Economía Agraria y Recursos Naturales. ISSN: 1578-0732. e-ISSN: 2174-7350. Vol. 16,2. (2016). pp. 89-109

A critical review of multi-criteria decision making in protected areas

Mónica de Castro[a] and Vicente Urios[b]

ABSTRACT: Multi-criteria analysis in collaborative decision making can provide a useful tool to improve the governance in protected areas with strong conflicts between stakeholders. This paper offers an in-depth review about MCDM methods in protected areas. The analysis considers the topics Land Use, Management, Species, and Zoning and it is based in two dimensions: Methods and Participation. Topics and MCDM methods and Topics and Participation were significantly related and contrasted using a Chi-squared test, respectively. We have identified two groups by topics: Zoning and Species use continuous non participative methods and Land Use and Management use discrete methods with increasing participation.

KEYWORDS: Collaborative Decision-Making, Multi-criteria analysis, protected areas.

JEL classification: Q50, C44.

DOI: 10.7201/earn.2016.02.04.

Una revisión crítica de la toma de decisiones multi-criterio en áreas protegidas

RESUMEN: El análisis multi-criterio para toma de decisiones colaborativa ofrece una herramienta útil para mejorar la gobernanza en áreas protegidas, con fuertes conflictos de intereses entre agentes. Este artículo ofrece una revisión en profundidad sobre métodos MCDM en áreas protegidas. El análisis considera los temas Uso de la tierra, Gestión, Especies y Zonificación, y se basa en dos dimensiones: Métodos y Participación. Los Temas y las Técnicas MCDM y los Temas y la Participación están significativamente correlacionados respectivamente según un test Chi-cuadrado. Hemos identificado dos grupos: Especies y Zonificación usan métodos continuos no participativos y Uso de la tierra y Gestión, utilizan métodos discretos donde la participación es creciente.

PALABRAS CLAVE: Análisis multi-criterio, áreas protegidas, toma de decisiones colaborativa.

Clasificación JEL: Q50, C44.

DOI: 10.7201/earn.2016.02.04.

[a] Universidad Rey Juan Carlos.

[b] Dpto. de Ciencias Ambientales y Recursos Naturales. Universidad de Alicante.

Acknowledgements: The authors would like to acknowledge the help of Luke Rice in improving the English and the help of the Editor and referees in improving the original manuscript.

Corresponding author: Mónica de Castro. E-mail: monica.decastro@urjc.es.

Received in July 2016. Accepted in November 2016.

1. Introduction

Multi-Criteria Decision Analysis (MCA) is "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individual or groups explore decisions that matter" (Belton and Stewart, 2002, p.2).

The use of Multi-Criteria Decision Analysis for Decision Making (hereafter MCDM) is particularly useful for resolving conflicts of interest, such as those related to the management of natural resources in protected areas, where economic, ecological and social interests clash with each other (Ananda and Herath, 2009). These methods provide a structured framework of discussion that may be helpful in resolving conflicts and optimizing resources. Moreover, they bring transparency to the processes of participation in the formulation of public policy for natural resource management (Ananda, 2007) and are an interesting source of information for managers.

Multi-criteria analysis in collaborative decision making can be a useful tool for implementing good governance. Graham *et al*. (2003) define good governance in protected areas on the basis of five attributes: legitimacy and voice, direction, performance, accountability and fairness. These attributes are based in the United Nations Development Program principles of good governance: Participation, Consensus orientation, Strategic vision, Responsiveness of institutions and processes to stakeholders, Effectiveness and Efficiency, Accountability to the public and to institutional stakeholders, Transparency, Equity and Rule of Law (UNDP, 1999). On the one hand, MCA provides a structured framework for decision making. On the other hand, Group Decision Making provides a scenario where it is possible to incorporate transparently the participation of stakeholders. The interactivity of the process has more chance of success to achieve the maximum consensus and regain the loss of reciprocity that sometimes is generated in protected areas. Thus, participatory multicriteria analysis can help to integrate some of these principles of good governance in the management of protected areas.

The concern for a good governance in protected areas has been driven by (i) the conflict generated by the use of resources, (ii) the growing role of local communities in the management of natural resources (Ostrom, 2000) and (iii) the social demand for an institutional framework characterized by globalization, transparency and public participation (Dearden *et al*., 2005). These three factors have made necessary to incorporate new forms of governance where stakeholder participation plays an important role in the structure of relations and that should be reflected in management actions. Parallel to the interest promoted by the quality of governance, an impulse of participatory MCDM has been generated (Mendoza and Martins, 2006). However, to date, there is a lack of comprehensive reviews on the use of participatory MCDM in protected areas.

There have been several literature reviews on MCDM in natural resource management. Ananda and Herath (2009), Huang *et al*. (2011) and Kiker *et al*. (2005) have reviewed the use of MCDM in natural resource management taking into account contaminated sites, the latter two provide broad reviews while the former focuses on

forest management. Moreover, the revisions of Diaz-Balteiro and Romero (2008), Mendoza and Martins (2006), Proctor and Qureshi (2005), Vacik *et al*. (2014) and Estévez and Gelcich (2015) consider participation. There has only been a mini-review on the use of MCDM in protected areas, but it does not take into account participation (Moffett and Sarkar, 2006).

Here, we provide a thorough review of studies on MCDM in protected areas. We reviewed 164 articles on MCDM in protected areas from 2000 to 2016. The literature review is analysed from two approaches: methods and participation. The first approach analyses the different MCDM methods according to the problem needing to be solved. The second one analyses the use of MCDM in collaborative decision making and the type of participation. Both approaches are based on four key issues in protected areas, or protected areas topics: Land Use, Management, Species and Zoning.

The three specific objectives of this paper are: (i) To review MCDM models and their application in protected areas between 2000 and 2016, (ii) To identify the major multi-criteria techniques in protected areas and the problems they solve, (iii) To analyse the evolution of participation to these models.

2. Methods

2.1. Literature search

The literature review has been performed through a search among journals included in the Journal Citation Reports (Science and Social Science). Given the multidisciplinary nature of the research, the search was conducted in the following areas: Operations Research/Management Science, Biodiversity Conservation, Economics, Forestry, Environmental Sciences/Ecology, Agricultural Economics and Policy, Business and Statistics/Probability.

