INFLUENCE ANALYSIS IN CONSENSUS SEARCH - A MULTI CRITERIA GROUP DECISION MAKING APROACH IN ENVIRONMENTAL MANAGEMENT[*]

Abstract

The environmental decision problems often are divisive, even in a technical realm, decision makers with strong personalities influence outcomes. The purpose of this study is to define and quantify the factors that affect the conservation objectives of a national natural park located in Colombia, South America adding the judgments of six decision makers with different knowledge (every decision maker is also a stakeholder representative). This paper uses a hybrid multiple criteria group decision making model (MCDM), combining the social network analysis (SNA), analytic hierarchy process (AHP) and similarity measures to solve the consensus and anchoring problem among environmental decision makers. The SNA technique is used to build an influential network relation map among decision makers and to obtain their weights for applying a weighted analytic hierarchy process. Then, the final decision matrices for every decision maker are compared between them in order to identify the consensus level of the problem.

1. Introduction

Shared responsibility for the protection of nature demands common solutions to existing problems. Environmental management decisions have been the cause of many debates and deep disagreements underlying the multifaceted nature of most environmental problems. Environmental management takes place at many levels (local communities, city, state) and involves a large number of stakeholders (such as landowners, entrepreneurs, urban planners, farmers...) with conflicting interests [1]. The complexity of environmental problems requires transparent and flexible decision-making processes that integrate different areas of knowledge and values [2]. Therefore, we can affirm that environmental planning is a multi-criteria and multi-stakeholder problem by nature [3] [4].

Multicriteria Decision Aid (MCDA) techniques are suitable for evaluating complex, multistakeholder uncertain problems [5]. Several authors have already introduced the use of MCDA techniques for Sustainability Assessment [6]. Many of them focused on the use of the technique Analytic Hierarchy Process (AHP) or Electre and Promethee class methods [7], [8] or [9]. From all of them, the AHP method proposed by [10] has been chosen because it provides an easy-to-understand framework for decision-making or evaluation problems and also it presents its strengths when working in scenarios with scarce information. AHP

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[*] For the title, try not to use more than three lines. Typeset the title in 10 pt Times Roman, bold and uppercase.

has also the flexibility to combine quantitative and qualitative factors, to handle different groups of actors, to combine the opinions expressed by many experts, and can help in stakeholder analysis.

The purpose of stakeholder analysis is to understand their behavior, expectations, relationships and influences or resources they can bring to the decision-making process [11]. [12] suggest that the increasing use of stakeholder analysis in natural resources management reflects the recognition that stakeholders can and should influence environmental decision-making processes. This approach is being promoted by the EU (Directive 2003/35/EC2), and by the U.S. the Environmental Protection Agency which promote citizen participation in environmental decision-making processes and have programs that evaluate their participation [13]

Decision makers recognize the need to understand who is affected by the decisions and actions they take and who has the power to influence their outcome [14]. Thus, it is helpful to consider the importance and influence of stakeholders. According to [15] a group decision is a product of member preferences and the processes used by the group to reach consensus [16]. These processes are shaped by a variety of factors, including member expertise [17], confidence [18] and extroversion [19]. These two above mentioned concepts, influence and consensus, are relevant for decision making processes in which individual power distribution does affect the procedure to reach the final result, as is the case of environmental management. For that, to help environmental managers to solve participatory decision making problems, we propose a model that combines multi criteria decision analysis and participatory procedures. This will be done by combining the use of Social Network Analysis and consensus matrices for the analysis of individual influences of participants and AHP for the decision making problem.

The remaining of the paper is as follows: in section 2 a literature review is presented, in section 3 the methodology is presented, in section 4 the application of the proposed methodology to the case study is presented with a broad description of the obtained results. Finally in section 5 the authors highlight the main conclusions of the work.

2. Literature review

As explained in the above section, in this paper we will propose a model that combines the use of Social Network Analysis and consensus matrices to assess influences for all the stakeholders that will participate in the AHP environmental decision making problem. Since we propose the combination of these two different techniques in this section we will carry out a literature review of both of them in order to justify their goodness.

2.1. Stakeholders influence and Social Network Analysis

According to [20] environmental issues often are divisive, even in a technical realm. [21] argued that strong personalities influence outcomes. Participants advocate positions, views are anchored, change is resisted, people hold covert opinions that are not explained and there is pressure to conform.

Several approaches have been proposed to investigate the relationships among stakeholders, like power versus interest grids, the urgency-power-legitimacy model [22] interrelationship diagrams[23], or actor-linkage matrices [24]. However, these techniques do not allow determining an individual value of the influence of each actor in a decision-making process.

Recently some authors [25] have proposed Social Network Analysis (SNA) [26]to calculate individual influence and trust for each actor. But as far as the authors know, these influence index have never been used before as individual weights for the stakeholders within a decision making process. SNA is based on the graph theory, allows measuring the strength of ties (flows of information or influence) between nodes (stakeholders) in order to obtain different values of centrality, prestige and power for each of them. Centrality is the most commonly used index to analyze influence of individuals. We have chosen the nodes´ closeness centrality as the most appropriate SNA indicators to assess the influence of the stakeholders [27] It indicates how close a node is to the other nodes in the network (geodesic distance). An actor is central if he/she can interact fast with all the other actors. The actors who have a high closeness index have many direct relationships with several members of the network. The higher the closeness centrality of a node, the faster he is able to interact with the other actors. There are many closeness measures, we use the Sabidussi measure [28]. Closeness is calculated as follows:

$$C_c^{'}(n_i) = \frac{g-1}{\sum\limits_{j=1}^{g} d(n_i, n_j)} \ .$$

(2.1)

With,
$d(n_i, n_j)$ is the distance between actor n_i and actor n_j
g is the total number of actors in the network

The Sabidussi closeness measure can be viewed as the inverse average distance between the actor (stakeholder in our problem) i and all the other actors. Closeness is an inverse measure of centrality in the sense that large numbers indicate that a node is highly peripheral, while small numbers indicate a node is more central. A lower closeness index of an actor shows a higher importance of this actor. We represent the importance index as the weight wj of each actor by normalizing an opposite measure I, as follows:

$$I = 1 / C_c^{'}(\mathrm{n}_i) \ . \tag{2.2}$$

$$W_j = \frac{I_j}{\sum_j I_j} \ . \tag{2.3}$$

Being I the importance of actor n_i represented as the influence over all actors and W_j is the weight for each actor. In order to determine the degree of influence or importance of the actors a Social Network of the actors will be built and then each actor's closeness centrality in this particular network will be measured. UCINET 6 [29] a specialized software tool for SNA, will be used. To build the network, a questionnaire will be designed in which each stakeholder will be asked about his/her opinion on the level of agreement with the rest of the stakeholders.

2.2. Consensus reaching and consensus degree

A consensus reaching process in a Group Decision Making (GDM) problem is an iterative process composed by several discussion rounds in which experts are expected to modify their preferences according to the advice given by a facilitator.

According to [30,31] and; [32] it is important to develop consensus models that take into account the weights of the experts (their importance) when adding their preferences but also advising how to change their preferences.

The search for consensus as expressed by [33] presents challenges and open questions to be addressed in the following areas: (1) counseling, (2) models of consensus based on trust (3) visualization and verbalization of the process, (4) the importance of the experts, (5) dynamic contexts of decision, and (6) persuasion.

In this paper we will analyze consensus from the perspective of areas 4 and 6:

- Importance of experts: According to [33] in group decision making, there are many situations where the expert knowledge is not equally important [34]. To model these situations the most common approach in the literature involves assigning a weight to the experts in the group.

- Persuasion (social influence): One of the tasks of the facilitator in consensus decision making processes is to give advice on how to change experts' opinions in order to increase the level of consensus [33].

