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DESIGNING AND COMPARING ZONING SCENARIOS FOR THE VIÑALES NATIONAL PARK, CUBA

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Abstract

Planning in protected areas requires the evaluation of multiple land attributes according to multiple objectives. This paper applies multicriteria decision analysis techniques in a spatial context to support zoning in the Viñales National Park, Cuba. The Park is to be zoned into three main use types, namely conservation, public use, and agriculture. Multicriteria land suitability analyses were coupled to multiobjective land allocation techniques to generate and compare zoning scenarios. Different methods were tested and the stability of the results was assessed through sensitivity analysis. Additionally, indices of landscape pattern were computed to compare the spatial configuration of the different scenarios. The results aimed at helping park managers and other stakeholders to visualise and understand the process that lead to the generation of land use scenarios in a clear and transparent way.

Key Words
Multicriteria analysis, multiobjective analysis, land suitability, protected area, zoning, landscape pattern

Introduction

In protected area management, zoning is used to spatially define land use objectives and restrictions, in a form understandable to stakeholders and users of area resources (Portman, 2007). Typically, zoning schemes consist of core areas, where strict nature conservation is enforced, and areas where gradually more intensive human presence and activities are allowed (Sabatini et al., 2007; Day, 2002; Bohnsack, 1996). When setting a zoning scheme, planners and managers need to evaluate the spatial distribution of land properties, and decide upon where to restrict or stimulate certain activities, or where to implement measures to protect natural resources and assets. This requires the evaluation of multiple land attributes according to multiple objectives: it can be described as a spatial multiobjective and multicriteria decision problem. It is multiobjective (sensu Eastman et al., 1998) because the goals to be achieved (i.e., the types of protection unit to be identified) are many. It is multicriteria because the suitability of the land for each type is given by the combination of several factors (Villa et al., 2002). It is spatial because most of factors have a geographical distribution, and are best represented by thematic maps. Therefore, zoning can be performed by conducting a multicriteria land suitability analysis for every type of protection unit, and comparing the results through optimization techniques (Keisler and Sundell, 1997; Geneletti, 2001). In this respect, many studies revealed the strength of linking Geographic Information Systems (GIS) with Decision Support Systems (DSS) that implement multicriteria decision analysis (MCDA) techniques, as discussed below.

Janssen et al. (2005) used a GIS-based DSS to compare three different alternatives of wetland management. Boteva et al. (2004) applied spatial MCDA to evaluate and compare conservation significance of vegetation communities and habitats for a proposed Natura 2000 site on the northwest coast of Crete, Greece. Geneletti (2004) prioritised the most critical forest patches for nature conservation in an Italian Alpine valley applying spatial MCDA on a set of landscape ecological indicators. Another example is the study of Strager and Rosenberger (2006): they used GIS in testing sensitivity of land prioritization to different preferences of stakeholder groups. Lang and Langanke (2005) developed a set of GIS tools aimed at facilitating the management of Natura 2000 sites. Although they did not explicitly link it to a DSS, they stated that “these tools were to provide a tangible framework for the applied questions of site management”, emphasizing the importance of transparency and sound spatial decision making in nature conservation areas.

Spatial MCDA techniques have been employed to support the specific task of protected areas planning. Bojórquez-Tapia et al. (2004) and Keisler and Sundell (1997) applied multicriteria modelling to redesign natural reserves. More specifically on zoning, Ridgley and Heil (1998) and Hjortsø et al. (2006) used multiobjective optimisation to generate land-use scenarios for protected-area buffer zones. In Portman (2007), Crossman et al. (2005), Villa et al. (2002), Brown et al. (2001), spatial MCDA was employed to achieve the optimal zoning of marine protected areas. Geneletti and van Duren (2008) applied MCDA in a spatial context to support the proposal of a new zoning scheme for a terrestrial protected area.

