Identifying a preservation zone using multi–criteria decision analysis

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Abstract
Identifying a preservation zone using multi–criteria decision analysis.— Zoning of a protected area is an approach to partition landscape into various land use units. The management of these landscape units can reduce conflicts caused by human activities. Tandoreh National Park is one of the most biologically diverse, protected areas in Iran. Although the area is generally designed to protect biodiversity, there are many conflicts between biodiversity conservation and human activities. For instance, the area is highly controversial and has been considered as an impediment to local economic development, such as tourism, grazing, road construction, and cultivation. In order to reduce human conflicts with biodiversity conservation in Tandoreh National Park, safe zones need to be established and human activities need to be moved out of the zones. In this study we used a systematic methodology to integrate a participatory process with Geographic Information Systems (GIS) using a multi–criteria decision analysis (MCDA) technique to guide a zoning scheme for the Tandoreh National Park, Iran. Our results show that the northern and eastern parts of the Tandoreh National Park that were close to rural areas and farmlands returned less desirability for selection as a preservation area. Rocky Mountains were the most important and most destructed areas and abandoned plains were the least important criteria for preservation in the area. Furthermore, the results reveal that the land properties were considered to be important for protection based on the obtained preservation zone. However, these parts are not fully covered under the current protection plans for the area.

Key words: Tandoreh National Park, Preservation zone, MCDA, Zoning

Resumen
Establecimiento de una zona de conservación utilizando el análisis de decisiones basadas en criterios múltiples.— La zonificación de una área protegida es un instrumento para dividir un paisaje en varias unidades de uso de la tierra. La gestión de estas unidades paisajísticas puede reducir los conflictos provocados por las actividades humanas. El parque nacional de Tandoreh es una de las áreas protegidas de Irán más diversas desde el punto de vista biológico. Si bien en general la zona está concebida para proteger la biodiversidad, existen numerosos conflictos entre la conservación de la misma y las actividades humanas. Por ejemplo, la zona ha suscitado muchas controversias y se ha considerado un impedimento para el desarrollo económico local, como el turismo, el pastoreo, la construcción de carreteras y el cultivo. Para reducir los conflictos entre las personas y la conservación de la biodiversidad en el parque nacional de Tandoreh, es preciso establecer zonas seguras y desplazar las actividades humanas fuera de ellas. Con vistas a establecer un plan de zonificación en el parque nacional de Tandoreh, en Irán, en el presente estudio hemos utilizado una metodología sistemática (SIG) que integra un proceso participativo con sistemas de información geográfica mediante el análisis de decisiones basadas en criterios múltiples (MCDA). Los resultados obtenidos ponen de manifiesto que las zonas septentrionales y orientales del parque situadas cerca de zonas rurales y tierras agrícolas resultaron ser menos adecuadas para establecer una zona de conservación. Las montañas rocosas fueron las zonas más importantes, mientras que las zonas más destruidas y las llanuras abandonadas constituían los criterios menos importantes para la conservación en la zona. Además, los resultados revelan que las tierras de propiedad son importantes para la protección dada el área de conservación obtenida. No obstante, estas partes no están totalmente cubiertas por los planes vigentes de protección de la zona.

Palabras clave: Parque nacional de Tandoreh, Área de conservación, MCDA, Zonificación

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Introduction

The zoning of protected area is an approach to reduce conflict by designating areas into different management and land use units (Hjortsø et al., 2006; Geneletti & van Duren, 2008; Zhang et al., 2013). Identification and delineation of management zones is necessary for effective management of protected areas. Detailed strategies and activities for different zones can only be defined after management zones are delineated. Multiple land characteristics can be evaluated using zoning, a complex decision–making process (Zhang et al., 2013). Typical zoning schemes include a preservation zone with a high level of protection. This kind of zoning can largely exclude human activities surrounded by zones that allow for increasing levels of human activities. Most protected areas in developing countries are suffering from the lack of zoning (Sabatini et al., 2007; Hull et al., 2011), which has now become a challenge for governments and land managers.