2.2. Classification scheme

The analysis is based in two dimensions: MCDM methods and Participation, and it has been considered through the topics Land Use, Management, Species and Zoning.

Multi-criteria methods

In this paper, the multi-criteria techniques have been grouped into eight classes: (i) AHP/ANP, (ii) Value/Utility (iii) Outranking (iv) Continuous, (v) Fuzzy, (vi) Soft, (vii) Mix and (viii) Others. The following paragraphs briefly describe these main multi-criteria techniques used in natural resource management.

(i) AHP/ANP: The Analytical Hierarchy Process (AHP) uses a pairwise comparison in order to obtain the relative importance of the criteria and of the alternatives on a hierarchical structure of the decision problem. It uses value

judgments and quantifies the importance of the criteria and objectives to prioritize management alternatives. Analytical Network Process (ANP) is a generalization of AHP, where the base is not a hierarchical structure but a network (Greco *et al*., 2005).

(ii) Value/Utility: The Multi-Atributte Value Theory (MAVT) and Multi-attribute Utility Theory (MAUT): The first obtains a function value for each criterion and then these individual functions are aggregated into a global value function. MAUT assumes that each criterion is directly associated with a quantitative attribute measured in cardinal scale (Belton and Stewart, 2002).

(iii) Outranking Techniques: Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) performs pairwise comparisons of the criteria and is based on improvement relationships to prioritize alternatives (Belton and Stewart, 2002). ELimination Et Choix Traduisant la REalité (ELECTRE) uses the same approach of PROMETHEE to define the ranking of alternatives based on relations of overrating, but uses a concordance and discordance analysis for the desirability of each alternative (Mendoza and Martins, 2006).

(iv) Continuous methods: Linear programming, Goal Programming and Compromise Programming are the most popular methods to resolve problems about management of natural resources. These techniques are continuous models using optimization techniques to select the best possible alternative. (Greco *et al*., 2005).

(v) Fuzzy methods: Use imprecise and uncertain information. This approach specifies each alternative with some degree of membership (Ananda and Herath, 2009).

(vi) Soft systems methods: Use a very small structure, based on group participation. "They give primacy to defining most relevant factors, perspectives and issues that have to be taken into account, and in designing strategies upon which the problem can be better understood and the decision process better guided" (Mendoza and Martins, 2006, p.17).

(vii) Mix: Uses various MCDM methods mixed to resolve the same problem, however, no one method are more important than another.

(viii) Others: Methods not included in the others groups.

Protected Area Topic

This review has focused on problems concerning protected areas, which in some cases incorporate empirical studies.

The papers have been grouped in four topics: (i) Land Use, (ii) Management, (iii) Species and (iv) Zoning, that include the following:

(i) **Land Use:** It refers to spatial planning, land/water use plans and works including issues on the use of resources within protected areas. Two sub-groups have been identified: Water, research carried out in river basins and Land, all the others. Although this group shares many features with Management and is difficult to define the threshold that distinguishes the topics, the land use is the issue causing the majority of conflicts in protected areas. Because of its importance it has been considered that it requires its own, unique topic. The difference between the two groups is that while the models identified in Management try to answer the question "how to manage?" the ones grouped in Land Use answer the question "how to use?"

(ii) **Management:** It takes into account issues related to the distribution of resources, such as project selection, design of policies and plans for sustainable management of resources. Within this group, three subgroups were identified: Resources, Strategies and Tourism. Resources include studies that solve problems on project prioritization and distribution of economic resources. The studies included in Strategies analyse problems related to the zoning of policies and management plans. Tourism refers to the management of sustainable tourism in protected areas.

(iii) **Species:** It refers to problems on wildlife management, control of alien species, zoning in relation to species distribution and ecosystem vulnerability.

(iv) **Zoning:** Includes problems on zoning and demarcation of protected areas and on the assignment of conservation priorities at the spatial scale.

Participation

Reviewed works have been classified considering the participation and collaboration of stakeholders, based on the model of Belton and Stewart (2002):

(i) **No Participatory:** Stakeholders' preferences are not incorporated in any stage of the decision-making process.

(ii) **Participatory without Collaboration:** The participants individually express their preferences without interacting among each other. Individual surveys or individual interviews are the usual methods to include this type of participation.

(iii) **Collaborative:** There is some interaction among participants in the decision making process.

Time periods

The data has been grouped into three homogeneous intervals each lasting four years in order to analyse the evolution of the observations: 2000-2003, 2004-2007, 2008-2011 and 2012-2016.

2.3. Data analysis

Results of the literature review were summarized and a Pearson's Chi-squared was used to test for significant differences. Also the Fisher exact test has been used. The analyses have been performed with the software R-Commander v.3.31 and Microsoft Excel 2010.

3. Literature review

3.1. Multi-criteria methods

The most used Multi-criteria methods are Continuous and MIX with 24.4 % and 20.7 % used respectively, followed by Value and AHP/ANP with 15.8 % and 13.4 % of reviewed articles (Table 1).

TABLE 1

Number and percentages of reviewed papers by method and topics

Topics	AHP/ ANP	Contin.	Fuzzy	Mix	Out-ranking	Soft	Value	Others	SUM	%
Land Use	9	7	1	8	1	2	8	2	38	23.2
Management	9	8	9	11	2	2	10	7	58	35.4
Species	4	3	2	7	1	3	6	2	28	17.1
Zoning	-	22	4	8	-	-	2	4	40	24.4
SUM	22	40	16	34	4	7	26	15	164	
%	13.4	24.4	9.7	20.7	2.44	4.2	15.8	9.1		

Source: Own elaboration.

We found a strong dependence between Multi-criteria methods and topics ($p < 0.001$ Chi-square). These results suggest that there are MCDM techniques that fit better to specifics problems in protected areas. Considering the topics, clear trends were found in Zoning and Species. The studies on Zoning use mostly continuous techniques as Integer programming and heuristic models combined with GIS. On the other hand, Land Use and Management mostly use discrete techniques, often combining different techniques in the same model. Recently, some studies on Land Use have been revised, and tend to combine GIS technology with participatory techniques. These are explained in more detail in section 3.3.