This paper presents an approach based on spatial multicriteria and multiobjective analysis to design and compare zoning scenarios for the Viñales Natural Park, one of the most visited protected areas of Cuba. A zoning scheme was adopted by the Park in 2003, and it is currently under revision. The study aims at supporting the revision process, by testing an approach to allocate protection levels in the Park area, and by providing the results to park managers in the form of scenarios, which are compared and assessed in terms of their general performance. The different scenarios are generated by changing the input to the process, so as to simulate different conditions, and their implication on the results. Currently, some divergences and conflicts exist between the types of areas proposed by the Plan of the Park and the provisions of other management tools existing in the area. This called for the proposal of a transparent and replicable method that could be used as a reference for updating the existing zoning scheme.

Protected Area Management in Cuba

Brief historical overview

Even though some initiatives were undertaken at the beginning of the 20th century by some researchers and personalities committed with the safeguard of the natural and cultural patrimony of Cuba, it is not until the 30's that the first protected areas were established in the country. In this decade, the Parque National Sierra de Cristal was established in the old province of Oriente, followed by the National Refuge of Hunt and Fishes Ciénaga de Zapata (1933), and the National Reserve of Flamingos, in the northern part of Camagüey province (1936). After the victory of Revolution in 1959, Law 239 was approved in order to conserve and promote the forest resources of the country, and nine National Parks were established, followed in 1963 by five natural reserves. In the period 1970-1995, the theoretical and practice foundations for a national protected area system were set. The National Commission for the Protection of Environment and Natural Resources was founded, and article 27 of new Constitution of the Republic of Cuba was devoted to the protection of the environment. In this period, an IUCN (The World Conservation Union) team of experts visit the island to interact with local institutions, and set the basis for planning and managing protected areas. Several studies on conservation and protection of natural resources were carried out, resulting in the proposal of more than 100 areas of important values for conservation, and the institution of the National Network of Protected Areas by the Council of Ministries in 1981. The last decade is marked by the birth of the Ministry of Science, Technology and Environment and the related National Centre of Protected Areas, whose mission is to plan and manage the National System of Protected Areas. In this period, the legal instruments for administration and control of protected area were consolidated by means of promulgation of Decree Law 201/99 of Protected Areas, the Environment Law of 1997 and the establishment of 35 protected areas.

The National System of Protected Areas

The proposed National System of Protected Areas (SNAP) provides for the following categories (CNAP, 2004):

- Protected areas of national significance: they represent the core of the system, by virtue of their size, representativeness, state of conservation, uniqueness, or other peculiar factors;

- Protected areas of local significance: areas that are valuable at provincial level, but limited in size and representativeness;

- Special regions of sustainable development: vast areas where the fragility of the ecosystems and their socioeconomic importance require measures of attention and coordination of national level in order to meet sustainable development objectives. They might include other management categories within their boundaries.

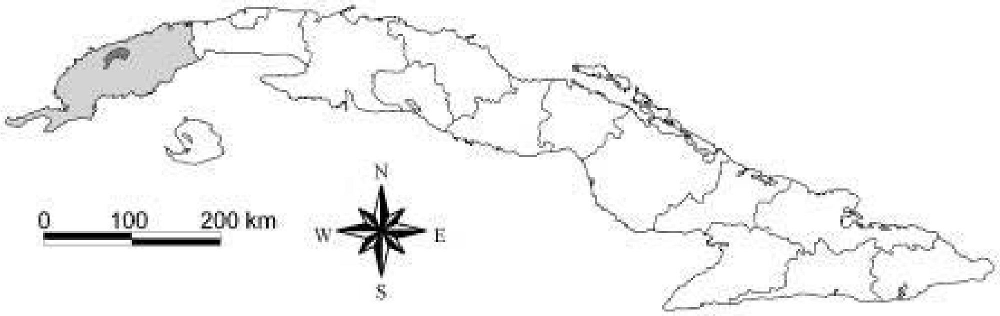
The SNAP is composed of 263 units, of which 80 are considered of national significance and the rest of local significance. Among the protected areas of national significance, there are 14 National Parks (among which the Viñales National Park), six Reservations of Biosphere, two UNESCO sites, and five RAMSAR sites. The proposed system covers 9.72% of the national territory; it would protect 95% of flora species found in the country, 100% of the endemic, native and migratory birds, 86% of critical habitats for birds, and 321 species of native vertebrates (apart from birds and aquatic vertebrates). In terms of conservation objectives, and consequently permitted activities, protected areas in Cuba are classified in the following management categories: Natural reserve, National park, Ecological reserve, Outstanding natural asset, Floristic reserve, Wildlife sanctuary, Protected natural landscape, and Protected Area of Managed Resources (Consejo de Estado de la Republica de Cuba, 1999).