The evaluation of multiple land attributes based on multiple objectives that inherently involve conflicts is necessary for decision–making regarding land use zoning. Multi–criteria decision analysis (MCDA) has been used to support complex decision making constrained by multiple conflicting objectives and criteria (Massam, 1988). The field of multi–criteria decision aiding (MCDA) has been developed since the 1960s. Methodological work focused on discreet methods has been carried out by Roy (Roy & Vincke, 1981; Roy, 1985, 1991) who took the lead in using multi–criteria assessment with the ELECTRE family of methods. The PROMETHEE method has been created by Brans (Brans et al., 1986). A REGIME method has been developed by Hinloopen & Nijkamp (1990), while the DEFINITE package has been developed by Janssen (Janssen, 1993). The NAIADE method has been developed by Munda (1995, 2008). Figueira et al. (2005) presented a survey of multi–criteria analysis methods. MCDA has the potential to be applied to a range of regional issues, such as. industrial development, waste management, and renewable energy. Moreover, the issues of sustainability assessment on the macro scale have been analyzed using MCDA methods. Guitouni & Martel (1998) offered an extensive survey of MCDA methods. Furthermore, a review of several MCDA sustainability applications was undertaken by De Montis et al. (2004). A good overview of existing approaches to multi–criteria evaluation of biodiversity in conservation planning has been done by Moffet & Sarkar (2008). The classical goal of finding an optimal solution is subject to a set of constraints that are characteristic of operations research, differing from the new paradigm in MCDA. The primary purpose of analysis in the MCDA paradigm is to search for a compromise solution that satisfies the decision maker, rather than some illusory optimum (Guitouni & Martel, 1998; Shmelev, 2012).

MCDA with geographic information systems (GIS) has been considered an important improvement to the conventional map overlay approach (Malczewski, 1999; Eastman, 2001; Malczewski, 2006; Hajkowicz, 2008; Greene et al., 2010). The method has been widely applied to land management planning (Phua & Minowa, 2005; Chang et al., 2008; Briceño–Elizondo et al., 2008; Dudley, 2008) and protected area zoning (Hjortsø et al., 2006; Portman, 2007; Geneletti & van Duren, 2008; Hull et al., 2011; Zhang et al., 2013).

Development and implementation of zoning methodology for protected areas is a critical strategy to enhance the appropriate conservation system. The lack of zoning in protected areas in Iran can stop many conservations activities, which may cause irreversible damage to local biodiversity. Therefore, a practical quantitative method needs to be developed to design zoning for protected areas in Iran. This zoning is easy to implement and is transferable to various national parks and protected areas.

This study aimed to evaluate the utility of MCDA for zoning the Tandoreh National Park in Iran. Specifically, we tried to illustrate how an MCDA framework can identify the preservation zones of a protected area.

Material and methods

Study area

Tandoreh National Park is located in north–east Iran (58º 33' – 58º 54' N and 37º 19' – 37º 33' E) near the Turkmenistan border. It covers approximately 44,848 ha and includes the national park and protected area (fig. 1). In view of the lack of river flows, springs are the main water resource in this area. Tandoreh National Park also has some waterways and streams, but there is no continuous flow in its stream bed all year round due to lack of rain and snow falls in the area. The park has a wide diversity of plants, encompassing 373 species from 60 families. The study area includes part of the highlands, hills and mountains of north Khorasan province. The existence of high mountains and deep valleys in Tandore National Park creates good habitats for mountainous wildlife. Five of seven feline species in Iran live in this area, such as the Persian leopard, *Panther pardus saxicolor*, the jungle cat, *Felis chaus*, the Pallas' cat, *Felis manual*, and the Eurasian lynx, *Lynx lynx*. Tandore National Park is one of the best habitats for Persian leopards in Iran. A total of 134 leopards were observed in the area in year 1991 and 60 in 2008. From the wild ungulates in the area, special mention is given to wild goats that live in herds of up to 100–150 in the highlands and wild sheep, *Ovis orientalis arkali*, that are the purest race of this species in Iran. Wolves can be observed in groups of two or five in the lowlands. The other mammals in this park are red fox, jackal, beech marten, hyena, and rodents such as pica. Birds can be seen in the lowlands, valleys, and near springs. *Gypaetus barbatus,* Eurasian griffon and Pheasanidae are considered endangered species in the park.

