budget year, but both federal and state authorities expect its importance to grow quickly as the public becomes more aware of and familiar with it.

The mandate to develop these programs involves providing monetary resources directly to landowners to help them achieve sustainable forest management. The fundamentals of these Mexican national programs are fully described in the "2001-2006 National Forest Program". The main aspects of the program consist of seven national strategies and 14 objectives which are designed to promote sustainable forest management in Mexico. To satisfy the objectives, the four national programs (FD, PD, NTP, and WH) were developed as the feasible programs to compete for the limited funds. But, first the 14 objectives and nine project categories are reduced into six management objectives specifically designed to: (1) improve economic benefits, (2) increase water yield, (3) increase recreational or other environmental benefits, (4) increase forest stocks, (5) reduce operational costs, and (6) increase yield of non-timber products. Note that some important biological objectives such as maintaining biodiversity or protecting wildlife habitat which are not within CONAFOR's areas of responsibility are not included in the above list. On the other hand, all the interested parties in Durango who are involved in multi-purpose forest resources management are considered part of the study. Those parties are grouped into those members of the public or government sector (PUB), landowners (LND), those who belong to the private sector (PRV), and members of non-governmental organizations (NGOs). The latter includes environmental groups and non-profit forest-interest organizations. Landowners, the most dominant group in Durango, consist of both common and private land owners. The common properties or *ejidos* are collectively owned expanses of land, which occupy up to 70 percent of the forestlands in the state of Durango (Alcorn & Toledo, 1998). Thus, the essence of this study is to determine the most efficient budgetary distribution among the four national programs in *ejido* forest lands, taking into account the views and aspirations of the four interest groups and the achievement of the six forest resources management objectives.

3. Methodology

3.1 The Analytic Hierarchy Process

Our interest in this paper is to optimally allocate a limited budgetary resource among four competing programs to achieve six *ejido* forest resources management objectives. A convenient multi-objective decision-making technique that can handle such a hierarchically-structured level of independent elements is the Analytic Hierarchy Process (Saaty, 1977, 1980, 1988, 1990, 1997, 2008b). This is a well-known technique, which has been successfully used to solve numerous multi-objective management problems (Kangas, 1992, 1994, 1999; Saaty, 2001; Duke & Aull-Hyde, 2002 to mention a few). The Analytic Hierarchy Process formulation of a problem involves describing the elements in a lower level in terms of some or all of the elements in the next higher level of the hierarchy (Saaty, 1980, 1988). Altogether, the process consists of the following steps: (1) describing an overarching objective in terms of an overall and ultimately desired direction (e.g. maximizing the overall utility); (2) identifying the interested parties, stakeholders, or decision makers involved; (3) defining the specific objectives that represent the wishes and aspirations of every interested party (or parties) (e.g. maximizing desired objectives, minimizing undesired outcomes and project costs, improving economic benefits and environmental conditions, etc.); and (4) articulating

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feasible alternatives that can be used to achieve the desired objectives (Saaty, 1998, 2008a, 2008b, 2010; Ansah 2015). Criteria and sub-criteria are used to articulate the specific objectives in step (3) especially when the objectives represent complex problems that need to be expressed in more detailed and ordinal forms (Duckstein & Tecle, 2002).

The theoretical foundation behind the AHP is the utility theory of value. Zahedi (1987) showed that the process of selecting alternatives is consistent with maximizing a decision maker's either single or multi-attribute utility functions (Saaty, 1998, 2003). Results implied that the AHP and the utility maximization process can be combined to solve decision problems. The problems can be multi-objective forest resource management approaches such as the problem under study that involves multi-attribute utility functions. The utility functions are usually described in terms of weights and relative rankings of alternatives that can be evaluated using AHP (Saaty & Vargas, 1982; Duke & Aull-Hyde, 2002; Proctor, 2005; Balteiro & Romero, 2008; Ford et al., 2017).

The overarching objective of this multi-objective forest resources management planning problem is maximizing the overall utility U of the system. Such maximization of the overall utility occupies the highest level in the hierarchical formulation of an AHP approach of solving a multi-objective problem. A utility model is a mathematical tool that describes a problem in terms of features such as goals or objectives that express the wishes and aspirations of individuals and/or groups. A very simple utility model can be described in terms of the overall utility value U, which is the sum of the products of the individual objective weights (a_i) and the decision variable Xi. Algebraically, this can be expressed as

$$U = \sum_i a_i X_i \tag{1}$$

in which $\boldsymbol{i}$ stands for an individual alternative. In a multi-objective problem, the alternative that produces the highest utility value becomes the most preferred management option (Tecle, 1992; Saaty, 1998, 2003; Tecle et al., 1998; Schmoldt et al., 2001a; Poff et al., 2012).