In spite of the work carried out in the last years and of the existing political willingness, there are a number of critical issues that are currently affecting the management and conservation of protected areas in Cuba. First of all, the SNAP still lacks a clear articulation in its different components, and suffers from an insufficient implementation of protected areas. This is mainly caused by a limited foreign-currency budget, and by a lack of qualified staff. The SNAP is also affected by an unbalanced management of different territories, and insufficient community involvement in the work within protected areas. The system is poorly valued and promoted at both national and international level. Additionally, the management is made difficult by the existence of sectoral interests that undermine the conservation objectives (e.g., forest exploitations), and by illegal activities and land uses (e.g., plant and animal species collecting and illegal hunting).

Study region

The Viñales Valley is located in the westernmost portion of Cuba, roughly 25 km to the North of the city of Pinar del Rio (Figure 1). It represents one of the most beautiful inland areas of the island, widely known also at international level. The landscape is characterised by a spectacular karst geomorphology, unique in the world. It combines heights of metamorphic rocks of Jurassic age with Karsts Mountains belonging to the Cretaceous, and well-known as *mogotes*, which are remnants of eroded limestone layers characterised by rounded and tower-like shape. The scenery is enriched by the presence of small-scale agricultural fields (mainly tobacco and small fruit plantations), dotted by traditional peasant houses (*bohios*), and by the architecture of Viñales town, founded in 1875. In the valley, a culture with a rich history and great diversity of customs and traditions has developed. Due to all these factors, the region was declared National Natural Monument in 1979, and UNESCO World Heritage Site in 2001. The Viñales National Park was formally established in 2001, and includes an area of 11 120 hectares.

Figure 1. Location of the Viñales Natural Park (dark grey) in the Province of Pinar del Rio (light gray), Cuba



Roughly 27 000 people live in the area. The settlement of Viñales is the core of tourism development, and it has been experiencing a rapid population growth over the last years, which inverted the previous trend. In 1999, there were 1 461 buildings and a population of less than 6 000, whereas in 2007 2 370 buildings and 7 865 inhabitants were counted. The main economic activities in the area are tourism, agriculture, forestry, cattle breeding, and services. The tourism industry is growing rapidly: the region received more than 37 000 visitors in 2007. There are 200 rooms in the three existent hotels, and more of 300 private houses that rent rooms in town. The climate is classified as tropical wet and dry (Aw). Temperature ranges between 20 and 29°C, with an average annual value of 24.7 °C. Precipitations average 1 825 mm/year and the relative humidity average is 84%. Soils show a great variety of conditions and evolutionary processes: from the skeletal soils of the steep slopes to the deep and highly developed soils, within valley floors and inter-mountainous depressions. Vegetation is characterised by high diversity and representativeness, due to the paleogeographic evolution and to the good conservation of some of the least accessible areas. The Park hosts several plant and animal species of high conservation value, particularly for their diversity and endemic character. More than a thousand plant species have been counted in the *mogotes*, of which 232 are endemic of Cuba and 23 exclusively found in the Park. As to fauna, 30% of the species (mainly amphibians, reptiles and birds) are endemic of Cuba. The area encompasses 92 archaeological sites related to the aboriginal Mesolithic and 86 related to fugitive slaves, as well as eight sites of rupicole art. The influence of human actions is not very strong in the inner sector of the Park, and it mainly resulted in forest degradation, as a consequence of timbering, and agricultural cultivations, especially in the valley floors.