Tandoreh National Park is a good example of tradeoffs between achieving biodiversity and human activities. The main disturbance in the area is grazing, which has a high negative effect on vegetation. The area was used as a pastureland before it was designated as a national park. We still can see gra-

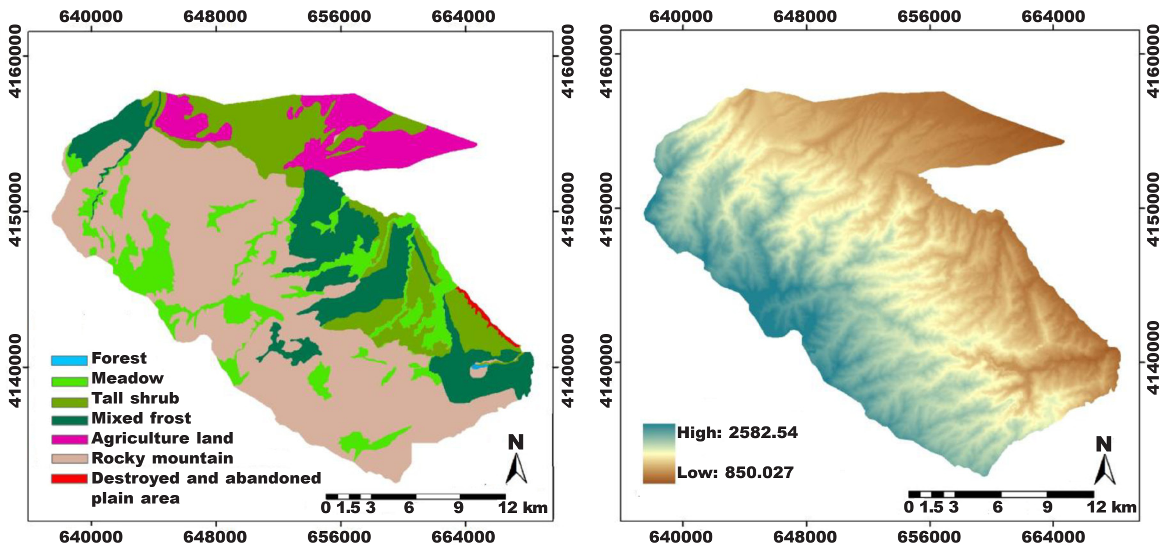

Fig. 1. Land cover map (left) and digital elevation map (right) of the study area.

Fig. 1. Mapa de la cobertura terrestre (izquierda) y mapa digital de elevación (derecha) de la zona de estudio.

zing in the park, but with less intensity. The other disturbances in the national parks are rural areas and roads that lead into or around the park. In this study we used three ways to show the conflict between human development and conservation goals: (1) the areas under high grazing were entered into the model as unsuitable areas for protection; (2) rural areas, roads and a 2 km buffer area around them have been removed from the model; and (3) rural areas and roads were used in the models as indexes with negative effects on the safe zone.

Defining the criteria

Semi–structured interviews and participatory meetings were designed to elicit knowledge, point of view, understandings, interpretations, and experiences of different stakeholders and academic experts in relation to the preservation zone. Criteria were identified according to the interviews and meetings. Table 1 shows criteria impacting the preservation zone. Although endangered species are included as important targets, the data for this kind of species are limited. This is especially true for the animals for whom knowledge of their their population size and distribution is poor. Ecologists and conservationists believe the habitat of endangered species is an essential criteria for survival. Therefore, in this study we used the map of habitat type rather than the distribution map of endangered species.

Selecting criteria

We used the Delphi method to select the correct criteria. Delphi is a systematic and interactive method which relies on a panel of independent experts (Ye et al., 2006; Guo, 2007). It is based on the principle that a structured group of experts achieve more accurate forecasts than unstructured groups or individuals (Rowe & Wright, 2001). The carefully selected experts answered questionnaires for criteria selection to evaluate preservation zone in three steps. After each step, the summaries of the experts' selection from the previous round and the reasons they provided for their judgments were fed back to the experts. The range of selected criteria decreased during this process and the group converged towards the 'appropriate' criteria. Finally, the process was ended after pre–defined stop criteria (*e.g.*, number of rounds, achievement of consensus, and stability of results).

Weighting criteria

To obtain the important weights for each criterion, we used the analytic network process (ANP) approach to rank the criteria with respect to the objective. Many studies have used this method to determine the weight of a criterion (Mohanty et al., 2005; Ramik, 2006; Dagdeviren et al., 2008; Aznar et al., 2010; Catron et al., 2013; Tavana et al., 2013; Yeh & Huang, 2014; Tadić et al., 2014). The ANP method is an improved version of the AHP method and it is more accurate for many complicated models using many criteria feedback and interrelations among criteria. It evaluates all relationships systematically by adding potential interactions, interdependences, and feedbacks in the decision–making system. The powerful side of this method is that it approaches a decision–making problem involving many complicated relationships in a simple way. This technique not only enables pair–wise comparisons of the sub–criteria under main criteria, but also allows

Tabla 1. Criteria and their weights for preservation.