In our proposal we will use the Social Network Analysis to assess the degree of importance of the experts, as explained in point 2.1., and the consensus index proposed by [35] based on the measure of similarity for every decision matrix of all participants, as explained in the following paragraph.

For each pair of experts (ek, et) $(k = 1,..., m-1, l = k+1,..., m)$ a similarity matrix $SM^{kl}_{ij} = (sm^{kl}_{ij})$ is obtained comparing the decision matrix of every decision maker E^k_{ij} with the rest of them $E^{k+1}_{ij} ...... E^l_{ij}$ as follows.

$$sm^{kl}_{ij} = 1 - \left| p^k_{ij} - p^l_{ij} \right|. \qquad (2.4)$$

With,

p_{ij} is the value of all the alternatives Ai against the criterion C_j, that is, the eigenvector, for each decision maker

A consensus matrix, $CM = (cm_{ij})$, is calculated by aggregating all the similarity matrices using the arithmetic mean as the aggregation function

$$cm_{ij} = \phi(sm^{kl}_{ij}, k = 1,...,m-1, l = k+1,...,m). \qquad (2.5)$$

With,

sm_{ij} is the similarity matrix for every decision maker

Once the consensus matrix is computed, the consensus degrees are obtained at three different levels.

   a. **Level 1 -** Consensus degree on pair of alternatives. The consensus index of an expert to the group of experts on the alternative x_i under criterion C_j is

$$CE^h_{ij} = cm_{ij} \qquad (2.6)$$

   b. **Level 2** - Consensus degree on alternatives. The consensus index of an expert to the group of experts on the alternative x_i

$$CA^h_i = \frac{1}{n} \sum_{j=1}^{n} CE^h_{ij} \qquad (2.7)$$

   c. **Level 3** - Consensus index on the decision matrix

$$CI^h = \frac{1}{m} \sum_{i=1}^{m} CA^h_i \qquad (2.8)$$

With, m is the number of criteria for every decision matrix.

Once the consensus index, CI, is obtained, it is compared with the minimum required consensus level, CL $\in$ [0, 1], which will depend on the particular problem we are dealing with. CL is a threshold value predefined by the moderator and may be different for each problem, A greater CI indicates more consensus. When CI $\geq$

CL, the consensus model finishes and the selection process is applied to obtain the solution by calculating the weighted (by stakeholder) aggregated decision matrix.

Otherwise, we need to give feedback to the decision makers and a new consensus round is applied. Additionally, the consensus model should avoid situations in which the global consensus measure may not converge to the minimum required consensus level. Based on [37] six types of consensus for the consensus index are defined as follows:

- None = 0 – 0.17
- Very Low = 0.17 – 0.33
- Low = 0.33 – 0.5
- Medium = 0.5 – 0.67
- High = 0.67 – 0.83
- Very High = 0.83 – 1.0

3. Methodology

In this paper we will propose a methodology based on a combination of consensus index, SNA and AHP techniques to help the environmental managers to define and quantify the factors that affect the conservation objectives, taking into account the views of the various interested and affected stakeholders. This work provides a novelty, which is to use the SNA to identify the most influential actors. Thus, a numerical influence can be calculated and this information can be considered for the final aggregation of the alternatives ´priorities in the evaluation model.

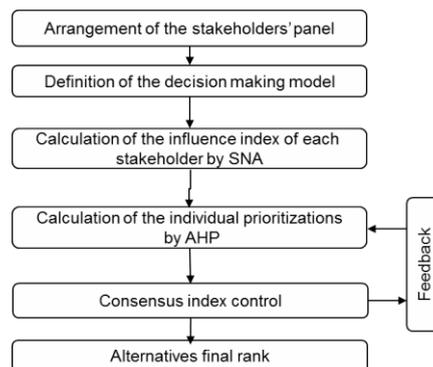The steps followed in the methodology are shown in figure 1:

Fig. 1. Methodological approach

The methodology will be applied to a particular environmental case study: to help the managers of the Cocuy Nationa Park (Colombia) to define and quantify the factors that affect the conservation objectives of the national natural park.

A more detailed explanation of the methodology will be presented during the description of the case study.

4. Case Study - EL COCUY NATURAL NATIONAL PARK

The Sierra Nevada del Cocuy lies in the eastern part of Colombia, between lats. 6°20' N. and 6°35' N. It forms the highest part of the Colombian Cordillera Oriental and trends nearly north-south (fig. 2). That part which stands above the snowline (that is, above an altitude of about 4600 m measured on the western slope) has a length of about 33 km and reaches an extreme altitude of about 5490 m in the Alto Ritacuva, a peak near its northern end. The highest peak near the southern end is Pan de Azúcar, with an altitude of about 5150 m. The area of the divide is covered with a nearly continuous chain of ice caps, one to two kilometers in width, and small outlying snowfields. The sierra is part of a 3000 km2 National Park established in 1970.

Fig. 2. Map of El Cocuy National Natural Park

There are several unsustainability factors that need to be assessed by the managers of the park. Regarding the environmental problems they have to face, some of them are directly related to the production system of local farmers, with the cutting and burning of forests in order to open pastures and sustain livestock, which has deteriorated the soil generating compaction, and does not allow development of agriculture anymore. Also, the destruction of natural habitat and indiscriminate hunting has decreased biodiversity, and many major water sources have been dried.

Regarding the social problems, it is very common for families to present a low level of food consumption, along with a dependence on *jornales* (work paid daily) due to poor family labor. The law enforcement is another factor that does not allow property owners to invest and work in their production units, for fear of being blackmailed or stolen.

In the technical-productive part another factor of unsustainability occurs because there is insufficient supply of food for cattle, resorting to over-grazing and gradual clearing of

forests for the expansion of pastures for livestock. Many farms have sustainable practices such as intercropping and minimal use of pesticides in production of food crop. In few other farms, they have minor species, fish ponds and beekeeping products as supplement diet.

The Natural Park needs to tackle all the above mentioned problems by linking the largest number of communities and organizations (stakeholders) to implement recovery programs, boosting sustainable urban and regional development. Also, they need to promote public participation processes for making investment decisions in order to contribute to the environmental sustainability of each stakeholder and seek to articulate participatory management processes (co-management programs in protected areas) that are more satisfactory in terms of decision-making results.

4.1. Arrangement of the stakeholders panel.

The institutions and organizations involved in the problem are identified as having responsibilities in managing the park or as interest groups. These are:

- U'was community: Indigenous Uwa also called *tunebos* have a social, political and ecological system that allows them to communicate with groups in other distant regions. They are located in high mountains, hills and plains reliefs of between 400 and 5,300 meters, covering the departments of Boyaca, Arauca, Norte de Santander, Santander and Casanare uwa live about 700 families along a territory of 450,000 hectares. They are dedicated to livestock and subsistence crops influenced by farmer tradition. Their main crop is corn.
- Tourists: The natural park has been the destination of climbers, hikers and tourists in general who feel attracted by the unique beauty of its landscapes. However, this activity is disorganized, because there is no control by the Parks Unit.
- Academic experts: environmental experts with knowledge about the national natural park of El Cocuy
- International tourists: Every year the park is visited by international climbers and tourists. Their point of view is different than the national tourists.
- Farmers and Livestock owners: There are farmers in high and low altitudes near the park area. They use the land for survival crops, practice extensive cattle ranching near wasteland areas. They also burn the wasteland in the summer, to prepare the ground for cattle.
- Park rangers: responsible for managing the conservation and protection of the protected areas.

4.2. Construction of the decision making model

The decision problem will be modeled with AHP method. In order to identify the clusters of criteria and alternatives, we worked with the stakeholders panel, since they are the ones who are interested in solving the problems of the park.

The goal of the decision making problem is the following: establish a prioritization between the problems faced by the park managers according to the strategic objectives of the park.