The Management Plan of Viñales National Park, in force since 2003, contains the first official zoning proposal. The Plan set three main zone types (or protection levels): conservation, public use, and socioeconomic areas. Conservation areas encompass natural assets characterised by high fragility and/or high representativeness. Conservation areas include the calcareous mountains and the isolated *mogotes*, except some small areas proposed for public or socioeconomic use. Regulations enforced in these areas forbid any kind of human activity, with the purpose of fostering natural processes. Only research and education activities are allowed. Public use areas include samples of representative values of the Park. They are easily accessible and devoted to recreation purposes. The management is aimed at promoting eco-tourism and educational activities in different forms, in compliance with site-specific technical regulations (carrying capacity, visitors' frequency, etc.), so as not to interfere with conservation objectives. The regulations focus on the identification of paths and areas, and on visitors' behaviour. Finally, socioeconomic areas aim at promoting traditional agricultural production, by enforcing a strict control on the intensity of practices, the use of chemical products, and the presence of invasive species. In these areas, activities for the protection and improvement of soils are programmed, agro-ecological techniques introduced, and modern agroforestry systems promoted, with the objective of obtaining healthier and more marketable produces.

Methods

Land suitability assessment

Land suitability analysis aims at identifying the most appropriate future land uses in a region according to specific sets of requirements and preferences (Malczewski, 2004; Collins et al., 2001). In this study, spatial MCDA techniques were applied to perform land suitability analysis (Joerin et al., 2001; Store and Kangas, 2001). In particular, the analysis aimed at assessing the aptitude of the Park area to host the three zone types described in the previous section: conservation, public use, and socioeconomic areas. In conservation areas (C), strict conservation of natural values applies, and human presence is minimised. In public use areas (P), the purpose is to preserve natural values, but also to promote compatible activities and tourism. Finally, socioeconomic areas (A) have been considered only with respect to agriculture suitability, due to the importance of this activity in the region, and the lack of data related to other activities, such as cattling. For each of the three protection levels, a map was generated that shows how suitable each location is for that specific use. The construction of these maps required the identification of a set of criteria that could be used to express the degree of suitability. Criteria selection was strongly influenced by the availability of information. Criteria were structured into a tree, as shown in Figure 2.
Four criteria were identified for C:

- Ecosystem representativeness. A measure of how well a site reflects all the habitats that are expected to occur in that geographical region (Edwards-Jones et al. 2000). The more representative a site is of a region, the better. The rationale behind it is that by protecting the most representative sites, we are more likely to preserve the total species and habitat diversity of the region under considerations (Geneletti, 2002);

- Vegetation naturalness. The degree to which an ecosystem is free from biophysical disturbance caused by human activities (Lesslie et al. 1988). The more natural, and therefore the less disturbed, the better. This is because the proximity to the natural conditions of a site influences the survival chances of the native flora and fauna. Additional reasons for assessing naturalness are tied to scientific considerations (undisturbed ecosystems are needed to set a reference for assessing the changes that affect disturbed ecosystems), as well as to emotional and recreational benefits (Smith and Theberge, 1986). The naturalness map was constructed by reclassifying vegetation through the naturalness scale proposed in Usher (1986).