The solution process includes arrangement of pairwise comparisons of the relative weights of the different objectives. This would allow the decision maker to determine a preferred management alternative where the weights represent the decision maker's preference structure on the objectives. Saaty (1988) used weights of 1,3,5,7, and 9 to respectively represent *equal* (or the preference of an objective weighted against itself), *moderately dominant, strongly dominant, very strongly dominant*, and *extremely dominant* of one objective over the other in a pairwise comparison. The weights of 2, 4, 6, and 8 represent the intermediate values between two consecutive pairs of the above values. Reciprocal values are entered in the transpose position and values between integers are permitted when desired. Use of this methodology is based on extensive research on the psychology of human preference behavior, which demonstrated that an individual cannot simultaneously compare more than five objects fairly and without having some confusion (Tversky & Kahneman, 1981; Kangas, 1994; Ford et al., 2017). To do a pairwise comparison, the relative weights (importance / preference) of elements at each hierarchical level are determined (Saaty, 2001). The analyst uses this to create the matrix of pairwise comparisons, *A*, in Equation 2 from which an eigenvector is computed (Saaty, 1998, 2003).

$$A = a_{ij} = \begin{bmatrix} 1 & w_1 / w_2 \ldots & w_1 / w_n \\ w_2 / w_1 & 1\ldots & w_2 / w_n \\ \vdots & \vdots & \vdots \\ w_n / w_1 & w_n / w_2 & 1 \end{bmatrix} \tag{2}$$

Here a_{ij} represents the pairwise comparisons of elements *i* and *j;* when $i = j$, then $a_{ij} = 1$. The ratio w_i/w_j is the relative importance or weight of element *i* over element *j*, while *n* is the total number of elements being compared. Because the AHP involves subjective assignment of values to utilities, the process may lead to some inconsistencies. To deal with this problem, Saaty (1980, 2003) proposed an eigenvector method for testing inconsistencies. For example, the inconsistency in the matrix *A* can be estimated using a Consistency Index (*CI*), which can be described in the form of Equation 3, which is

$$CI = (\lambda_{\max} - n)/(n-1) \tag{3}$$

where $\lambda_{\max}$ is the largest eigenvector in matrix *A*. This value ($\lambda_{\max}$) is obtained using Equation 4, which involves multiplying the matrix a_{ij} by the vector of relative importance or weights, w_i.

$$\lambda_{max} = \sum_i \sum_j a_{ij} w_i \tag{4}$$

The vector of relative weights, w_i, is obtained by first normalizing each column and then each row in the matrix A (Saaty, 1988). Such a matrix has to be estimated for each decision variable at all levels of the system. In each level, the eigenvector is scaled to add up to one to obtain level-wise priorities. We developed a basic approach using a spreadsheet to calculate both the relative weights and the eigenvectors. If the pairwise comparisons in the $n \times n$ matrix include no inconsistencies, then $\lambda_{\max} = n$; otherwise *A* is simply the reciprocal of the matrix (Saaty, 2001). The more consistent the comparisons are the closer the value of the computed $\lambda_{\max}$ becomes to ***n.*** A consistency ratio (*CR*) determined using Equation 5 indicates the coherence of the pairwise comparisons (Alonso & Lamata, 2006):

$$CR = 100\ (CI / ACI) \tag{5}$$

where *ACI* is the average consistency index for randomly generated comparisons, which varies with the size of the developed matrix (Saaty, 1988). Kangas (1994) considers the appropriate value for *CR* to be 0.10 or less.

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3.2 Data acquisition and problem formulation

A questionnaire was used to obtain the basic data for this study. Twenty representative individuals involved in forest resources management were identified and asked to answer an online questionnaire to reveal their personal preferences on the way the budget for forest resources management in Durango should be allocated. The identified individuals belong to each one of the four interested groups described above. However, seven of the 20 refused to participate in the study. Hence, we used only the responses from the 13 consenting respondents to construct the decision matrix used in the pairwise comparisons (see Appendix AI). Of the 13 individuals, four were from the public sector, three were landowners, three were members of non-government organizations, and three were from the private sector. The questionnaire started with self-identification of the respondents, followed by questions on their knowledge of the four national programs and others related to the desired management objectives.

To use the information for the intended decision making process, the data were averaged and then formulated into a matrix of preferences for each interested party. This was followed by calculating the eigenvectors and determining the consistency indexes to check for potential inconsistencies (Saaty, 2003). A similar process was followed for the management objectives. But, in this case, we made pairwise comparisons of each management objective with each interested party and for which a consistency test was also made. The arrangement of the data in the form of a matrix, calculations of the eigenvector and consistency indexes, making the pairwise comparisons for alternative preferences and arriving at optimal budgetary allocation are done step by step in a hierarchical framework.