Tabla 1. Criterios para la conservación y sus pesos.

Factors	Descriptions	Weights
Sources of disturbance	For the success of conservation actions, a key factor is the distance from sources of disturbance (Valente & Vettorazzi, 2008)	
Village	Rural areas are not located inside a national park However, four villages near the park have negative environmental effects due to the agricultural activities	0.131
Road	The roads inside the park are trails that are used for walking and ecotourism purpose	0.071
Agriculture land	13% of the park area is agriculture land	0.070
Destroyed and abandoned	These places are destroyed by tourists 0.4% of the park area is damaged and plains are abandoned	0.001
Natural variables		
Slope	Higher slops are more sensitive to disturbance	0.055
Altitude	Higher elevation areas are less accessible with fewer disturbances	0.024
Springs	Springs have an ecological importance, allowing movement of fauna and contributing to dispersion of biota (Eastman, 2001)	0.073
Species habitat	Habitat species are critical for conservation	
Rocky mountain	This area is habitat to *Panthera pardus*, *Capra aegagrus* and *Ovis orientalis vignei* 41% of the park's area is rocky mountain	0.190
Meadow	This area is habitat to *Vipera ammodytes* and *Ophisaurus apodus* The 11.5% of the park area is meadow	0.104
Tall shrub	This area is habitat to *Testudo graeca* 16% of the park area is tall shrub	0.099
Forest	This area is habitat to many birds such as *Parus major*, *Upupa epops*, *Merops apiaster*, *Otus scops*, *Cuculus canorus* More than 80 bird species live in this habitat 0.1% of the park area is forest	0.092
Mixed forest	This area is habitat to *Ochotona rufescens* and *Spermophilus fulvus* 18% of the park area is mixed forest	0.091

the decision–maker to independently compare all the sub–criteria within interactions. Figure 2 shows a comparison of AHP and ANP methods. Decision–making problems that occur in firms cannot be explained by hierarchical structure alone. The criteria and alternatives in a problem can lie in interactions. Under such circumstances, a complicated analysis would be necessary to determine the weights of all the components. The ANP method is used for such problems and it is based on the same pair–wise comparisons as the AHP (Sevkli et al., 2012). For pair–wise comparisons, the 1–9 scale of Saaty (1980) is used as shown in Saaty (2008, table 1). In the ANP model, all the components and relationships are defined and the relationships are determined as two–way interactions. In the model, the network structure is used and all the relationships in a cluster (namely, relationships among sub–criteria in a cluster and relationships between sub–criteria under different clusters) are considered. Because of the involvement of relationships among sub–criteria under a cluster and interactions among different criteria, the ANP method is useful to obtain more accurate and more effective results such as those in a complex and crucial decision–making problem. The ANP method has three