4.2.1.   Alternatives

After discussing all the matters, the stakeholder's panel proposed the following list of the 8 main problems to be analyzed and prioritized:

> Objective 1: Socio Political fragmentation and loss of traditional knowledge of Uwa community.
> Objective 2: Logging, burning and clearing of vegetation to maintain pastures and crops between the Andean forests in the eastern sector.
> Objective 3: Infrastructure without environmental impact studies and mitigation measures (deposits, canals, bridges, roads)
> Objective 4: Extensive grazing on the park.
> Objective 5: Clogging and rapid drying of peatlands, lakes and springs
> Objective 6: Tourism poorly managed in the park.

4.2.2. Criteria

The following criteria were chosen to prioritize problems. They are the conservation goals of the natural park
- Keep the eco-systemic connectivity of forest areas and wilderness.
- Preserve habitats and populations of endemic species.
- Keep the water supply that feeds the river basins.
- Protect the Uwa territory that overlaps with the Park.
- Protect outstanding scenic values.

4.3. Calculate the influence index for every stakeholder

Calculate the influence index for every stakeholder, by asking the decision makers the following question [38]

"Q1.Which stakeholder do you think may agree with your opinion regarding the ranking of the goals of Cocuy National Park?".

Each decision maker gives his/her opinion and matrix D is built according to the scale:

No agreement with your opinion = 0
Low level of agreement with your opinion = 1
Medium level of agreement with your opinion = 2
High level of agreement with your opinion = 3
Very high level of agreement with your opinion = 4

$$
\begin{array}{l}
S_1 \; \textit{Uwas} \\
S_2 \; \textit{tourist} \\
S_3 \; \textit{academic} \\
S_4 \; \textit{tourist int} \\
S_5 \; \textit{farmers} \\
S_6 \; \textit{park rangers}
\end{array}
\rightarrow D =
\begin{array}{c}
S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6
\end{array}
\begin{pmatrix}
0 & 2 & 2 & 1 & 2 & 3 \\
1 & 0 & 2 & 2 & 1 & 3 \\
2 & 3 & 0 & 2 & 3 & 2 \\
2 & 3 & 0 & 0 & 1 & 2 \\
3 & 2 & 2 & 0 & 0 & 1 \\
3 & 2 & 3 & 2 & 2 & 0
\end{pmatrix}
$$

Once matrix D is obtained, an influence network is obtained by means of software UCINET ® as seen in Fig 3. This influence network shows the connections between every stakeholder with the rest of them. A thick line shows a greater influence between two stakeholders, the red path shows a strong connection between the stakeholder and the rest of them, on the other hand the blue path shows a weak connection between the stakeholders which means weak influence between them.
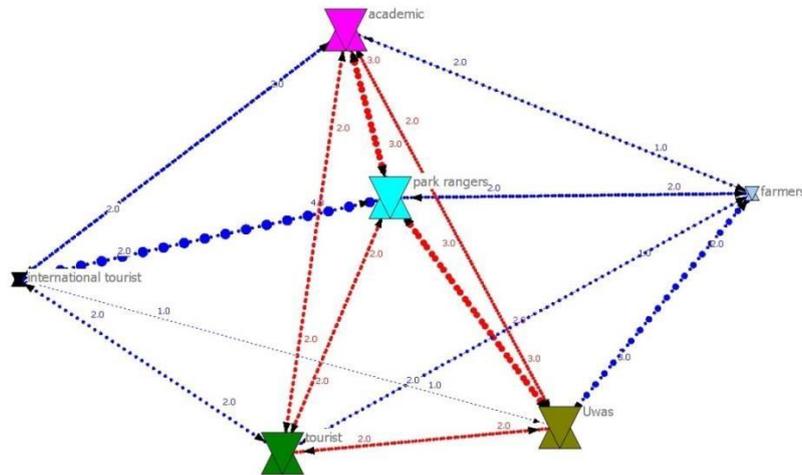

Fig. 3. Network of influence relationship between stakeholders and weights for stakeholders; developed by using UCINET® from the matrix D

The SNA closeness index for every stakeholder $C_c'(n_j)$, the importance of every stakeholder I_j, and their weights W_j are obtained using the equation 2.1, 2.2 and 2.3 as follows:

$$C_j' = \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} \begin{pmatrix} 0,455 \\ 0,500 \\ 0,455 \\ 0,714 \\ 0,833 \\ 0,357 \end{pmatrix} \rightarrow I_j = \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} \begin{pmatrix} 2,20 \\ 2,00 \\ 2,20 \\ 1,40 \\ 1,20 \\ 2,80 \end{pmatrix} \rightarrow W_j = \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{matrix} \begin{pmatrix} 0,18644068 \\ 0,16949153 \\ 0,18644068 \\ 0,11864407 \\ 0,10169492 \\ 0,23728814 \end{pmatrix}$$

These Centrality indices allow us to know which stakeholders are more influential with respect to the others. They show that there is one stakeholder, S_6 (park rangers), whom the rest of them consider more influential when trying to solve management problems of the park. Next in importance would be both S_1 (Uwas) and S_3 (Academics). At the other end, we have S_3 (farmers) who show the lowest influence on the group.

These individual influence indices will be used to weight the stakeholders when aggregating their priorities with the geometric mean as described in section 5.2.

4.4. Calculation of the individual prioritizations by AHP

In this step we show the calculation of the individual prioritization by using AHP. In Fig. 4 we can see the structure of the model presented.
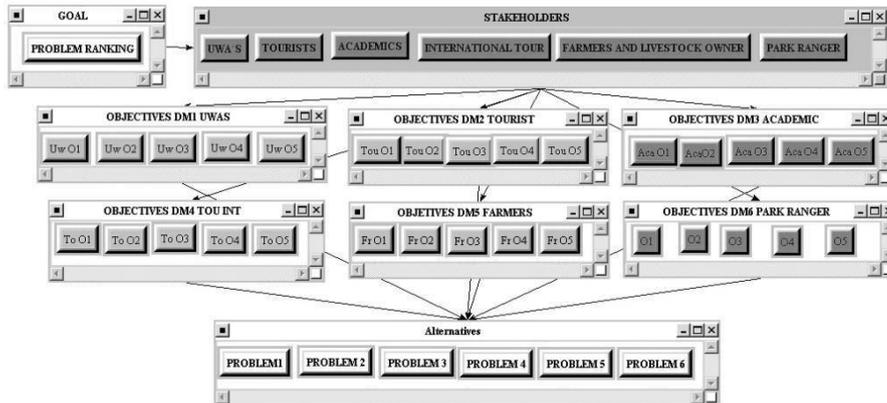

Fig. 4. Hierarchy structure of the problem with six decision makers - Superdecisions ® software

After having obtained the individual prioritization, we use the subset W_j to assign different weights to the decision makers. and that way we calculate the final prioritization of the park problems for the whole group of decision makers with the weighted AHP [39,40].

The pairwise comparison between objectives for each decision maker gives us the matrix Cr, where every column is an eigenvector that represents the importance of every objective for each decision maker.