Formulation of the problem in an AHP framework follows four hierarchical steps (see Figure 2). The first step consists of identifying an overarching objective of the study. The purpose is to allocate a one year forest management budget in the state of Durango, Mexico to achieve optimal resources productivity. The second step is to determine the relative importance or weights of all interested parties that represent the various resources and arrange them as level two in the hierarchically structured framework. Kangas (1994) suggested that the assignments and pairwise comparisons of the weights may be done by the office staff administering the resource management since its members may have a better understanding of the relative importance of each resource type and the interested parties involved (Saaty & Vargas, 1982). As such, pairwise comparisons of the weights of the parties and the resources involved were based on personal knowledge of the area and the role the interested parties play in the management of natural resources as in Proctor (2005). We also considered the scope of the forest law, which gives more importance to forest landowners than to any other groups in the management of forest resources.

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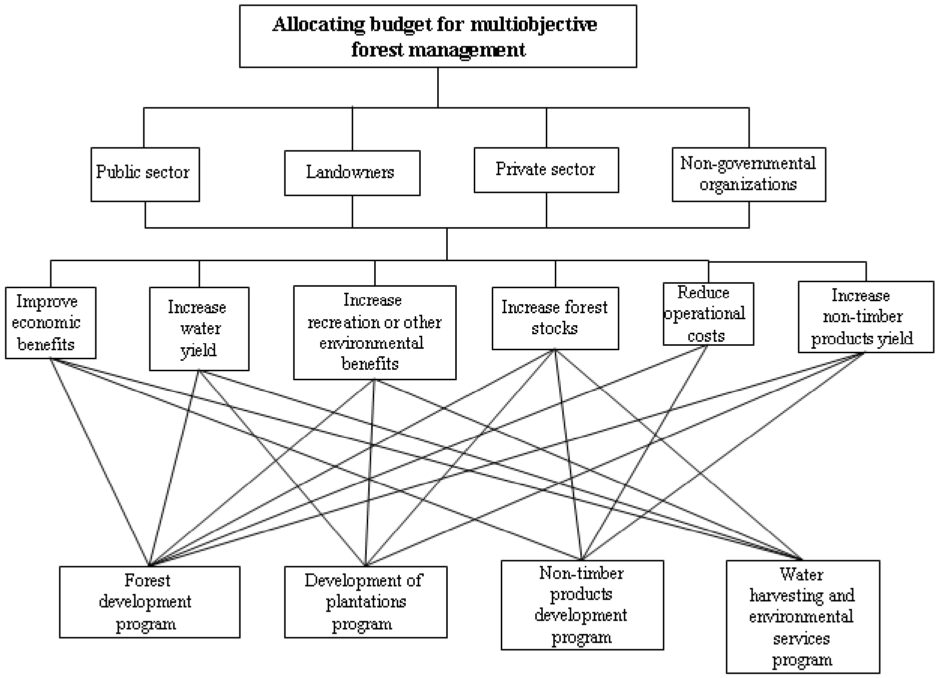

Figure 2 An AHP flow chart of optimal budget allocation for multi-objective forest resources management in Durango, Mexico

The third step consisted of describing the six management objectives and their relative weights. The latter came from the responses to the survey questionnaires. The last one in the hierarchy, level 4, consists of arranging the national forest resources/service development alternative programs. Starting from the bottom, the elements in each level are usually linked with the elements in the level above it. However, we also find that not every element in a lower level is linked with every element in the level above it. For example, the *plantation development program* is not linked with the *improve economic benefits* objective in the level above it (see Figure 2). This usually takes place when an element in the lower level is not related to one or more elements in the upper level as described in Saaty (1988). In any case, the hierarchical structure in an AHP links one level with the immediate levels above and below it (if there are any), thereby mathematically tying the entire decision-making process together (Saaty, 1988, 2010, 2017).