Since 2013, fewer studies using continuous techniques were reviewed. However, the use of all discrete methods has increased since 2008. Moreover, the framework of Adaptive Management in response to the biological complexity of ecosystems incorporates the concept of uncertainty in many studies on protected area management

(Prato, 1999). The methods that treat uncertainty due to randomness, as stochastic models have been displaced for methods that treat uncertainty due to imprecision, as fuzzy models. There has been an increase in the use of simple models, that can be easily understood by stakeholders, such as AHP and group participation techniques. These tend to be unstructured and based on interaction and iteration. The use of Soft Methods, for example, suggest that some MCDM techniques, orientated towards a new paradigm of protected areas management, indicate a recognition towards the importance of community participation.

The increase in the use of simple models that can be easily understood by stakeholders such as AHP and group participation techniques unstructured and based on interaction and iteration, for example, Soft methods, suggest some MCDM techniques oriented towards a new paradigm of protected areas management, that gives importance to community participation.

Finally, it is interesting to note an increasing trend to use Spatial MCA to work on all topics since 2012. Riccioli *et al*. (2016) use this technique to analyse the degree of some relevant features of biodiversity in the Region of Tuscany to solve problems about management. Lu *et al*. (2014), Reza *et al*. (2013) and Walter *et al*. (2016) use Spatial MCA to deal with problems about land use, zoning and species, respectively.

3.2. Protected area topics

This review has focused on problems concerning protected areas, which in some cases incorporate empirical studies. The papers have been grouped in four topics: (i) Land Use, (ii) Management, (iii) Species and (iv) Zoning:

(i) Land Use: Refers to spatial planning, land/water use plans and, generally, studies including issues on the use of resources within protected areas.

(ii) Management: Takes into account issues related to the distribution of resources, such as project selection, design of policies and plans for sustainable management of resources.

(iii) Species: Refers to problems on wildlife management, control of alien species, zoning in relation to species distribution and ecosystem vulnerability.

(iv) Zoning: Includes problems with zoning and demarcation of protected areas and with the assignment of conservation priorities at the spatial scale.

The problem of land use has increased in relative terms over the last decade. Species have also gained importance in recent years, although less steeply and zoning increased very strongly between 2004 and 2007, but less in recent years. Management has been stable in all periods, although it has been the most studied topic. The data suggest a greater concern about issues caused by anthropogenic use of resources in protected areas.

Land use

The most used MCDM techniques are AHP and the techniques based on the theory of value, such as Multi-attribute Value Theory (MAVT) and Multi-attribute Utility Theory (MAUT). GIS studies, use discrete techniques such as AHP and MAVT, unlike research on zoning which employs mainly linear and integer optimization and heuristic models.

The application of multi-criteria in water management often covers large areas and includes a large number of stakeholders, as they tend to study large rivers. In this review we have selected only those studies that include, even partially, a protected area, and where the goal is to resolve issues on the sustainable use of water.

Management

Conservation planning at regional level includes the management of natural resources organizations with opposite attributes and that have limited resources available for implementation. This has created a need to prioritize between different alternatives that optimize resource management but that also consider the preferences of the stakeholders. Papers dealing with this issue in protected areas have analysed problems on Resources, Strategies and Tourism.

Strategies: In this group only one paper using continuous techniques has been reviewed. Bertomeu and Romero (2001) propose a model to maximize biodiversity considering "the edge effect" in forest management plans, using Goal Programming.

In this subgroup studies that have applied discrete techniques are by far the most abundant ones. Tzionas *et al*. (2004) design a Decision Support System based on Fuzzy Logic to evaluate restoration strategies of a lake in Greece. Other studies like Kijazi and Kant (2011) and Oikonomou *et al*. (2011) also use Fuzzy Techniques for solving various problems with strategic management.

Some studies incorporate uncertainty through stochastic models. Prato (2000) incorporates uncertainty in a stochastic model to identify the most efficient management plan, at the landscape scale, and determines its efficiency, maximizing the expected utility function. This work differences between publicly owned landscapes, whose objective is the management of ecosystems and landscapes of private property, with the goal of economic efficiency. Other studies have focused on solving specific problems on wetland management. Pavlikakis and Tsihrintzis (2003) compare three MCDM techniques from the Ecosystem Management approach: MAUT, Compromise Programming and AHP to integrate stakeholders' preferences on four alternative management plans of a Greek National Park included in the Ramsar category. Herath (2004) and Hajkowicz (2008) also include the preferences of local communities in the management of wetlands in Australia using AHP and Direct Rating respectively.

Finally, some studies concerning the identification of indicators for natural resource management in protected areas have been reviewed too: Mendoza and Prabhu

(2000) define indicators of sustainable forest management in a forest in Malaysia using participatory techniques such as the Delphi method and Nominal Group Technique for integrating the views of experts and stakeholders. Wolfshlener and Vacik (2008) also used ANP to define indicators of sustainable forest management under "pressure-state-response" and used them to evaluate four management strategies.

Tourism: The paper that we analysed on outdoor activities and tourism within protected areas solved a variety of problems. Rudolphi and Haider (2003) is the only revised paper that uses ELECTRE, specifically a hybrid between ELECTRE and AHP, and applies it to define management plans for visitors to a National Park in Canada and the conservation of ecological integrity. Gómez-Navarro *et al*. (2010) used ANP to prioritize sustainable tourism management strategies at a National Park in Venezuela incorporating the opinions of experts and stakeholders. Arabatzis and Grigoroudis (2010) evaluated the satisfaction of tourists at a National Park in Greece using specific software for this purpose, MUSA-Multi-criteria Satisfaction analysis, based on MAVT. The most common form of participation methods used are individual surveys.

Resources: The majority of the papers included in this subgroup used mainly multi-criteria techniques based on the Expected Utility Theory (MAUT). Davis *et al*. (2006) develop a theoretical framework for selecting conservation investments that deal with different priorities of biodiversity conservation, considering the quality of the resources, the threat to the quality of resources and the economic costs, in the Sierra Nevada eco-region (California). Kurttila *et al*. (2006) calculated the subsidy that compensates for the loss of utility derived from the conservation of biodiversity on private land in Finland, firstly defining the utility functions and then maximising them through heuristic optimization techniques. Hajkowicz (2008, 2009) uses MAUT and Compromise Programming to distribute financial resources for environmental conservation in Australia. Schmoldt and Peterson (2001) used multi-criteria analysis for the allocation of economic resources. They used AHP to prioritize eight projects in a National Park according the allocation of economic resources.