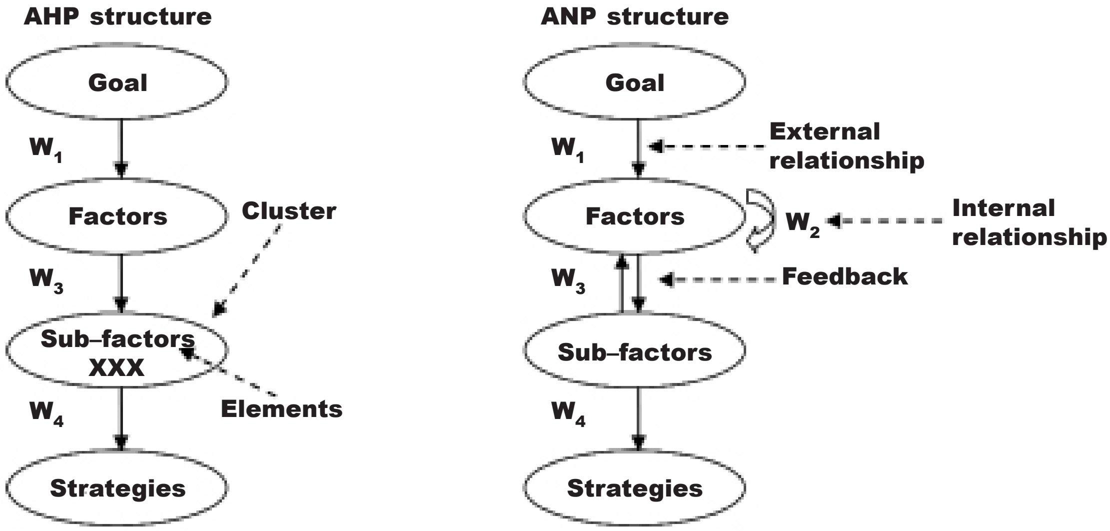

Fig. 2. A high–level comparison of AHP and ANP (W_1 is a vector that represents the impact of the goal, namely, selecting the best strategy according to SWOT factors, W_2 is a matrix that represents the inner dependence of the SWOT factors, W_3 is a matrix that denotes the impact of the SWOT factor on each of the SWOT sub–factors, and W_4 is a matrix that denotes the impact of the SWOT sub–factors on each of the strategies).

Fig. 2. Comparación de alto nivel entre los procesos analítico jerárquico (AHP) y analítico en red (ANP) (donde W_1 es un vector que representa los efectos del objetivo, esto es, seleccionar la mejor estrategia de acuerdo con los factores de DAFO, W_2 es una matriz que representa la dependencia interna de los factores de DAFO, W_3 es una matriz que indica los efectos del factor de DAFO en cada uno de los subfactores de DAFO y W_4 es una matriz que indica los efectos de los subfactores de DAFO en cada una de las estrategias).

matrix analyses: super matrix, weighted super matrix, and limit matrix. The super matrix provides relative importance of all the components and the weighted super matrix is used to determine the value that is obtained by the super matrix values and the value of each cluster. In the limit matrix, the constant values of each value are determined by taking the necessary limit of the weighted super matrix. The results of the decision–making problem are gained from the limit matrix scores. It is important to value the criteria and alternatives of the experts and experienced people to achieve more consistent and reliable results (Saaty, 1999, 2003). In our study, the relative importance weights were calculated from freely available software for academic purposes known as Super Decisions Software (http://www.superdecisions.com).

Determining preservation zone

A suitability evaluation using the GIS–based MCDA has been developed as a tool to support decision–making systems for management policies and strategies (Malczewski & Jackson, 2000; Geertman & Stillwell, 2004; Malczewski, 2004; Gerber et al., 2008). Information about several criteria is combined by MCDA to form a single index of evaluation. To combine continuous factors by applying a weight to each factor, a linear combination is used followed by a summation of the results to yield a suitability map (Malczewski, 2000; Eastman, 2001).

$$S = \sum_{i=1}^{n} w_i x_i \prod_{j=1}^{m} c_j \qquad \text{Eq (1)}$$

where S is the suitability, w_i the weight of factor i, n the number of factors, x_i the criterion score of factor i in continued range. Since the scales on which criteria are measured are different, standardization must be performed for all factors before combining them using Eq (1). Moreover, if necessary, all factors must be transformed so that they are positively or negatively correlated with suitability. In this study, standardization was performed using a GIS fuzzy set membership function on to a 0–255–byte scale through the IDRISI program (Eastman, 2001) with 0 as the lowest and 255 as the highest suitability. Herein, we categorized the continuous suitability map into suitable and unsuitable classes.

Results

Table 1 shows the list of selected criteria. The criteria were divided into three groups: (1) sources of disturbance, (2) slope, altitude and spring, and (3) species habitat. Species habitat was the most important criteria for preservation (table 1). Rocky Mountain, meadow,