4. Results

Optimal allocation of the available budget in this study is made by evaluating the four national resources development programs with respect to their performances in achieving the six desired management objectives. Normally, expert consultants and actual management decision-makers are involved in assigning the preference structures or weights to the objectives (Saaty & Vargas, 1982; Zanakis et al., 1995; Duckstein & Tecle, 2002; Ford et al., 2017). In this study, the authors first assumed the roles of both the expert consultants and the decision-makers and calculate the weights using Kangas'

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(1994) methodology. The matrix of interested parties' responses and the relative weights assigned to each interested party are shown in Appendix AI. The relative weights are 0.18 for the public sector (PUB), 0.51 for the landowners (LND), 0.17 for the private sector (PRV), and 0.14 for the non-government organizations (NGO). In this arrangement, the relative importance given to landowners is much higher than that assigned to the other stakeholders (see the Table in Appendix AI). This makes the values of $\lambda_{\max}$ = 4.25, *ACI* = 0.90, *CI* = 0.08, and *CR* = 0.09. The *CR* value here is within the standards recommended by Kangas (1994), i.e., $CR \leq 0.1$.

The next step consists of determining the relative importance of each objective to the various interested parties. Here, the responses to the questionnaires are first averaged, then normalized and arranged in a matrix format to indicate objective-interested party relationships as shown in Table 2. The Table also shows the relative importance of each objective where the objective that receives the highest overall weight of 0.97 is *increasing forest stocks*.

Table 2
Objective values and weights given by each interested party involved in the multi-objective forest management decision process

Objectives	**Interested Parties**				
	PUB	LND	PRV	NGO	Overall Weights
Improving economic benefits	0.10	0.26	0.18	0.09	.63
Increasing water yield	0.25	0.12	0.12	0.24	.73
Increasing recreation or other environmental benefits	0.23	0.07	0.19	0.22	.71
Increasing forest stocks	0.24	0.28	0.24	0.21	.97
Reducing operational costs	0.06	0.18	0.13	0.07	.44
Increasing non-timber products yield	0.12	0.09	0.14	0.17	.52
$\lambda_{\max}$	6.50	6.37	6.60	6.16	
CR	0.08	0.06	0.10	0.03	

On the other hand, *reducing operational costs* receives the lowest overall weight of 0.44. In a similar manner, the relationships between the four alternative forest resources development programs and the desired objectives are given in Table 3. Using values from Table 2, Table 3 and the weights in Appendix AI, the global utility (or budget allocation) value with respect to a particular management alternative program is determined using Equation 6.

$$GP_i = \left[\sum_{j=1}^{4} LPIG_j \left\{ \sum_{k=1}^{6} (LPO_{jk} \times LPMS_{ik}) \right\} \right] \tag{6}$$

where GP_i is the desired global budgetary ratio (or global utility value) obtained using management alternative program *i*, $LPIG_j$ is the specific utility level or relative weight

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assigned to interest group j, LPO_{jk} is the local utility or relative weight of objective k from the point of view of interest group j, and $LPMS_{ik}$ is the specific utility level or relative weight of management alternative i (national program) with respect to objective k. Note that a special attention should be paid in determining GP_i because all management objectives do not have links with all management alternatives. Hence, there are no $LPMS_{ik}$ values reported for some of the cells in Table 3. In such a situation, Saaty (1988) recommends to follow a procedure similar to that we have done in this paper. In any case, the sum of all GP_i's must be equal to one.

Table 3
Local priorities of management alternatives (national programs) with respect to decision objectives (level 3 to 4)

Objectives	Management alternatives (National Programs)*				$\lambda_{\max}$	*CR*
	FD	PD	NTP	WH		
Improving economic benefits	0.44	-----	0.17	0.39	3.03	0.02
Increasing water yield	0.20	0.20	------	0.60	3.00	0.00
Increasing recreation or other environmental benefits	0.17	0.39	------	0.44	3.03	0.02
Increasing forest stocks	0.16	0.42	0.14	0.27	4.07	0.03
Reducing operational costs	0.67	-----	0.33	------	2.00	0.00
Increasing non-timber products yield	0.30	0.16	0.54	------	3.01	0.01

* Dotted cells represent the management objectives that do not have costs associated with a particular national program.

Also, note that Equation 7 is the numerical application of Equation 6 that determines the global utility value (0.307) for the forest development program (FD).

$$GP_{FD} = [0.18 \times \{(0.10 \times 0.44) + (0.25 \times 0.20) + (0.23 \times 0.17) + (0.24 \times 0.16) + (0.06 \times 0.67) + (0.12 \times 0.30)\} + 0.51 \times \{(0.26 \times 0.44) + (0.12 \times 0.20) + (0.07 \times 0.17) + (0.28 \times 0.16) + (0.18 \times 0.67) + (0.09 \times 0.30)\} + 0.17 \times \{(0.18 \times 0.44) + (0.12 \times 0.20) + (0.19 \times 0.17) + (0.24 \times 0.16) + (0.13 \times 0.67) + (0.14 \times 0.30)\} + 0.14 \times \{(0.09 \times 0.44) + (0.24 \times 0.20) + (0.22 \times 0.17) + (0.21 \times 0.16) + (0.07 \times 0.67) + (0.17 \times 0.30)\}] = 0.307 \qquad (7)$$

The global utility values for the other three national resources development programs are similarly determined to be 0.214 for PD, 0.177 for NTP, and 0.303 for WH. These show that the resource development program with the highest global utility value is *forest development* (FD), very closely followed by *water harvesting* (WH). The calculated values are based on the wishes and aspirations (or utilities) of representative groups of community members (Zanakis et al., 1995; Chiou et al., 2009). Based on this, the government would allocate the budget for forest resources management among the four national resources development programs to best achieve the desired management objectives.