Species

64.28 % of the papers relating to one or more species use GIS technology. Young *et al*. (2011) designed a risk assessment for a rare plant, *Panax quinquefolius* L. in a National Park in Virginia, USA, identifying potential areas of abundance to strengthen protection regulations. Pasqualini *et al*. (2011) evaluated different management options for the pine *Pinus pinaster* in Corsica, considering the fire risk, using Spatial MCA.

Other studies use habitat requirements of specific species to solve problems on species conservation. Store and Kangas (2001) and Kurttila *et al*. (2002) analysed habitat requirements for a slow-growing tree species *Skeletocutis odora* and two mammals *Pteromys volans* and *Alces alces* respectively. The first used a heuristic optimization technique HERO, combined with AHP and GIS. The latter uses AHP for weighting and SMART for the ranking of alternatives.

Some studies focus on the conservation of forest species in Europe. Dhar *et al.* (2008), prioritize six conservation strategies of a species of yew *Taxus L. Bacata* in Austria, using AHP to evaluate them. Romero-Calcerrada and Luque (2006) used an indicator species (*Picoides trydactilus*) for assessing the biodiversity of a forest of Finland, obtaining functions and habitat suitability maps of this species.

In addition, the problems with habitat vulnerability may be analysed using spatial data, at a landscape scale. Fuller *et al*. (2010) assess the threats to biodiversity from three areas in Malaysia including both protected and unprotected areas. They used a GIS database to evaluate and incorporate biodiversity threats with Fuzzy functions. Vimal *et al*. (2012) used the presence-absence of important species, large areas of high ecological value and landscape diversity to identify spatial patterns of ecological vulnerability.

A large number of studies use the habitat requirements and the habitat vulnerability of specific species to solve problems associated with species conservation in protected areas. These problems are usually solved using Spatial MCA with multitechniques combined with GIS, similar to Zoning.

Zoning

The issues regarding the planning of protected areas also follow a very defined profile; they solve virtually everything mainly through continuous techniques such as Heuristic Models or Integer Programming combined with GIS. The uncertainty is usually incorporated using simulation techniques, although some studies explicitly incorporate stochastic functions as constraints of the objective function.

The most important concern of these studies is the adequate representation of different species within spatial units that incorporate the degree of threat, vulnerability and continuity in the models, considering cost constraints. In recent years there has been a significant effort to model the spatial connectivity, which is incorporated into the models through nonlinear functions of great complexity (Liu *et al*., 2012; Moilanen, 2007; Moilanen and Arponen, 2011; Wood and Dragicevic, 2007).

3.3. Participation

The topics that incorporate a higher percentage of studies using participation are Land Use with 21.34 % followed by Management with 18.90 %. Moreover, participative Land Use papers highlight that 92.10 % of the studies focused on this topic (Table 2).

TABLE 2

Global and Topic Percentage of reviewed papers with participation

Topics	Number of papers	Global %	Topic %
Land Use	35	21.34	92.10
Management	31	18.90	53.45
Species	11	6.71	39.29
Zoning	6	3.66	15

Source: Own elaboration.

We found a strong dependence between participation and PAT ($p < 0.001$ Chi-square). These results suggest a strong tendency to incorporate stakeholders' preferences when solving problems related to land use and management issues in protected areas and to not include them in the other topics. This may be due to the fact that issues associated with the use of resources generate most of the conflicts.

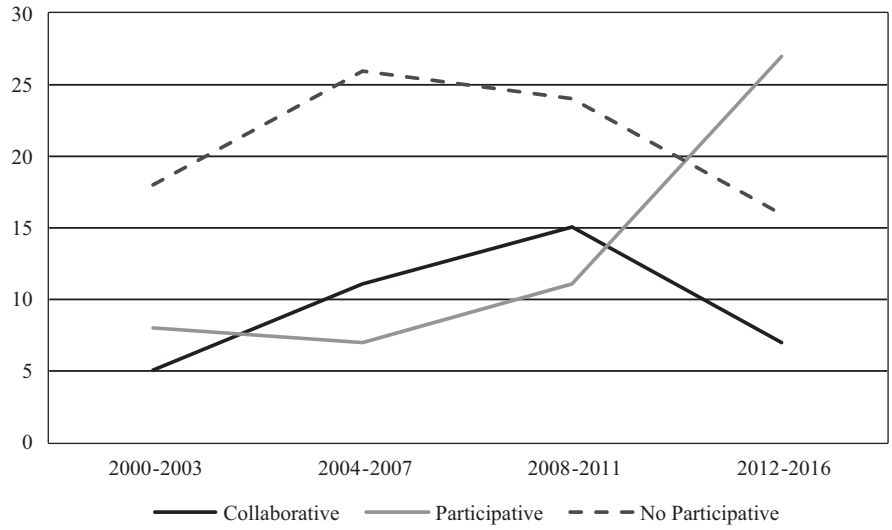
Figure 1 shows the evolution of the participation in the considered period according to the topics. It identifies a very significant increase in participation since 2008, considering all topics. This is due to the proliferation of participatory studies in Species since 2008. This increase is particularly seen in regard to the control of alien species between 2008-2011, though since 2011, the participation has increased in all topics. However, while participation without collaboration shows a greater percentage in the first two periods, the collaboration has increased in 2004-2007, but since 2008 it has reduced. This decrease in the level of collaboration could be due the fact that decision-making processes, with a high degree of collaboration, are very laborious and costly in both time and resources.