Final prioritization of the objectives with AHP for each stakeholder:

Objectives	S1 Uwas	S2 Tourist	S3 Academic	S4 Tourist int	S5 Farmers	S6 Park rangers
Objective 1	0,0557	0,0758	0,0753	0,1032	0,1109	0,2153
Objective 2	0,5357	0,4813	0,0889	0,1032	0,3567	0,2521
Objective 3	0,2589	0,1929	0,6603	0,3618	0,4144	0,2521
Objective 4	0,1253	0,0419	0,0337	0,0699	0,0440	0,0467
Objective 5	0,0235	0,2081	0,1418	0,3618	0,0740	0,2337

Table 1. CR matrix - Final prioritization of the objectives with AHP for each stakeholder

The following decision matrices E_{ij}^k show the given values to each environmental objective (alternatives i in rows, which was presented in heading 4.2.1), against every conservation goal (criteria j in columns, which was presented in heading 4.2.2) for each stakeholder k. Every column of the matrices E_{ij}^k is an eigenvector result of the pairwise analysis between every environmental problem.

$$E^1 = \begin{pmatrix} 0,0181 & 0,3546 & 0,0212 & 0,5145 & 0,0214 \\ 0,1106 & 0,0708 & 0,1109 & 0,0277 & 0,1518 \\ 0,2803 & 0,1771 & 0,3800 & 0,0333 & 0,4514 \\ 0,0829 & 0,0245 & 0,1068 & 0,0499 & 0,0696 \\ 0,1544 & 0,3254 & 0,2903 & 0,2470 & 0,2680 \\ 0,3538 & 0,0476 & 0,0908 & 0,1275 & 0,0379 \end{pmatrix}_{S1-Uwas} \quad E^2 = \begin{pmatrix} 0,0546 & 0,0268 & 0,0263 & 0,2703 & 0,0268 \\ 0,2227 & 0,1874 & 0,0481 & 0,0310 & 0,1874 \\ 0,1086 & 0,2042 & 0,3407 & 0,2703 & 0,2042 \\ 0,0752 & 0,0969 & 0,1010 & 0,1088 & 0,0969 \\ 0,0636 & 0,0528 & 0,3755 & 0,0725 & 0,0528 \\ 0,4753 & 0,4319 & 0,1083 & 0,2471 & 0,4319 \end{pmatrix}_{S2-Tourist-1}$$

$$E^3 = \begin{pmatrix} 0,0232 & 0,0302 & 0,0257 & 0,4134 & 0,0260 \\ 0,3239 & 0,2426 & 0,1225 & 0,1283 & 0,2039 \\ 0,0996 & 0,1668 & 0,1083 & 0,1996 & 0,2260 \\ 0,3546 & 0,2426 & 0,1727 & 0,1160 & 0,2260 \\ 0,1415 & 0,2426 & 0,5143 & 0,1160 & 0,2480 \\ 0,0572 & 0,0752 & 0,0564 & 0,0267 & 0,0701 \end{pmatrix}_{S3-Academic} \quad E^4 = \begin{pmatrix} 0,0237 & 0,0245 & 0,0257 & 0,1514 & 0,0312 \\ 0,1616 & 0,2402 & 0,2039 & 0,1893 & 0,1686 \\ 0,0509 & 0,0449 & 0,0675 & 0,0363 & 0,0777 \\ 0,1570 & 0,1462 & 0,1640 & 0,0992 & 0,2554 \\ 0,5351 & 0,4486 & 0,4954 & 0,4744 & 0,4097 \\ 0,0718 & 0,0955 & 0,0435 & 0,0494 & 0,0574 \end{pmatrix}_{S4-Tourist-int}$$

$$E^5 = \begin{pmatrix} 0,0371 & 0,0375 & 0,0236 & 0,3833 & 0,0304 \\ 0,3829 & 0,1461 & 0,1179 & 0,1673 & 0,1435 \\ 0,1659 & 0,2774 & 0,1839 & 0,0645 & 0,1535 \\ 0,0843 & 0,1348 & 0,0723 & 0,1309 & 0,1535 \\ 0,2419 & 0,2581 & 0,5396 & 0,2089 & 0,3657 \\ 0,0879 & 0,1461 & 0,0626 & 0,0450 & 0,1535 \end{pmatrix}_{S5-Farmers-and-livestock-owners} \quad E^6 = \begin{pmatrix} 0,0475 & 0,0255 & 0,0299 & 0,2366 & 0,0235 \\ 0,2267 & 0,1552 & 0,1318 & 0,1844 & 0,1832 \\ 0,0915 & 0,1133 & 0,0940 & 0,0900 & 0,0724 \\ 0,0929 & 0,2450 & 0,1306 & 0,0710 & 0,1707 \\ 0,4984 & 0,3976 & 0,5699 & 0,3838 & 0,4813 \\ 0,0429 & 0,0634 & 0,0438 & 0,0342 & 0,0689 \end{pmatrix}_{S6-Park-rangers}$$

A graphical representation of the prioritization of all the environmental problems given by each decision maker, which was presented in table 1, can also be seen in Fig 5.

Fig. 5. Problem ranking by decision maker

Analyzing these result we can observe that there are four DMs who show similar priorities, that is, their ranking of park problems is similar. They consider that *Clogging and rapid drying of peatlands, lakes and springs* should be considered the most important problem to be solved. They are the farmers, park rangers, academics and one of the tourists. However, we can observe that one of the DMs, namely S2 *national tourists* show very different prioritization profiles. For example, according to S2 *national tourists* the most important problem they should focus on is *Tourism poorly managed in the park*.

These results show that stakeholders have conflicting interests and each of them has solved the decision making problem according to his own interests.

This is the usual situation when solving environmental management problems and when trying to give voice to all the involved stakeholders. Therefore, the use of the consensus index step is highly recommended in this particular situation

We have also carried out a comparison between the final group prioritization for the whole problem both using the same importance for every DM with simple AHP and using the weighted AHP (by using the weighted geometric mean, as we can see in Eq. 5.1) with the weights W_j obtained by SNA.

$$aij^{WGM} = \prod_{k=1}^{m} (a_{ij}^{(k)})^{q_k} \qquad (5.1)$$

This can be seen in Fig 6 below:

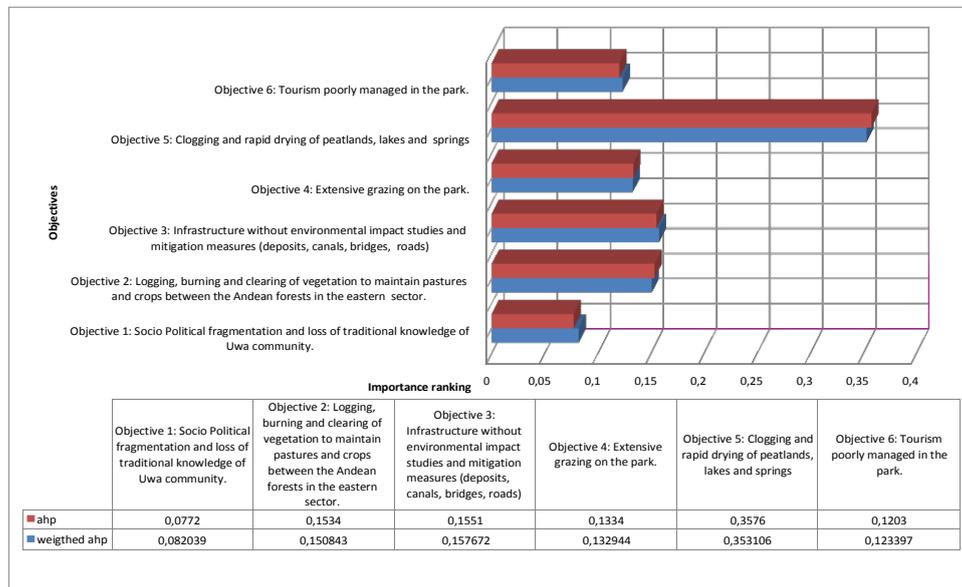|	Objective 1: Socio Political fragmentation and loss of traditional knowledge of Uwa community.	Objective 2: Logging, burning and clearing of vegetation to maintain pastures and crops between the Andean forests in the eastern sector.	Objective 3: Infrastructure without environmental impact studies and mitigation measures (deposits, canals, bridges, roads)	Objective 4: Extensive grazing on the park.	Objective 5: Clogging and rapid drying of peatlands, lakes and springs	Objective 6: Tourism poorly managed in the park.
ahp	0,0772	0,1534	0,1551	0,1334	0,3576	0,1203
weigthed ahp	0,082039	0,150843	0,157672	0,132944	0,353106	0,123397

Fig. 6. Final ranking of environmental problems (aggregated by geometric mean)

In this figure we can observe that there is no much difference between the two results, that is, the weighting of the stakeholders has not changed the final group prioritization of the park environmental problems. This is due to the fact that the most important decision makers have similar opinions.