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In the past, decisions on budget allocations followed no systematic approach. For instance, the available funds for the particular budget year considered in this paper were allocated as 53% for forest development, 35% for plantations development, 12% for non-timber products, and zero to water harvesting. However, if the budget were distributed among all four national resources development programs *water harvesting and environmental service development* program would take some part of the budget. Such an arrangement would proportionally reduce the funds that would be allocated to *forest development* and the other two programs. Figure 3 compares this revised budget allocation with the actual budget distribution above. The hypothetical allocations of the annual budget of $4.10 million among the four resources development programs (FD, PD, NTP and WH) for one year were obtained using Equation 6 and in a manner similar to the calculation for FD using Equation 7.

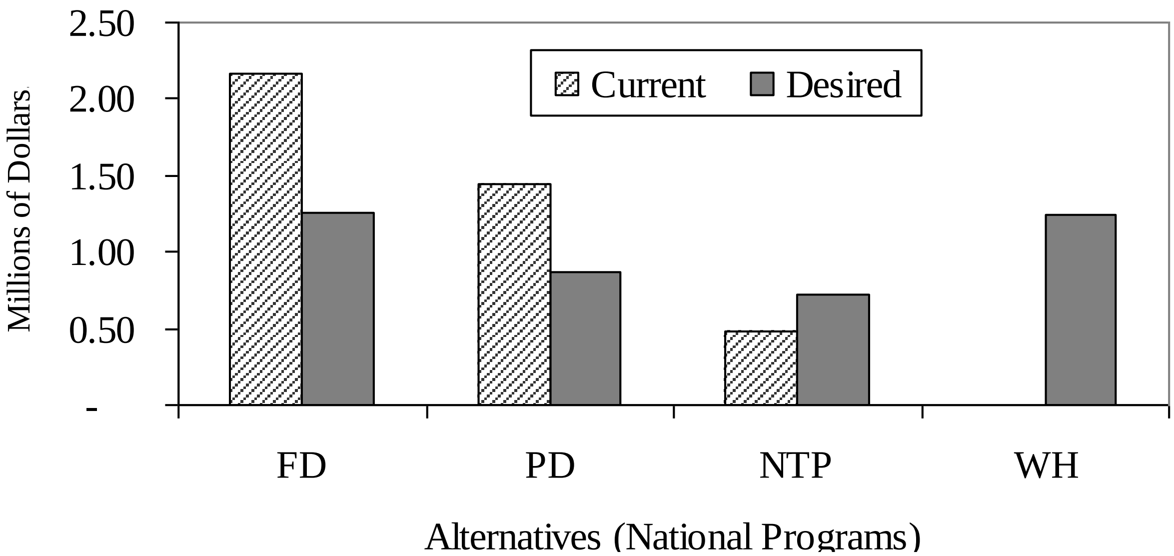

Figure 3 Comparing actual (current) and hypothetical budget allocations to the four resources development programs in the state of Durango, Mexico; the actual budget allocation does not include funding to the *water harvesting* program (WH) in the year

5. Sensitivity analysis

An important aspect of any modeling effort is testing the reliability and robustness of the model in performing as desired under varying input variables/parameters. This is sensitivity analysis and it can be done by testing the effects of changes in one or more of the utilities of the interested parties on the desired budget allocation among the four forest resources management programs (see Figure 3). Performing sensitivity analyses on all the decision variables would be repetitive, very tedious, and unnecessarily time consuming. Hence, we only performed a sensitivity analysis on the effect of changes in the utilities of one interested party (or decision-maker), the Landowners, on the global utility values (see Figure 4). In this analysis, the utilities of the other three decision-makers are kept constant.