- Presence of caves and karst structures. They represent geosites whose value needs to be protected. Distance from these sites was used as an indicator, which can be measured over the whole study area;

- Disturbance. Distance from the main sources of disturbances (human settlements and roads) was considered;

Four criteria were selected for P:

- Presence of sites of interest. Sites of natural interest and sites of cultural landscape interest were considered. In both cases, distance from the sites was used as indicator;

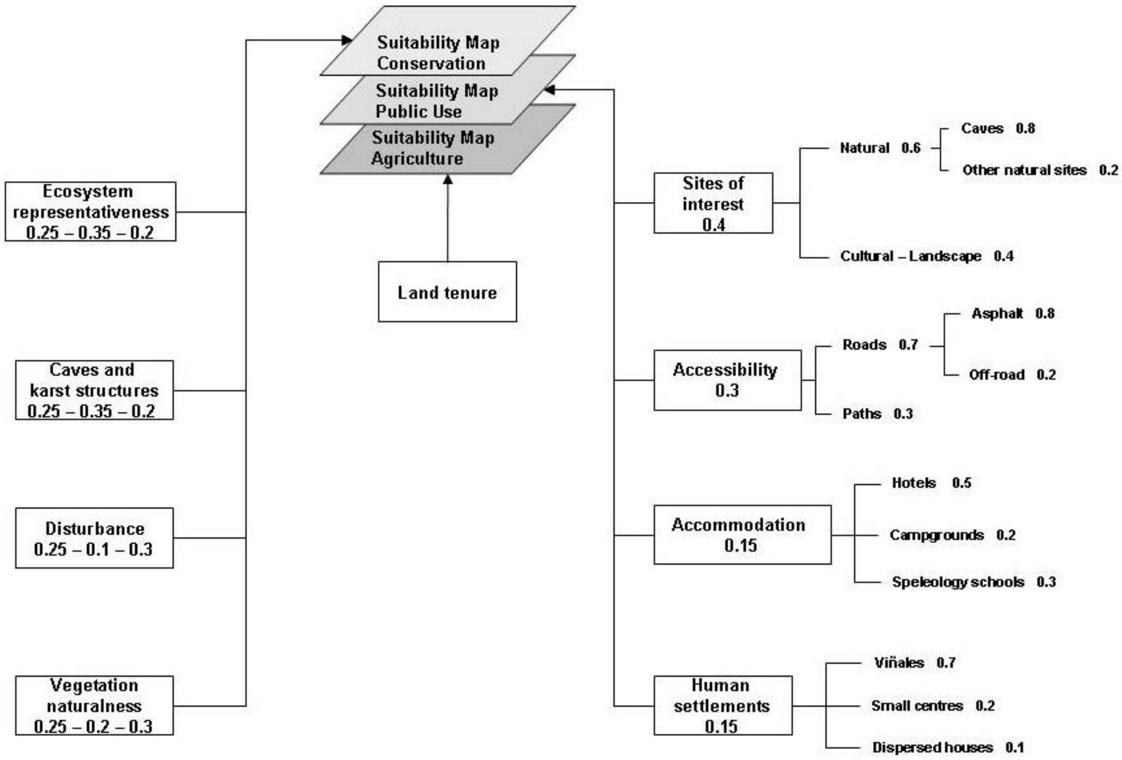
- Accessibility. Three sub-criteria were considered to account for accessibility: distance from paved roads, from unpaved roads, and from trails;

- Accommodation. The distance from accommodation structures (hotels and campgrounds) was considered;

- Human settlements. Three sub-criteria were considered: distance from Viñales, distance from small centres, and distance from scattered settlements.

Due to lack of data, land suitability assessment for A was limited to one criterion: land tenure. Two main tenure types were considered: land that belongs to farmers (private property) and land held by national co-operatives. Raster maps (cell size: 20 m) were generated in a GIS for each of the above-described criteria and sub-criteria.