Next, in figures 7-12 we present a sensitivity analysis showing how a weight increment changes the final importance of every problem for each stakeholder:

─── Objective 1: Socio Political fragmentation and loss of traditional knowledge of Uwa community.

─── Objective 2: Logging, burning and clearing of vegetation to maintain pastures and crops between the Andean forests in the eastern sector.

─── Objective 3: Infrastructure without environmental impact studies and mitigation measures (deposits, canals, bridges, roads)

─── Objective 4: Extensive grazing on the park.

─── Objective 5: Clogging and rapid drying of peatlands, lakes and springs

─── Objective 6: Tourism poorly managed in the park.
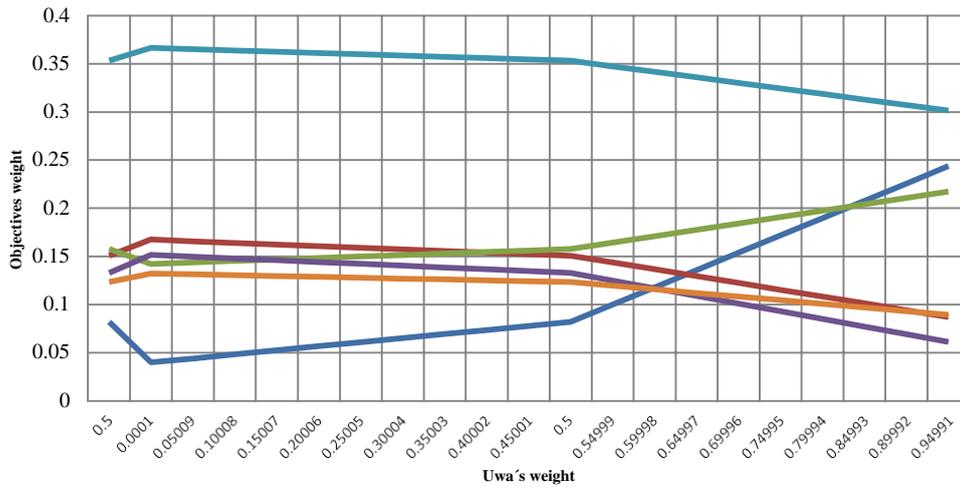
Fig. 7. Uwa weight sensitivity
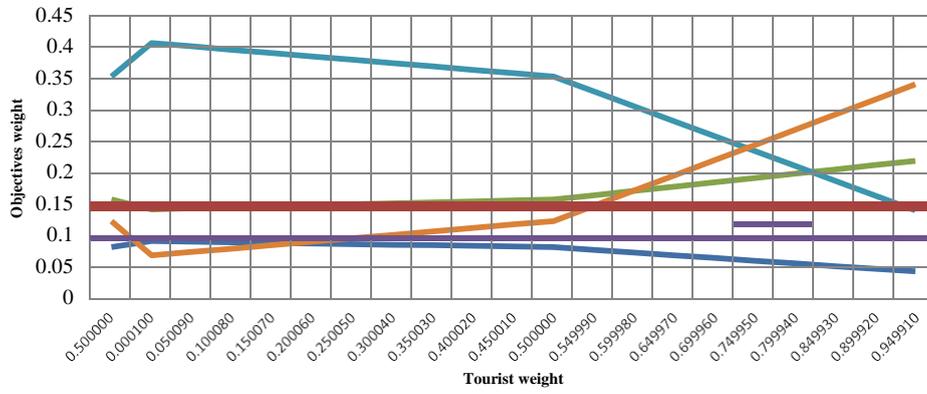
Fig. 8. Tourist weight sensitivity
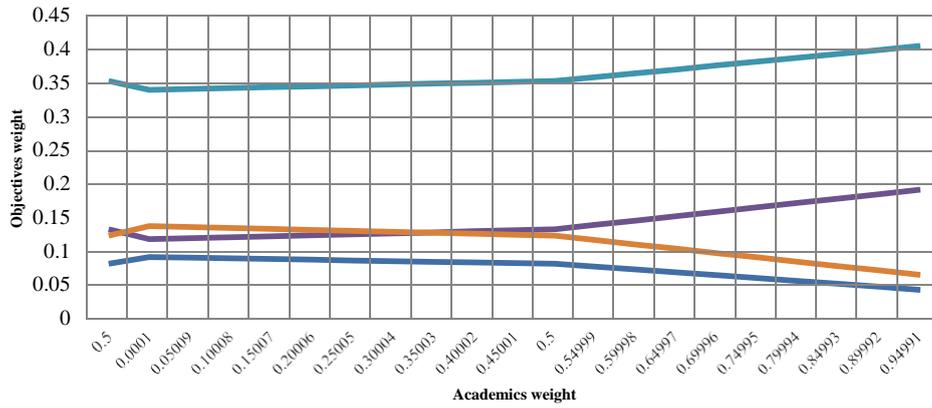
Fig. 9. Academics weight sensitivity
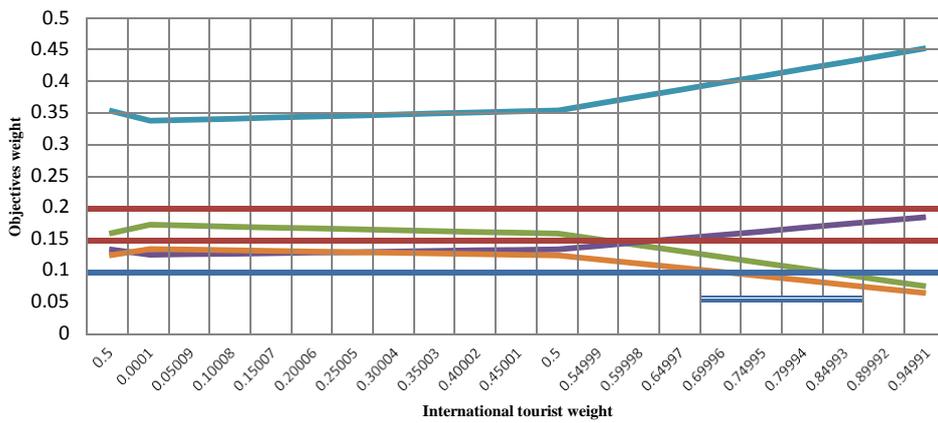
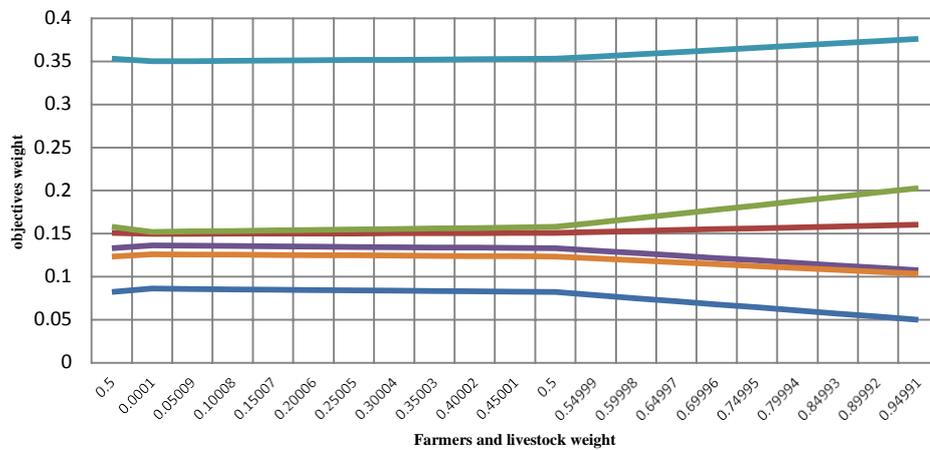Fig 10. International tourists weight sensitivity