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The results of the sensitivity analysis show that the Analytic Hierarchy Process is very reliable for optimal budget allocation among the different and competing forest resources management programs in Durango, Mexico. This reliability is indicated by the small variation in the global utility values of each natural resources development program with changes in the landlord's utility values (see Figure 4). As shown in the figure, the change in the global utility value for *water harvesting* is very little, ranging from 0.350 to 0.370, as the landlord's utility value decreases from 0.5 to 0.0. On the opposite side, when the landowner's utility value is between 0.5 and 1.0, there is a slight rise, from 0.350 to 0.385, in the global utility for *forest development*. Likewise, the global utility values for *development of plantation* and the *non-timber products development programs* are lower than those of the above and do not change significantly with changes in the landlord's utility values. Also the basis for providing the necessary budget is related to the land tenure system prevailing in the State of Durango, Mexico, where new forest policies are formulated to help landowners. Hence, it makes sense that the preference for budget allocation favors landowners, albeit slightly, compared to the other interested parties involved. In spite of the latter, however, there is little or no sensitivity in the derived utility levels of the resource development programs with changes in the decision-maker's utility values. Hence, for the little difference observed between the outcomes of the two most desirable forest resources management alternatives, *forest development and water harvesting.*

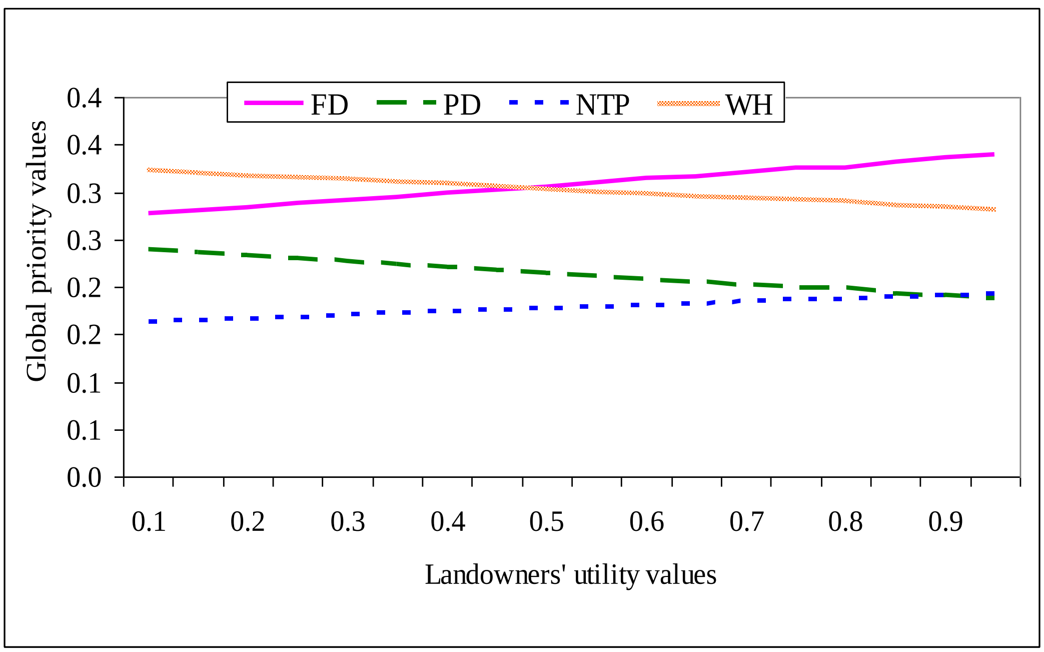

Figure 4 Effect of changes in landowner's utility values on global priority values. In this test, the utility values of the other interested parties are assumed to be equal

To corroborate the sensitivity analysis results, we performed a *t*-test, along with a test for homogeneity of variances, by dividing the landowner's utility values into two classes:

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those having utility values less than 0.50 as class 1, and those with utility values greater than or equal to 0.50 as class 2. In the process, the four resources development programs of FD, PD, NTP and WH are considered to be dependent variables while their utility values are classes or factors of independent variables. In the end, a result of the *t*-test indicates existence of no significant differences between the two classes. This means that changing the utility values of landowners does not have a significant effect on the overall preference or on the prioritization of one resource development program over the others under consideration.

6. Conclusions and recommendations

This study used the multi-criterion decision-making technique, AHP, to optimally allocate a scarce forest management budget among the different forest resources development programs in the state of Durango, Mexico. We analyzed the attitudes of four representative decision-making groups toward an optimal allocation of a scarce budgetary fund among four national programs to achieve six management objectives. Two of the four programs, *forest development* and *water harvesting/environmental services*, received the highest budget allocation in accordance with their higher global utility values. However, since *water harvesting/environment services* constitutes a new program, its funding has to come by reducing the budgetary share of the other programs, especially that of *forest development.* This should lead to a fair and optimal allocation of the entire budget among the four national forest resources management programs in Durango, Mexico.