Figure 2. Criteria tree for the three suitability maps (with weights)



In order for criteria and sub-criteria to be comparable, their values were assessed with respect to a pre-defined value scale, ranging from one (most desirable condition) to zero (least desirable condition). Thus, value functions were built that turn the score of a given criterion into a value between zero and one (Beinat, 1997; Malczewski, 1999). This score represents the suitability of the land for a specific zone type, according to the criterion under consideration. Value functions were assessed for all criteria and sub-criteria expressed by continuous variables (Figure 3). One should note the difference between the value function related to distance from roads within the criterion accessibility, and that related to distance from roads within the criterion disturbance. This is due to the different objective against which the distance from roads is assessed: being close to a road is desirable because it improves accessibility by tourists, but it has negative effects on nature conservation, due to nuisance caused by traffic. Categorical variables were assessed through direct assignment of values in the 0-1 range (Table 1). Weights were then assigned to each criterion according to its relative importance, within the tree it belongs to (this was obviously not required for A, because only one criterion was considered). As a convention, each weight ranged from zero to one, and the sum of all weights within each level of a tree was equal to one. Weights were assigned during a meeting session, which was attended by both a group of researchers involved in this study, and a group of experts working in the Park. During the meeting, different perspectives emerged about the weight set for C, whereas the opinions on the weight set for P were virtually consensual. For this reason, three different weight sets were considered for C. The first set assigns to all criteria the same importance; the second set gives to ecosystem representativeness and the presence of caves a higher importance than to disturbance and vegetation naturalness. On the contrary, the third set assign a slightly higher importance to disturbance and naturalness. Weight sets are presented in Figure 2. The standardised maps were combined on a cell-by-cell basis, using the weighted linear combination method (Malczweski, 1999). As a result, a suitability map was generated for each of the protection levels, and for each of the weight sets.

Table 1. Normalisation scores of the categorical variables

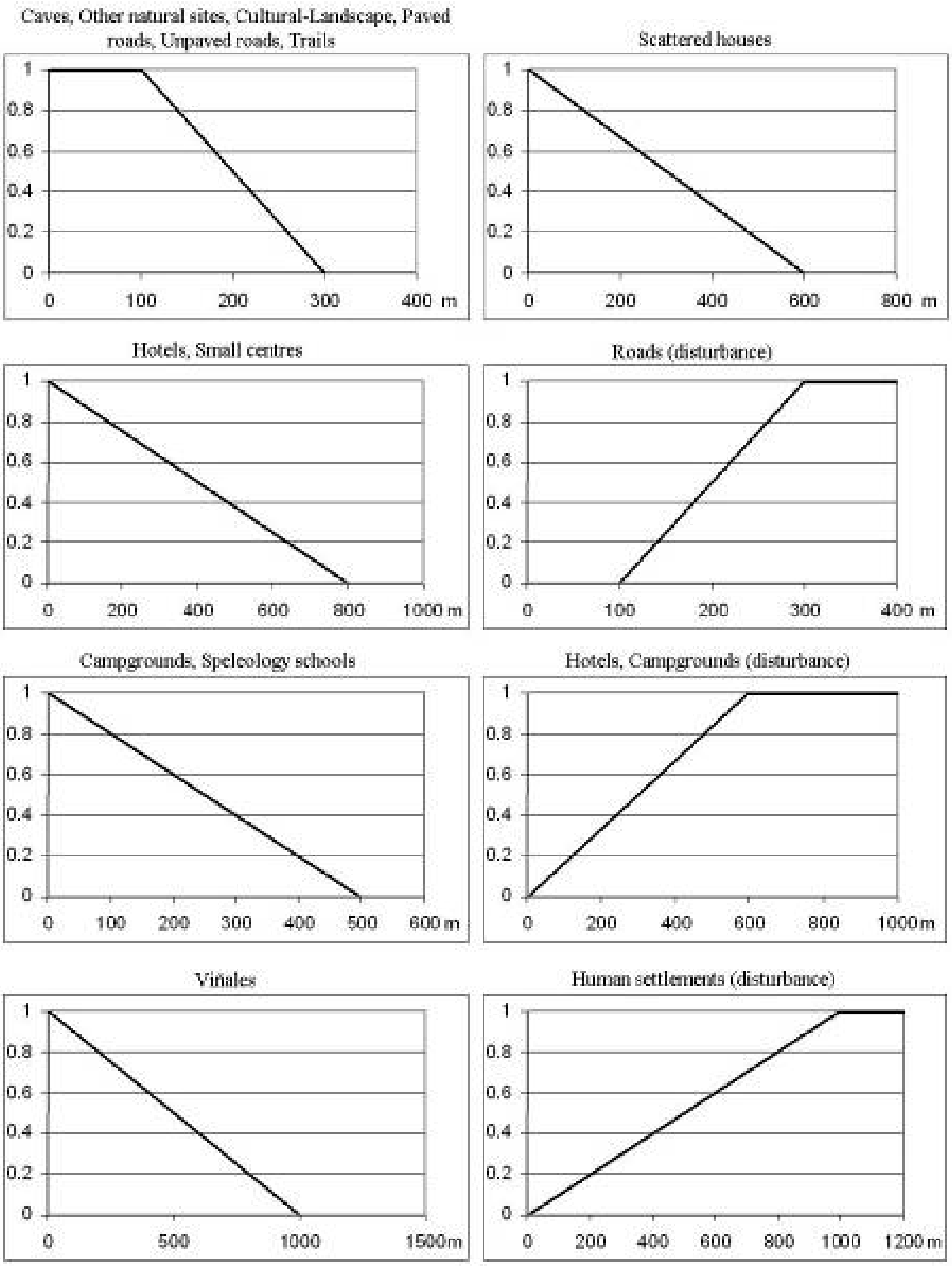
Ecosystem representativeness	Score
Mogote	1.0
Pinewood	0.9
Mogote and secondary forest	0.8
Pinewood and oaks	0.7
Secondary forest	0.6
Pine plantations	0.3
Secondary vegetation and agriculture	0.1