This increase in the collaborative processes in 2004-2011 is largely due to the development of innovative MCA techniques in collaborative decision making in the first decade of this century, for example, Deliberative Multi-Criteria Evaluation (DMCE) and Decision Analysis Interview (DAI). The pioneering research in using this type of methodology was carried out in Australia where Proctor and Dreschler (2003) use a DMCE to identify appropriate options for recreation in a vast area of 2.4 million ha, which includes several protected areas with different degrees of protection. The process employs a software with interactive support among participants and a Citizens Jury. Marttunen and Hamalainen (2008) use another participatory technique that implies a high degree of collaboration, the Decision Analysis Interview (DAI), using multi-criteria analysis. This paper develops a process of collaborative decision making to design a regulatory policy at a large watercourse. The main findings indicate the importance of special care in planning, design and preparation of the process and emphasize the importance of interactivity to ensure data consistency. On the other hand, interactivity generate transparency in the process and can increase stakeholders' confidence. Zendehdel *et al.* (2010), in Iran, introduced early collaboration in a deliberative process, using an intensity index (Social Rank Order of

Alternative Impacts, SROAI) that is maintained throughout the process. The aim is to ensure the consistency of the group's decision and ensure transparency. In addition, minority groups see their preferences represented in decision-making and all stakeholders adopt a greater willingness to reach agreements.

FIGURE 1

Evolution of participative MCDM methods in reviewed papers



Source: Own elaboration.

Since 2012, 64.10 % of the papers reviewed have used some type of participation. The results are interesting particularly the increase in participation when zoning protected areas.

Land use

The use of resources is the issue that generates the most relevant conflicts in protected areas. This may be one of the reasons why the use of participatory and collaborative techniques experienced such a big increase. 92.10 % of articles reviewed in this group include participatory techniques and 54.05 % include collaboration. This result reflects the need for solutions close to consensus that minimize conflicts of stakeholders on the use of natural resources.

Most of the studies that incorporate participatory techniques where developed in Northern European countries. Ananda (2007) and Ananda and Herath (2008) incorporate stakeholders' preferences to define land use in Finnish forests using AHP and

MAVT. Hiltunen *et al*. (2009) employ interactive software that uses heuristics models (MESTA) to support decision-making on sustainable forest management in Finland.

In the last few years there has been a tendency to use participatory techniques combined with GIS. Fitzimons *et al*. (2012) and Arciniegas *et al*. (2011) incorporate the preferences of the agents over spatial definitions of predefined criteria, in most cases with satellite data and expert opinion. Strager and Rosenberg (2006) also discussed the same problem in the Cacapon River watershed, Virginia, identifying the preferences before defining the maps with GIS. They analysed separately the preferences of "nonlocal" experts and of local stakeholders, finding significant differences.

Nordstrom *et al.* (2010) use GIS and MAVT to prioritize the use of a natural park in Sweden, and also incorporate stakeholders' preferences to define the criteria and alternatives, from the early stages of the decision problem.

Arciniegas *et al.* (2011) also use interactive GIS maps with a novel use of visualization techniques (Table Touch) as a support tool for discussion in a decision-making process on land use zoning in the Netherlands. However, these maps are designed based on expert judgment with stakeholder preferences incorporated later.

GIS has also been used in combination with collaborative techniques. Duke and Aull-Hyde (2002) and Mustajoki *et al*. (2011) incorporate deliberative techniques in decision-making processes on land use. The first study considers the preferences of the general population and the other two consider stakeholders' preferences and use deliberative techniques to elicit their preferences. Kazana *et al*. (2003) and Terra *et al*. (2014) are the only studies classified in this group that do not consider the preferences of the stakeholders to resolve problems about land use. These studies suggest a high heterogeneity in the employed techniques and also in the way to incorporate stakeholders' preferences into the decision making process.

The studies related to water use are characterized by a high degree of participation and collaboration, often using collaborative techniques such as Decision Analysis Interviews (DAI) and Deliberative Multi-Criteria Evaluation (DMCE). The only research that does not include participative techniques is and Harmancioglu (2010). However, Ananda and Proctor (2013) evaluate the scope of collaborative watershed management and planning at a wetland system in northern Australia and they analyse the high transaction costs related with collaborative initiatives. They note the importance of the institutional configurations that support the decision-making processes as a key to control this problem.

Management

Most of the models that consider the preferences of stakeholders are included in Tourism and Strategies. This may be due to two reasons: firstly, tourism is a major source of short-term resources in protected areas and secondly, the management of resources associated with the use of land is one of the largest problems generating conflict, exacerbated in protected areas by restrictions arising from formal protection.

Participation is included in the 53.45 % of the papers included in Management, with the 19.30 % belonging to collaborative techniques. They have been used in theoretical models concerning design and evaluation of macro-policies in recent years. Oikonomou *et al*. (2011) compare different scales in the social assessment with stakeholders and integrate the evaluation of ecosystem services in a protected area in Greece. Another example is the evaluation of the social acceptability of three management plans in a National Park on Mount Kilimanjaro developed by Kijazi and Kant (2011).

Also Hjorstø (2004) and Zendehdel *et al*. (2010) use participatory techniques. These studies use various techniques such as Soft Systems, visualization and outranking techniques.

Species

Of the articles reviewed that include Species as a topic, 39.29 % contain participatory techniques and 17.86 % include collaboration. These percentages refer to studies on alien species control and reflect the need to include the views of stakeholders collaboratively when considering problems with social and economic impacts. These studies indicate the importance of including the preferences of local populations to make effective management plans.

Zoning

Between 2012-2016, 90.63 % of the reviewed articles on Zoning exclude participatory techniques, therefore only two of them considered the preferences of the stakeholders. Sharifi *et al*. (2002) use collaborative techniques to integrate the preferences of stakeholders to solve problems with illegal settlements in the Tunari National Park in Bolivia. Bojórquez-Tapia *et al*. (2004) choose AHP and MAVT to design a National Park in Mexico, integrating stakeholders' preferences collaboratively to define the boundaries and zoning the Sierra San Pedro Mártir National Park. This research is based on the approach "Land Suitability Assessment" (LSA), which considers the interests of stakeholders in defining the appropriate use of the land. These two analyses use GIS.

Nevertheless, we have found a different trend in the most recent period. There has been a decrease of research related with zoning, however 42.86 % of the papers reviewed include the participation of stakeholders. Zhang *et al*. (2013) integrate a strong level of participation when zoning the Meili Snow Mountain National Park (China) using GIS and Fuzzy methods. Lu *et al*. (2014) use Multi-criteria spatial analysis based on a scenario analysis to identify the priority protection areas in Taiwan. They include the stakeholders′ opinions using in-depth interviews with experts and stakeholders early in the process.