There are at least three major reasons for the need for optimal forest resources management budget allocation. First, since the money comes from taxes, its distribution should make it possible to provide the greatest amount of goods and services to the largest number of people in the State. Second, an optimal budgetary distribution process can help resources managers put their scarce budgetary funds where they are most needed and efficiently used. Third, the developed approach must be a convenient technique for simultaneous management of multiple forest resources to achieve multiple objectives as in Tecle (1992), Balteiro and Romero (2008), Saaty (2008b), and Perez-Verdin et al. (2009). The multi-objective approach is more advantageous than a traditional and inefficient, single objective and single resources management approach (Tecle, 2007). Using the multi-objective decision-making approach in this study *water harvesting and environmental services* can be handled simultaneously with *forest* and *non-timber development programs* to benefit not only landowners but the entire *ejido* community who uses the resources as a whole. Hence, we recommend the use of the AHP not only because it enables optimal allocation of scarce resources to do the greatest good for the largest number of people, but because it also engenders active participation of the public in resolving natural resources management-related conflicts (Balteiro et al., 2009; Nordstrom, 2010; Groselj et al., 2016; Nilsson et al., 2016). This is possible because AHP is capable of handling numerous types of qualitative as well as quantitative information such as ordinal data from public opinions and cardinal and ratio data types generated using all sorts of research endeavors (Saaty, 2008a; Šporčić, et al. 2010; Šporčić, 2012). One method such as that of Duke and Aull-Hyde (2002), for example, can be used to gather a large amount of public opinions. An additional strength of the AHP is its ability to normalize non-commensurable data and express it in the form of ratio scale to make

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handling of a complex multiobjective problem analysis easy (Tecle, 1992; Mendoza & Prabhu, 2000; Saaty, 2008a).

The AHP is widely used to evaluate and solve many different kinds of multi-objective decision problems (Saaty, 1990, 2001, 2008a, 2008b; Schmoldt et al., 2001a, 2001b; Duke & Aull-Hyde, 2002; Macharis et al., 2004; Hajkowicz & Higgins, 2006), in general, and various types of forest resources management problems such as those in Balteiro and Romero (2008), Ananda and Herath (2009), Perez-Verdin et al. (2009, 2011), Šporčić et al. (2010), Poff et al. (2010, 2012), to mention some. But, to the best of our knowledge, this is the first time the AHP has specifically been used to optimally distribute scarce budget resources among four *ejido*-based forest resources management programs designed to achieve six objectives of four interested parties. A sensitivity analysis was conducted on the effects of varying the utility values of landowners on the global utility values that determined the budget distribution among the four competing forest resources management programs. The analysis results show the reliability and robustness of the AHP in allocating the budget.

Another benefit of using the AHP is its integrative assessment of numerous interacting and at times competing forest resources components. It takes advantage of not only the synergistic relationships among the various components of a multi-objective decision problem, but also incorporates the risks and uncertainties inherent in such a complex problem to reach a realistic and acceptable decision outcome (Macharis et al., 2004). Weights and public preferences are heavily used to hierarchically interconnect various decision-makers, their objectives and the different alternative management schemes involved. These aspects of the AHP are the reasons for its desirability, wide use and success to solve various types of multi-objective forest resources management problems.

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APPENDIX A

AI. Pairwise comparisons (*A*) of stakeholder's utilities and vector of weights (*w*)

$$\begin{array}{ccc} & \boldsymbol{A} & \boldsymbol{w} \\ Aw = a_{ik} = & \begin{array}{cc} & \begin{array}{cccc} PU & LD & PR & NG \end{array} \\ \begin{array}{c} PU \\ LD \\ PR \\ NG \end{array} & \begin{bmatrix} 1 & 1/4 & 2 & 1 \\ 4 & 1 & 3 & 3 \\ 1/2 & 1/3 & 1 & 2 \\ 1 & 1/3 & 1/2 & 1 \end{bmatrix} \end{array} \times & \begin{bmatrix} 0.18 \\ 0.51 \\ 0.17 \\ 0.14 \end{bmatrix}; \lambda_{\max} = 4.25; CR = 0.09 \end{array}$$

PU = Public Sector; LD = Landowners; PR = Private Sector; and NG = Non-government organizations

AII. Pairwise comparisons of stakeholders' management objective values and vector of weights