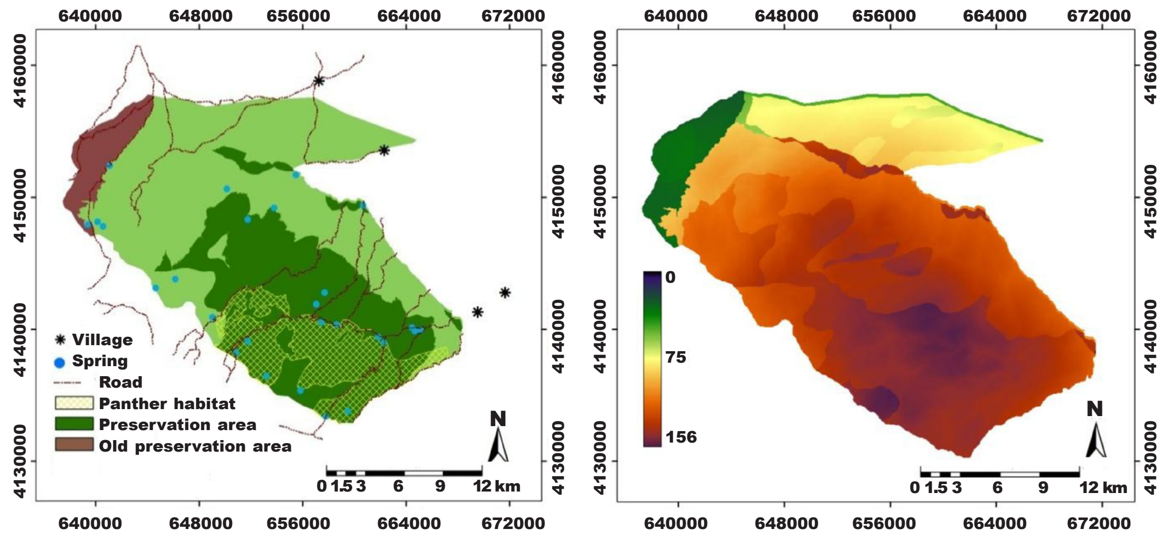

Fig. 3. Suitability map for preservation in the Tandoreh National Park.

Fig. 3. Mapa de idoneidad para la conservación en el parque nacional de Tandoreh.

tall shrubs, forest and mixed forest were the second most important, and sources of disturbance such as rural area, road, and agriculture land and destroyed and abandoned plains were the third most important criteria for preservation.

A suitability map was created to show the areas with the highest priority for preservation based on the weighted criteria (table 1). Generally, the area with high suitability values for preservation was found at elevations above 1,300 m (fig. 3). The highest suitability values were observed in the south and central parts of the park. In contrast, the lowest suitability values were found at lower elevations along the north and east boundaries of the park, which is close to rural areas (fig. 3).

Discussion and conclusion

Tandoreh National Park is one of the most biologically and culturally diverse protected areas in Iran. The area was designed for biodiversity conservation; however human activates effect the ecosystem of the park in a negative way. In other words, there is a huge conflict between conservation goal, and local economic development such as tourism, road construction, cultivation, and grazing. Therefore, it is highly demanded to determine a safe zone for biodiversity conservation and ensuring that human activities are located outside the zone. Our results showed that the eastern and northern areas of the park, which are close to human activities such as villages and agricultural land, returned the lowest suitability. Because Tandoreh is one of the best habitats for the Persian panther, *Panther pardus saxicolor* (Ziaee, 2009) the park managers put a lot of effort into protecting their habitats. We used the habitats of panthers as an important factor to define the safe zone. As shown in figure 3, the habitats of this species are located inside the safe zone, indicating that the protection of these animals depends on protection of safe zone.

The results revealed the importance of land properties for protection. However, these areas are not fully covered by the current protection plan (fig. 3). As can be observed from figure 3, the new zoning is completely different from the old zoning. The area which was considered as safe zones in the old zoning retrieved lower protection priority in our results. However, this result was expected because the systematic methodology did not play any role in the old zoning, and it was based on expert knowledge alone. The availability of habitat maps can be a solid base for the suitability analysis of the zone. In this sense we could make use of a good quality dataset and the experience of local and thematic experts, which has a very strong effect in the analyses. Future improvements will likely require more accurate distribution maps for individual speciesand assessment of the fragility and sensitivity of the different habitat types.

The IUCN recommends that the primary management objectives in a protected area are to preserve its natural ecosystems and species and their associated habitat in at least 75% of the land or water bodies therein (called 75% rule) (Dudley, 2008). Moreover, Dudley (2008) mentioned that 'hard' zones can be assigned to an IUCN category when they are clearly mapped, recognized by legal or other effective means, and have distinct and unambiguous management aims that can be assigned to a particular protected area category (the 75% rule is not relevant). In this study, about 42% of land in the national park is protected areas based on the 'preservation zone'. We presented a systematic method that combines participatory planning with a GIS–based MCDA technique to objectively design land use zones in the protected area. The zoning of protected areas that considers both socioeconomic and biodiversity factors has moved to the forefront of conservation planning (Stewart & Possingham, 2005; Klein et al., 2008). Here we have described a method to evaluate zoning plans that shows the tradeoffs between biodiversity conservation goals and human developments. Tradeoffs between conservation and socioeconomic interests must be considered in any planning process in order to adequately conserve ecosystems.

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