4. Conclusions

The use of multi-criteria techniques in protected areas in recent years has been important mainly to solve problems regarding "how to manage" rather than "where to manage." Multi-criteria techniques have been used in all topic areas. However, they have been most commonly used to analyse decision making related to land use, followed by zoning and problem management.

There seems to be a clear and upward trend in the use of participative, multi-criteria methods in protected areas. Collaborative methods increased very fast at first, but in the last few years their use has decreased, strengthening MCDM techniques with a slighter level of participation.

We have identified two groups with marked differences in the use of multi-criteria and participatory techniques. Species conservation and protected area zoning generally use GIS technology and continuous methods, highly structured and highly complex and do not consider the interests of stakeholders. However, the issues that have an economic and social impact such as the problems concerning the control of alien species, incorporate participatory techniques with a high degree of collaboration, little structure and high iterativity. On the other hand, the problems of management and land use employ discrete methods, used with an increasing degree of participation.

Integrating participation in multi-criteria analysis seems to be associated with the use of techniques that are easy to understand and use, requiring no specific knowledge, which are flexible and which promote interactivity. Furthermore, the concern to integrate the uncertainty due to the imprecision of individual preferences becomes important, with a strong development of Fuzzy Logic based models, in recent years. The need to adapt the processes of decision making not only to the characteristics of the problem to be solved but also to participants seems to be of paramount importance.

The inclusion of GIS technology in virtually all studies done in the last decade on zoning and in recent years on land use is very important. The combination of GIS technology with collaborative decision making becomes very useful in solving problems with land use. These studies can serve as a basis for developing participatory models for problem solving in species conservation and in protected area design. In fact, the use of Spatial MCA has significantly increased to help manage all types of problems in protected areas.

The collaboration has been integrated, mainly through Soft Systems, to solve problems with a major social impact, as with the problems of water use, alien species control and some theoretical models on management. The enormous amount of resources and time required does not allow an easy application and it would be advisable to find a compromise between the availability of time and resources and the degree of collaboration in the process of decision making.

Finally, we recommended the development of empirical studies on valuable and vulnerable ecosystems with a high ecological value and with strong conflicts bet-

ween stakeholders, applying participative MCDM to improve governance. In terms of practice, MCDM must adopt a participatory posture with a balanced level of participation, to ensure the voice of the stakeholders is heard in the decision-making processes, with flexible and operational models.

References

Ananda, J. (2007). "Implementing participatory decision making in forest planning". *Environmental Management*, 39(4): 534-544. http://doi.org/bdrq4n.

Ananda, J. and Herath, G. (2008). "Multi-attribute preference modelling and regional land-use planning". *Ecological Economics*, 65(2): 325-335. http://doi.org/fpgpwq.

Ananda, J. and Herath, G. (2009). "A critical review of multi-criteria decision making methods with special reference to forest management and planning". Ecological Economics, 68(10): 2535-2548. http://doi.org/fqnc5q.

Ananda, J. and Proctor, W. (2013). "Collaborative approaches to water management and planning: An institutional perspective". *Ecological Economics*, 86: 97-106. http://doi.org/btbp.

Arabatzis, G. and Grigoroudis, E. (2010). "Visitors' satisfaction, perceptions and gap analysis: The case of Dadia–Lefkimi–Souflion National Park". *Forest Policy and Economics*, 12(3): 163-172. http://doi.org/bhgvmv.

Arciniegas, G., Janssen, R. and Omtzigt, N. (2011). "Map-based multicriteria analysis to support interactive land use allocation". *International Journal of Geographical Information Science*, 25(12): 1931-1947. http://doi.org/b52fxj.

Belton, V. and Stewart, T. (2002). *Multiple criteria decision analysis: an integrated approach*. Springer Science and Business Media.

Bertomeu, M. and Romero, C. (2001). "Managing forest biodiversity: a zero-one goal programming approach". *Agricultural Systems*, 68: 197-213. http://doi.org/cs3tq7.

Bojórquez-Tapia, L.A., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., Solares, M.J. and Cruz-Bello, G. (2004). "Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir National Park, Mexico". *Biological Conservation*, 117(2): 111-126. http://doi.org/fmn6rt.

Davis, F.W., Costello, C. and Stoms, D. (2006). "Efficient conservation in a utility-maximization framework". *Ecology and Society*, 11(1): 33.

Dearden, P., Bennett, M. and Johnston, J. (2005). "Trends in global protected area governance, 1992–2002". *Environmental Management*, 36(1): 89-100. http://doi.org/btk5zj.

Dhar, A., Ruprecht, H. and Vacik, H. (2008). "Population viability risk management (PVRM) for in situ management of endangered tree species. A case study on a Taxus baccata L. population". *Forest Ecology and Management*, 255(7): 2835-2845. http://doi.org/cfxns2.

Diaz-Balteiro, L. and Romero, C. (2008). "Making forestry decisions with multiple criteria: A review and an assessment". *Forest Ecology and Management*, 255(8): 3222-3241. http://doi.org/b9jqth.

Duke, J.M. and Aull-Hyde, R. (2002). "Identifying public preferences for land preservation using the analytic hierarchy process". *Ecological Economics*, 42(1): 131-145. http://doi.org/dkbqdw.

Estévez, R.A. and Gelcich, S. (2015). "Participative multi-criteria decision analysis in marine management and conservation: Research progress and the challenge of integrating value judgments and uncertainty". *Marine Policy*, 61: 1-7. http://doi.org/btbq.

Greco, S., Figueira, J. and Ehrgott, M. (2005). *Multiple criteria decision analysis. Springer's International series*. Springer, New York.

Fitzsimons, J., Pearson, C.J., Lawson, C. and Hill, M.J. (2012). "Evaluation of land-use planning in greenbelts based on intrinsic characteristics and stakeholder values". *Landscape and Urban Planning*, 106(1): 23-34. http://doi.org/btbr.

Fuller, D.O., Meijaard, E.M., Christy, L. and Jessup, T.C. (2010). "Spatial assessment of threats to biodiversity within East Kalimantan, Indonesia". *Applied Geography*, 30(3): 416-425. http://doi.org/b44tn9.

Gómez-Navarro, T., García-Melón, M. and Acuna-Dutra, S. (2010). "An ANP approach to assess the sustainability of tourist strategies for the coastal national parks of Venezuela". *Technological and Economic Development of Economy*, 4: 672-689. http://doi.org/b44tn9.