Public sector preferences

	EE	WY	REC	FS	OPC	NTP
EE	*1.00*	0.33	0.33	0.33	3.00	1.00
WY	3.00	*1.00*	2.00	0.50	3.00	3.00
REC	3.00	0.50	*1.00*	2.00	4.00	1.00
FS	3.00	2.00	0.50	*1.00*	3.00	2.00
OPC	0.33	0.33	0.25	0.33	*1.00*	0.50
NTP	1.00	0.33	1.00	0.50	2.00	*1.00*

$$\times \begin{bmatrix} 0.10 \\ 0.25 \\ 0.23 \\ 0.24 \\ 0.06 \\ 0.12 \end{bmatrix}; \lambda_{\max} = 6.50; CR = 0.08$$

Landowners preferences

	EE	WY	REC	FS	OPC	NTP
EE	*1.00*	3.00	3.00	1.00	2.00	2.00
WY	0.33	*1.00*	2.00	0.50	0.33	2.00
REC	0.33	0.50	*1.00*	0.25	0.33	1.00
FS	1.00	2.00	4.00	*1.00*	3.00	2.00
OPC	0.50	3.00	3.00	0.33	*1.00*	2.00
NTP	0.50	0.50	1.00	0.50	0.50	*1.00*

$$\times \begin{bmatrix} 0.26 \\ 0.12 \\ 0.07 \\ 0.28 \\ 0.18 \\ 0.09 \end{bmatrix}; \lambda_{\max} = 6.37; CR = 0.06$$

Private Sector preferences

	EE	WY	REC	FS	OPC	NTP
EE	*1.00*	3.00	1.00	1.00	0.50	1.00
WY	0.33	*1.00*	1.00	0.50	1.00	1.00
REC	1.00	1.00	*1.00*	0.50	3.00	2.00
FS	1.00	2.00	2.00	*1.00*	3.00	1.00
OPC	2.00	1.00	0.33	0.33	*1.00*	1.00
NTP	1.00	1.00	0.50	1.00	1.00	*1.00*

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Non-governmental organizations preferences

	EE	WY	REC	FS	OPC	NTP
EE	*1.00*	0.33	0.33	0.33	1.00	1.00
WY	3.00	*1.00*	1.00	1.00	3.00	2.00
REC	3.00	1.00	*1.00*	1.00	4.00	1.00
FS	3.00	1.00	1.00	*1.00*	3.00	1.00
OPC	1.00	0.33	0.25	0.33	*1.00*	0.33
NTP	1.00	0.50	1.00	1.00	3.00	*1.00*

$\times \begin{bmatrix} 0.09 \\ 0.24 \\ 0.22 \\ 0.21 \\ 0.07 \\ 0.17 \end{bmatrix}$; $\lambda_{\max}$ =6.16; *CR*=0.03

EE = Improve economic benefits; WY = Improve water yield; REC = improve recreation/ environmental services; FS = Increase forest stocks; OPC = Reduce operational costs; and NTP = increase non-timber products yield.

AIII. Pairwise comparisons of forest resources management programs, and corresponding vector of weights (*w*) and other parameters related to each objectives.

Improve Economic Benefits

	FD	NTP	WH	*w*
FD	*1.00*	3.00	1.00	0.44
NTP	0.33	*1.00*	0.50	0.17
WH	1.00	2.00	*1.00*	0.39

$\lambda_{\max}$ =3.03; *CR*=0.02

Improve Water Yield

	FD	PD	WH	*w*
FD	*1.00*	1.00	0.33	0.20
PD	1.00	*1.00*	0.33	0.20
WH	3.00	3.00	*1.00*	0.60

$\lambda_{\max}$ =3.00; *CR*=0.00

Improve Recreation and Environmental Services

	FD	PD	WH	*w*
FD	*1.00*	0.50	0.33	0.17
PD	2.00	*1.00*	1.00	0.39
WH	3.00	1.00	*1.00*	0.44

$\lambda_{\max}$ =3.03; *CR*=0.02

Increase forest stocks

	FD	PD	NTP	WH	*w*
FD	*1.00*	0.50	1.00	0.50	0.16
PD	2.00	*1.00*	3.00	2.00	0.42
NTP	1.00	0.33	*1.00*	0.50	0.14
WH	2.00	0.50	2.00	*1.00*	0.27

$\lambda_{\max}$ =4.07; *CR*=0.02

Reduce operational costs

	FD	NTP	*w*
FD	*1.00*	2.00	0.67
NTP	0.50	*1.00*	0.33

$\lambda_{\max}$ =2.00; *CR*=0.00

Increase non-timber products

	FD	PD	NTP	*w*
FD	*1.00*	2.00	0.50	0.30
PD	0.50	*1.00*	0.33	0.16
NTP	2.00	3.00	*1.00*	0.54

$\lambda_{\max}$ =3.01; *CR*=0.01

FD = Forest Development; PD = Plantations Development; NTP = Non-timber products; WH = Water Harvesting

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