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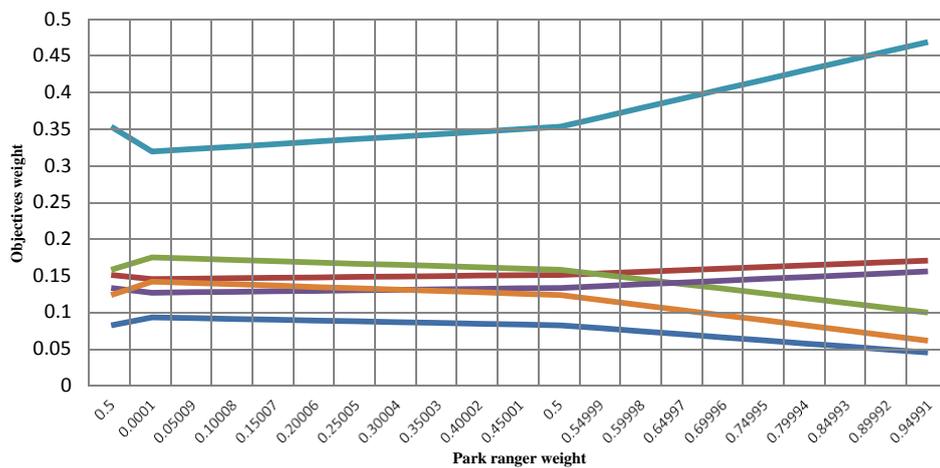Fig 11. Farmers and livestock weight sensitivity

Fig. 12. Park ranger sensitivity

4.5. *Calculate the consensus index and final ranking of alternatives*

Finally, we calculate the consensus index for the problem and show the final consensus ranking for the environmental problems of the national natural park. Also we want to demonstrate that even though the final ranking of the environmental problems doesn't change with the weighted AHP method, that occurs because the most important (biggest weight or influence) decision makers have similar opinions about the problems we want to measure.

The consensus between all stakeholders is calculated at the three levels exposed in the section 2.2. As follows:

a. Level 1

At this level the consensus index of a stakeholder to the group of stakeholders on the alternative P_i (environmental problems) under criterion $Objective_j$ (objectives of conservation) is calculated according to Eq. 2.6. The consensus degree on a pair of alternatives CE_{ij}^h for each DM can be seen below.

$$CE^1 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9808 & 0,6743 & 0,9949 & 0,7765 & 0,9938 \\ 0,8471 & 0,8765 & 0,9609 & 0,8877 & 0,9712 \\ 0,8230 & 0,9333 & 0,7789 & 0,9012 & 0,6954 \\ 0,9270 & 0,8514 & 0,9626 & 0,9447 & 0,8891 \\ 0,8168 & 0,8764 & 0,7914 & 0,8584 & 0,8624 \\ 0,7447 & 0,8852 & 0,9651 & 0,9051 & 0,8815 \end{pmatrix}$$
Uwas — objective 1, objective 2, objective 3, objective 4, objective 5

$$CE^2 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9754 & 0,9309 & 0,9975 & 0,8694 & 0,9965 \\ 0,9123 & 0,9404 & 0,9107 & 0,8903 & 0,9762 \\ 0,9374 & 0,9224 & 0,8103 & 0,8145 & 0,8844 \\ 0,9208 & 0,9093 & 0,9602 & 0,9729 & 0,9110 \\ 0,7494 & 0,7184 & 0,8595 & 0,7865 & 0,6983 \\ 0,6474 & 0,6537 & 0,9511 & 0,8094 & 0,6457 \end{pmatrix}$$
tourist −1 — objective 1, objective 2, objective 3, objective 4, objective 5

$$CE^3 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9849 & 0,9309 & 0,9977 & 0,8574 & 0,9965 \\ 0,8735 & 0,9174 & 0,9637 & 0,9292 & 0,9630 \\ 0,9374 & 0,9333 & 0,8730 & 0,8710 & 0,8757 \\ 0,7438 & 0,8859 & 0,9422 & 0,9700 & 0,9115 \\ 0,8117 & 0,8702 & 0,9075 & 0,8213 & 0,8544 \\ 0,8452 & 0,9026 & 0,9764 & 0,9261 & 0,9018 \end{pmatrix}$$
academic — objective 1, objective 2, objective 3, objective 4, objective 5

$$CE^4 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9851 & 0,9295 & 0,9977 & 0,7878 & 0,9944 \\ 0,8879 & 0,9192 & 0,9024 & 0,9185 & 0,9779 \\ 0,9017 & 0,8572 & 0,8461 & 0,9035 & 0,8541 \\ 0,9020 & 0,9245 & 0,9492 & 0,9729 & 0,8879 \\ 0,6849 & 0,8067 & 0,9075 & 0,7312 & 0,8448 \\ 0,8510 & 0,9026 & 0,9711 & 0,9364 & 0,8971 \end{pmatrix}$$
int −tourist — objective 1, objective 2, objective 3, objective 4, objective 5

$$CE^5 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9851 & 0,9279 & 0,9969 & 0,8694 & 0,9950 \\ 0,8262 & 0,9368 & 0,9637 & 0,9292 & 0,9646 \\ 0,9145 & 0,8639 & 0,8730 & 0,9148 & 0,8844 \\ 0,9276 & 0,9245 & 0,9373 & 0,9581 & 0,9336 \\ 0,8168 & 0,8764 & 0,8974 & 0,8584 & 0,8624 \\ 0,8510 & 0,8823 & 0,9764 & 0,9364 & 0,8684 \end{pmatrix}$$
farmers — objective 1, objective 2, objective 3, objective 4, objective 5

$$CE^6 = \begin{array}{c} P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6 \end{array} \begin{pmatrix} 0,9820 & 0,9953 & 0,9955 & 0,8761 & 0,9954 \\ 0,9161 & 0,9398 & 0,9624 & 0,9425 & 0,9800 \\ 0,9703 & 0,9139 & 0,9217 & 0,9043 & 0,8949 \\ 0,8772 & 0,9276 & 0,9589 & 0,9568 & 0,9427 \\ 0,7116 & 0,8309 & 0,9179 & 0,7775 & 0,7835 \\ 0,8930 & 0,8986 & 0,9782 & 0,9492 & 0,9077 \end{pmatrix}$$
park −rangers — objective 1, objective 2, objective 3, objective 4, objective 5

b. Level 2

At this level the consensus degree on alternatives is calculated. The consensus index of a stakeholder to the group of stakeholders on the alternative i (environmental problems). The consensus degree on alternatives CA_i^h, where h is each decision maker, can be seen below.

$$CA = \begin{array}{c} Uwas \\ Tourist -1 \\ Academic \\ Tourist-\text{int} \\ Farmers \\ Park - ranger \end{array} \begin{pmatrix} 0,8566 & 0,8495 & 0,9090 & 0,8789 & 0,8822 \\ 0,8571 & 0,8458 & 0,9149 & 0,8572 & 0,8520 \\ 0,8688 & 0,8899 & 0,9290 & 0,8750 & 0,9094 \\ 0,8869 & 0,9020 & 0,9408 & 0,9111 & 0,9181 \\ 0,8917 & 0,9177 & 0,9558 & 0,9011 & 0,9174 \end{pmatrix}$$
objective 1, objective 2, objective 3, objective 4, objective 5

c. Level 3

According to [31] the greater the value of CI ($0 \leq CI \leq 1$), the greater the agreement between an individual expert (E^h) and the group as a collective. When $\min_{h} CI^h$ is greater than a threshold value $\gamma \in$ [0.5, 1], fixed a priori by the group of expert, then the consensus reaching process ends and the selection process is applied to achieve the solution of consensus.