Graham, J., Amos, B. and Plumptre, T.W. (2003). *Governance principles for protected areas in the 21st century*. Proceeedings from the *Fifth World Parks Congress* in Institute on Governance (pp.1-2), Durban, South Africa.

Hajkowicz, S.A. (2008). "Supporting multi-stakeholder environmental decisions". *Journal of Environmental Management*, 88(4): 607-614. http://doi.org/c933cd.

Hajkowicz, S. (2009). "Cutting the cake: Supporting environmental fund allocation decisions". *Journal of Environmental Management*, 90(8): 2737-2745. http://doi.org/fhsfsq.

Herath, G. (2004). "Incorporating community objectives in improved wetland management: The use of the analytic hierarchy process". *Journal of Environmental Management,* 70(3): 263-273. http://doi.org/fh2r76.

Hiltunen, V., Kurttila, M., Leskinen, P., Pasanen, K. and Pykäläinen, J. (2009). "Mesta: An internet-based decision-support application for participatory strategic-level natural resources planning". *Forest Policy and Economics*, 11(1): 1-9. http://doi.org/c49j5v.

Hjortsø, C.N. (2004). "Enhancing public participation in natural resource management using Soft OR-an application of strategic option development and analysis in tactical forest planning". *European Journal of Operational Research*, 152(3): 667-683. http://doi.org/b46nq3.

Huang, I.B., Keisler, J. and Linkov, I. (2011). "Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends". *Science of the Total Environment*, 409(19): 3578-3594. http://doi.org/cm6qzj.

Kazana, V., Fawcett, R.H. and Mutch, W.E. (2003). "A decision support modelling framework for multiple use forest management: The Queen Elizabeth Forest case study in Scotland". *European Journal of Operational Research*, 148(1): 102-115. http://doi.org/d6z5t4.

Kijazi, M.H. and Kant, S. (2011). "Social acceptability of alternative forest regimes in Mount Kilimanjaro, Tanzania, using stakeholder attitudes as metrics of uncertainty". *Forest Policy and Economics*, 13(4): 242-257. http://doi.org/fj4bz5.

Kiker, G.A., Bridges, T.S., Varghese, A., Seager, T.P. and Linkov, I. (2005). "Application of multicriteria decision analysis in environmental decision making". *Integrated Environmental Assessment and Management*, 1(2): 95-108. http://doi.org/fv6jgn.

Kurttila, M., Pukkala, T. and Loikkanen, J. (2002). "The performance of alternative spatial objective types in forest planning calculations: A case for flying squirrel and moose". *Forest Ecology and Management*, 166(1): 245-260. http://doi.org/d7zxq7.

Kurttila, M., Pykäläinen, J. and Leskinen, P. (2006). "Defining the forest landowner's utility-loss compensative subsidy level for a biodiversity object". *European Journal of Forest Research*, 125(1): 67-78. http://doi.org/ctz6s6.

Liu, X., Lao, C., Li, X., Liu, Y. and Chen, Y. (2012). "An integrated approach of remote sensing, GIS and swarm intelligence for zoning protected ecological areas". *Landscape Ecology*, 27(3): 447-463. http://doi.org/ft236n.

Lu, S.Y., Shen, C.H. and Chiau, W.Y. (2014). "Zoning strategies for marine protected areas in Taiwan: Case study of Gueishan Island in Yilan County, Taiwan". *Marine Policy*, 48: 21-29. http://doi.org/btbs.

Marttunen, M. and Hämäläinen, R.P. (2008). "The decision analysis interview approach in the collaborative management of a large regulated water course". *Environmental Management*, 42(6): 1026-1042. http://doi.org/d35bdj.

Mendoza, G.A. and Prabhu, R. (2000). "Development of a methodology for selecting criteria and indicators of sustainable forest management: a case study on participatory assessment". *Environmental Management*, 26(6): 659-673. http://doi.org/b85bs7.

Mendoza, G.A. and Martins, H. (2006). "Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms". *Forest Ecology and Management*, 230(1): 1-22. http://doi.org/c5bnmf.

Moffett, A. and Sarkar, S. (2006). "Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations". *Diversity and Distributions*, 12(2): 125-137. http://doi.org/c69zts.

Moilanen, A. (2007). "Landscape zonation, benefit functions and target-based planning: Unifying reserve selection strategies". *Biological Conservation*, 134(4): 571-579. http://doi.org/chc5dq.

Moilanen, A. and Arponen, A. (2011). "Setting conservation targets under budgetary constraints". *Biological Conservation*, 144(1): 650-653. http://doi.org/cd6gmg.

Mustajoki, J., Saarikoski, H., Marttunen, M., Ahtikoski, A., Hallikainen, V., Helle, T. and Varmola, M. (2011). "Use of decision analysis interviews to support the sustainable use of the forests in Finnish Upper Lapland". *Journal of Environmental Management*, 92(6): 1550-1563. http://doi.org/ccxh63.

Nordström, E.M., Eriksson, L.O. and Öhman, K. (2010). "Integrating multiple criteria decision analysis in participatory forest planning: Experience from a case study in northern Sweden". *Forest Policy and Economics*, 12(8): 562-574. http://doi.org/ft9h5k.

Oikonomou, V., Dimitrakopoulos, P.G. and Troumbis, A.Y. (2011). "Incorporating ecosystem function concept in environmental planning and decision making by means of multi-criteria evaluation: the case-study of Kalloni, Lesbos, Greece". *Environmental Management*, 47(1): 77-92. http://doi.org/dx74jq.

Ostrom, E. (2000). "Collective action and the evolution of social norms". *Journal of Natural Resources Policy Research*, 6(4): 235-252. http://doi.org/btbt.

Pasqualini, V., Oberti, P., Vigetta, S., Riffard, O., Panaïotis, C., Cannac, M. and Ferrat, L. (2011). "A GIS-based multicriteria evaluation for aiding risk management Pinus pinaster Ait. forests: A case study in Corsican Island, Western Mediterranean region". *Environmental Management*, 48(1): 38-56. http://doi.org/ff5rvv.

Pavlikakis, G.E. and Tsihrintzis, V.A. (2003). "Integrating humans in ecosystem management using multi-criteria decision making". *JAWRA Journal of the American Water Resources Association,* 39(2): 277-288. http://doi.org/ck33dk.

Prato, T. (1999). "Multiple attribute decision analysis for ecosystem management". *Ecological Economics*, 30(2): 207-222. http://doi.org/cx28nt.

Prato, T. (2000). "Multiple attribute evaluation of landscape management". *Journal of Environmental Management,* 60(4): 325-337. http://doi.org/dr6b3w.

Proctor, W. and Drechsler, M. (2003). "Deliberative multi-criteria evaluation: a case study of recreation and tourism options in Victoria, Australia". In *European Society for Ecological Economics, Frontiers 2 Conference,* Tenerife, Spain, pp. 11-15.

Proctor, W. and Qureshi, E. (2005). "Multi-criteria evaluation revisited". In *Proceedings of the Australia New Zealand Society for Ecological Economics Conference*, Massey University, Palmerston North, New Zealand, pp. 11-13.

Reza, M.I.H., Abdullah, S.A., Nor, S.B.M. and Ismail, M.H. (2013). "Integrating GIS and expert judgment in a multi-criteria analysis to map and develop a habitat suitability index: A case study of large mammals on the Malayan Peninsula". *Ecological Indicators*, 34: 149-158. http://doi.org/btbv.

Riccioli, F., Fratini, R., Boncinelli, F., El Asmar, T., El Asmar, J.P. and Casini, L. (2016). "Spatial analysis of selected biodiversity features in protected areas: a case study in Tuscany region". *Land Use Policy*, 57: 540-554. http://doi.org/btbw.

Romero-Calcerrada, R. and Luque, S. (2006). "Habitat quality assessment using weights-of-evidence based GIS modelling: The case of Picoides tridactylus as species indicator of the biodiversity value of the Finnish forest". *Ecological Modelling,* 196(1): 62-76. http://doi.org/cdw9xk.

Rudolphi, W. and Haider, W. (2003). "Visitor management and ecological integrity: one example of an integrated management approach using Decision Analysis". *Journal for Nature Conservation*, 11(4): 346-354. http://doi.org/dmw572.

Schmoldt, D.L. and Peterson, D.L. (2001). "Strategic and tactical planning for managing national park resources". In Schmoldt, D., Kangas, J., Mendoza, G.A., Pesonen, M. (Eds.): *The analytic hierarchy process in natural resource and environmental decision making* (pp. 67-79). Springer, Netherlands.

Sharifi, M.A., Van den Toorn, W., Rico, A. and Emmanuel, M. (2002). "Application of GIS and multicriteria evaluation in locating sustainable boundary between the Tunari National Park and Cochabamba City (Bolivia)". *Journal of Multi-Criteria Decision Analysis*, 11(3): 151-164. http://doi.org/cp3bkx.

Store, R. and Kangas, J. (2001). "Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling". *Landscape and Urban Planning,* 55(2): 79-93. http://doi.org/b2f4n8.

Strager, M.P. and Rosenberger, R.S. (2006). "Incorporating stakeholder preferences for land conservation: Weights and measures in spatial MCA". *Ecological Economics,* 58(1): 79-92. http://doi.org/cpsvnq.

Terra, T.N., dos Santos, R.F. and Costa, D.C. (2014). "Land use changes in protected areas and their future: The legal effectiveness of landscape protection". *Land Use Policy*, 38: 378-387. http://doi.org/btbx.

Tzionas, P., Ioannidou, I.A. and Paraskevopoulos, S. (2004). "A hierarchical fuzzy decision support system for the environmental rehabilitation of Lake Koronia, Greece". *Environmental Management*, 34(2): 245-260. http://doi.org/dxmzts.

United Nations Development Programme. (1999). *Human development report 1999*. Oxford University Press, New York.

Vacik, H., Kurttila, M., Hujala, T., Khadka, C., Haara, A., Pykäläinen, J., Honkakoski, P., Wolfslhener, B. and Tikkanen, J. (2014). "Evaluating collaborative planning methods supporting programme-based planning in natural resource management". *Journal of Environmental Management*, 144: 304-315. http://doi.org/btbz.

Vimal, R., Pluvinet, P., Sacca, C., Mazagol, P.O., Etlicher, B. and Thompson, J.D. (2012). "Exploring spatial patterns of vulnerability for diverse biodiversity descriptors in regional conservation planning". *Journal of Environmental Management,* 95(1): 9-16. http://doi.org/c9w3sj.

Walter, M., Tomás, S.L., Munda, G. and Larrea, C. (2016). "A social multi-criteria evaluation approach to assess extractive and non-extractive scenarios in Ecuador: Intag case study". *Land Use Policy*, 57: 444-458. http://doi.org/btb2.

Wolfslehner, B. and Vacik, H. (2008). "Evaluating sustainable forest management strategies with the analytic network process in a pressure-state-response framework". *Journal of Environmental Management*, 88(1): 1-10. http://doi.org/c2zjxk.

Wood, L.J. and Dragicevic, S. (2007). "GIS-based multicriteria evaluation and fuzzy sets to identify priority sites for marine protection". *Biodiversity and Conservation*, 16(9): 2539-2558. http://doi.org/bj3vq4.

Yilmaz, B. and Harmancioglu, N.B. (2010). "Multi-criteria decision making for water resource management: A case study of the Gediz River Basin, Turkey". *Water SA*, 36(5): 563-576.

Young, J.A., van Manen, F.T. and Thatcher, C.A. (2011). "Geographic profiling to assess the risk of rare plant poaching in natural areas". *Environmental Management*, 48(3): 577-587. http://doi.org/d6w33x.

Zendehdel, K., Rademaker, M., De Baets, B. and Van Huylenbroeck, G. (2010). "Environmental decision making with conflicting social groups: A case study of the Lar rangeland in Iran". *Journal of Arid Environments*, 74(3): 394-402. http://doi.org/c886rf.

Zhang, Z., Sherman, R., Yang, Z., Wu, R., Wang, W., Yin, M., Yang, G. and Ou, X. (2013). "Integrating a participatory process with a GIS-based multi-criteria decision analysis for protected area zoning in China". *Journal for Nature Conservation*, 21(4): 225-240. http://doi.org/btb3.