The final level shows the consensus index on the decision matrix CI^h, this consensus shows the level of agreement between stakeholders. We give a threshold value CL of 0,83 for this problem searching a very high consensus, as we show in the scale based **on [37]** in section 2.2. That means if we have a greater value than CL we assume that the consensus is reached for the problem, otherwise we need to give feedback to the decision makers and a new consensus round is applied. The consensus index for every stakeholder can be seen below.

$$CI = \begin{pmatrix} \overset{DM1\ UWAS}{0,8752} & \overset{DM\ 2\ TOURIST}{0,9058} & \overset{DM\ 3\ ACADEMIC}{0,9167} & \overset{DM\ 4\ TOURIST\ INT}{0,8654} & \overset{DM\ 5\ FARMERS}{0,9118} & \overset{DM\ 6\ PARK}{0,8944} \end{pmatrix}$$

We can observe that all stakeholders have a very high consensus level (CI>0.83) bigger than our threshold value of 0,83. It means that every stakeholder may agree with the final prioritization given by the weighted AHP process. Then, we assume that the consensus is reached for this problem and we suggest the final prioritization given by the weighted AHP process.

5. Conclusions

In this paper a hybrid MCDM model combined with SNA and AHP have been used to solve a consensus problem in an environmental decision making problem. The SNA technique has been used to build an influential network relation map among decision makers and to obtain their weights for applying a weighted AHP. Then, the final decision matrices for every decision maker have been compared in order to identify the consensus level of the problem.

Regarding the results obtained with the SNA, we can see that the most influential stakeholder are the park rangers. This may be due to they are the official agency of the Park, with the ability to analyze the evolution of the Park and therefore they generate information without vested interests, and the rest of the group trusts them. The other stakeholders who also show an important influence on the group are the U'was community, probably due to their economic activity and the Academics, probably due to their ideological activity.

Regarding the results obtained through the participative decision making process based on AHP we found that results do not change when we consider all the stakeholders with the same influence or with different importance in the decision making problem. This may be due to the stakeholder who differed with the group as a collective, only affect the final prioritization when their influence (weight of a decision maker) increases in the weighted AHP model, as we can see in the sensitivity analysis of the consensus reaching process in its second step.

The calculation of the consensus index has given us an effective way to prove if the stakeholders agree with the final ranking given by the AHP process. In our case the index obtained for all the stakeholders is quite high, showing a great degree of consensus among them.

Regarding the scientific contribution of this paper, the developed model offers a new way of combining decision making support and participatory procedures. This method is able to provide a systematic course of analysis of the alternatives under examination and of the different decision makers who might participate in the process.

Finally, we want to highlight that this study offers an effective tool that could be used to set the guidelines for the design of strategic objectives for the development of the Natural Park.

Apart from the aforementioned advantages that arise from the application of the AHP in complex decision environments, one of the most significant strengths is the fact that the DMs gain more awareness of the elements at stake while structuring the model and thus learn about the problems while solving them [41]. Traceability is one of the great advantages of the AHP procedure.However, our methodology is not free of criticism. The use of SNA and AHP can be very time consuming, somewhat difficult to apply until the logic is understood and relies much on judgements. For the former an experienced facilitator is required and for the latter a balanced group of real decision makers or experts is needed.

Concerning the utility and applicability of this tool and findings to similar cases, the procedure is easily adaptable Although the proposal has been specifically applied to the evaluation of environmental problems of the Cucuy Nationa Park of Colombia, it can be adapted to any type of decision-making problem in the environmental field, provided the criteria and the group of stakeholders are correctly identified.

As future lines of investigation, the research team aims at reproducing the procedure elsewhere. For that, other NP managers must bear in mind three key rules: first, to arrange a panel of stakeholders fully representative and motivated; second, to provide an appropriate mean of communication among them and; third, to take this methodology as a whole procedure and to devote the necessary time to it.

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6. References

1. Regan HM, Colyvan M, Markovchick-Nicholls L. A formal model for consensus and negotiation in environmental management. *Journal of Environmental Management*. 2006;80(2):167-176. doi:10.1016/j.jenvman.2005.09.004.

2. Reed MS. Stakeholder participation for environmental management: A literature review. *Biological Conservation*. 2008;141:2417-2431. doi:10.1016/j.biocon.2008.07.014.

3. Gómez-navarro T, García-melón M. DESIGN OF AN EFFICIENCY INDEX FOR THE RANK ORDER OF SOIL REMEDIATION TECHNIQUES. 2011;10(5):34963.

4. Aragonés-beltrán P, Garcia-Melón M, Estruch-Guitart V. ANALYSIS OF THE PARTICIPATION OF STAKEHOLDERS IN ENVIRONMENTAL MANAGEMENT BASED ON ANP : APPLICATION TO A SPANISH NATURAL PARK. *IJAHP*. 2015;7(1):2-14.

5. Belton V, Stewart T. *Multiple Criteria Decision Analysis: An Integrated Approach.*; 2002.

6. Ginevičius R, Podvezko V. Evaluating the changes in economic and social development of Lithuanian counties by multiple criteria methods. *Technological and Economic Development …*. 2009.

7. Ramzan N, Degenkolbe S, Witt W. Evaluating and improving environmental performance of HC's recovery system: A case study of distillation unit. *Chemical Engineering Journal*. 2008.

8. Solnes J. Environmental quality indexing of large industrial development alternatives using AHP. *Environmental Impact Assessment Review*. 2003.

9. Beccali M, Cellura M, Mistretta M. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renewable Energy*. 2003.

10. Saaty T. The analytic hierarchy process: planning, priority setting, resources allocation. *M cGraw-Hill*. 1980. http://scholar.google.com/scholar?q=The+Analytic+Hierarchy+Process.+Plannin g,+Priority+Setting,+Resource+Allocation&btnG=&hl=es&as_sdt=0,5#0. Accessed March 20, 2014.

11. Varvasovszky Z. Review article Stakeholder analysis : a review. 2000;15(3):239-246.

12. Prell C, Hubacek K, Reed M. Stakeholder Analysis and Social Network Analysis in Natural Resource Management. *Society & Natural Resources*. 2009;22(January 2008):501-518. doi:10.1080/08941920802199202.

13. Charnley S, Engelbert B. Evaluating public participation in environmental decision-making: EPA's superfund community involvement program. *Journal of environmental management*. 2005;77(3):165-182. doi:10.1016/j.jenvman.2005.04.002.

14. Reed MS, Graves A, Dandy N, et al. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*. 2009;90(5):1933-1949. doi:10.1016/j.jenvman.2009.01.001.

15. Bonner BL, Bolinger AR. Separating the confident from the correct: Leveraging member knowledge in groups to improve decision making and performance. *Organizational Behavior and Human Decision Processes*. 2013;122(2):214-221. doi:10.1016/j.obhdp.2013.07.005.

16. Bonner BL, Baumann MR. Informational intra-group influence : The effects of time pressure and group size. 2008;66(September 2006):46-66. doi:10.1002/ejsp.

17. Kirchler, Erich; Davis JH. The influence of member status differences and task type on group consensus and member position change. *Journal of Personality and Social Psychology*. 1986;51(1):83-91.

18. Janet A Sniezek RAH. Accuracy and confidence in group judgment. *Organizational Behavior and Human Decision Processes*. 1989;43(1):1-28.

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19.   Bonner BL, Sillito SD, Baumann MR. Collective estimation: Accuracy, expertise, and extroversion as sources of intra-group influence. *Organizational Behavior and Human Decision Processes*. 2007;103(1):121-133. doi:10.1016/j.obhdp.2006.05.001.

20.   Burgman M. Risks and decisions for conservation and environmental management. 2005. https://books.google.es/books?hl=es&lr=&id=3EZBOGhlookC&oi=fnd&pg=PR9&dq=burgman+2005&ots=rjboaVZsUR&sig=WFsE8aY2Io_u0GwWZnEKp9VgF4M. Accessed November 16, 2015.

21.   Krinitzsky E. Earthquake probability in engineering—Part 1: The use and misuse of expert opinion. The Third Richard H. Jahns Distinguished Lecture in engineering geology. *Engineering Geology*. 1993. http://www.sciencedirect.com/science/article/pii/001379529390030G. Accessed November 16, 2015.

22.   Mitchell, Ronald K;Agle, Bradley; Wood DJ. Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of who and What Really Counts. *Academy of Management Rewiew*. 1997;22(4):853-886.

23.   Bryson JM. What to do when Stakeholders matter. *Public management review*. 2004;6(1):21-53. doi:10.1080/14719030410001675722.

24.   Biggs S, Matsaert H. An actorâ€• oriented approach for strengthening research and development capabilities in natural resource systems. *Public Administration and Development*. 1999;19(3):231-262. doi:10.1002/(SICI)1099-162X(199908)19:3<231::AID-PAD71>3.0.CO;2-E.

25.   Wu J, Chiclana F. A social network analysis trust-consensus based approach to group decision-making problems with interval-valued fuzzy reciprocal preference relations. *Knowledge-Based Systems*. 2014;59:97-107. http://www.scopus.com/inward/record.url?eid=2-s2.0-84897660200&partnerID=40&md5=a8ebbe40d16a8813d7934715e2cb0b5a.

26.   Wasserman S, Faust K. *Social Network Analysis*. 15th print. New York: Cambridge University Press; 2007.

27.   Hannerman R, Riddle M. *Introduction to Social Network Methods*.; 2015.

28.   Sabidussi G. Index of a graph. *Psychometrika*. 1966;31(4):581-603.

29.   Stephen P Borgatti & Martin G. *Analyzing Social Networks*.

30.   Chiclana F, Tapia García JM, Del Moral MJ, Herrera-Viedma E. A statistical comparative study of different similarity measures of consensus in group decision making. *Information Sciences*. 2013;221:110-123. http://www.scopus.com/inward/record.url?eid=2-s2.0-84880358467&partnerID=40&md5=9431656656f467c8ee6e6f320f962bff.

31.   Wu J, Chiclana F, Herrera-Viedma E. Trust based consensus model for social network in an incomplete linguistic information context. *Applied Soft Computing*. 2015:1-13. doi:10.1016/j.asoc.2015.02.023.

32.   Xu J, Wu Z. A discrete consensus support model for multiple attribute group decision making. *Knowledge-Based Systems*. 2011;24(8):1196-1202. doi:10.1016/j.knosys.2011.05.007.

33.   Cabrerizo FJ, Chicalana F, Herrera-viedma E. Challenges and Open Questions in Soft Consensus Models. 2013:944-949.

34.   Herrera F, Herrera-viedma E, Verdegay JL. Choice processes for non-homogeneous group decision making in linguistic setting. 1998;94:287-308.

35.   Chiclana F, Herrera-Viedma E, Herrera F, Alonso S. Some induced ordered weighted averaging operators and their use for solving group decision-making problems based on fuzzy preference relations. *European Journal of Operational Research*. 2007;182(1):383-399. http://www.scopus.com/inward/record.url?eid=2-s2.0-34147108016&partnerID=40&md5=85f55eb7ef3d593b491ce643f294b926.

36.   Chiclana F, Herrera-Viedma E, Herrera F, Alonso S. Some induced ordered weighted averaging operators and their use for solving group decision-making problems based on fuzzy preference relations. *European Journal of Operational Research*. 2007;182(1):383-399.

37.   Mata F, Mart L, Herrera-viedma E. An Adaptive Consensus Support Model for Group Decision-Making Problems in a Multigranular Fuzzy Linguistic Context. 2009;17(2):279-290.

38.   Fishbein M, Triandis HC, Kanfer FH, Becker M, Middlestadt SE. Factors influencing behavior and behavior change. In: *Handbook of Health Psychology*. Mahwah New Jersey Lawrence Erlbaum 2000.; 2001.

39.   Saaty, T. L., & Peniwati K (2013). G decision making: drawing out and reconciling differences. R publications. *Group Decision Making: Drawing out and Reconciling Differences*. RWS Publications; 2013.

40.   Xu Z. On consistency of the weighted geometric mean complex judgement matrix in AHP. *European Journal of Operational Research*. 2000;126(3):683-687. doi:10.1016/S0377-2217(99)00082-X.

41.   Rosso M, Bottero M, Pomarico S, La Ferlita S, Comino E. Integrating multicriteria evaluation and stakeholders analysis for assessing hydropower projects. *Energy Policy*. 2014;67:870-881. doi:10.1016/j.enpol.2013.12.007.

Answers to Reviewer #3:

We want to thank reviewer nr. 3 for his/her comment and suggestions to improve the paper. We have followed all of them. Please find below the answers to each of them.

Regarding presentation, I suggest the following:

1- **Thoroughly reviewing the manuscript for English language grammar and style consistent with scientific manuscripts.**
We have reviewed the whole manuscript and modified some grammatical and scientific expressions

2- **Removing redundancies such as the sentence 'GDM problem is an interactive...' in section 2.2 first paragraph and last paragraph on p. 4.**
We have removed the second one

3- **Replacing ',' with '.' when numeric results.**
We have done it along the manuscript.

4- **Increasing the size of figure 5 and adding the numeric values corresponding to the results reported in the figure.**
We have inserted a bigger figure. However, we do not show the numeric values because there are too many and to show all of them will be a little bit confusing. For that we have indicated that those final numerical results can also be seen in table 1

5- **Adding titles for axis for figure 6. Also, in this figure, all charts have the x-axis start with a '0.5' which appears misplaced. To further improve readability, I suggest adding a marker on the x-axis reflecting the 'base' weight.**
We have done it.

6- **Replacing 'prove' to 'demonstrate' in section 4.5 p. 18.**
We have done it.

7- **Re-write section 5 'Conclusion' to highlight 1) summary of the work, 2) key contribution, and 3) limitations and future work. Avoid future tense such as in the first paragraph, fragmentation and one sentence paragraphs, etc.**
The Conclusions section has been thoroughly reviewed and improved. Some paragraphs have been added according to your suggestions.

Regarding content, I suggest the following:

1- **Ensure that the order of stakeholders is reported in a consistent manner. For example, on page 10, S1 is Uwas, S2 is park rangers, etc., while on page 12 S2 is local tourists, and on page 19, S2 is academic.**
The order of the stakeholders is now consistently reported.

2- **The statement on page 14 indicating that the Uwas most important problem to be solved is 'Socio-political fragmentation...' appears to be inconsistent with the results shown in figure 6 which (as the weight for the Uwas stakeholder**

approaches 1), the preference is for 'Clogging and rapid drying' followed by 'Socio-political fragmentation…'
The statement has been reviewed and modified accordingly.

3- **Provide additional discussion and insight into the results obtained, for example, the decision matrices on page 13, for Uwas, E(3,5) = 0.4514 which sounds counter-intuitive.**
We have provided additional discussion to improve the description of the Eij matrices

4- **Add a paragraph in the conclusion highlighting the limitations and suggestions for future work.**
The Conclusions have been reviewed and improved according to this suggestion.