Vegetation naturalness	Score
Natural	1.0
Seminatural	0.8
Slightly modified	0.6
Disturbed	0.2
Artificial	0.0

Land tenure	Score
Private	1.0
Co-operative	0.5

Raster suitability maps do not represent an appropriate input to zoning because suitability values are assigned to individual cells, rather than to land units that can be properly identified, delimited, and managed. Zoning units should be relatively large and compact, as well as easily recognisable on the ground (Geneletti and van Duren, 2008). Additionally, in protected-area planning, these units should have an explicit ecological meaning, rather than being based on administrative or land use boundaries. For this reason, hydrological basins were selected as the most appropriate land unit. The identification of basins was carried out by using GIS functionalities and the Digital Elevation Model as input map. A minimum size of 60 ha was set in order to filter out the smallest watersheds. Each basin was assigned the average land suitability value of the pixels that form it. This implied a loss of spatial detail, but allowed information to be referred to actual spatial entities, rather than cells.

Figure 3. Value functions



Design of zoning scenarios

The design of zoning scenarios required, as a first activity, to set land demands for each zone. Four different land demand schemes were considered in this study (Table 2, first column). The first one keeps the land distribution of the zoning scheme currently enforced in the Park, which assign 50% of the territory to C, 30% to P, and 20% to A. The second and third demand schemes reduce C areas, by increasing P and A areas, respectively. Finally, the fourth scheme increases C areas at the expenses of P.

Table 2. Allocation scenarios

Land demand	Weights	Allocation method	Scenario ID
Conservation: 50% Public Use: 30% Agriculture: 20%	Set 1	Stepwise	1
		Simultaneous	2
	Set 2	Stepwise	3
		Simultaneous	4
	Set 3	Stepwise	5
		Simultaneous	6
Conservation: 45% Public Use: 35% Agriculture: 20%	Set 1	Stepwise	7
		Simultaneous	8
	Set 2	Stepwise	9
		Simultaneous	10
	Set 3	Stepwise	11
		Simultaneous	12
Conservation: 40% Public Use: 30% Agriculture: 30%	Set 1	Stepwise	13
		Simultaneous	14
	Set 2	Stepwise	15
		Simultaneous	16
	Set 3	Stepwise	17
		Simultaneous	18
Conservation: 60% Public Use: 20% Agriculture: 20%	Set 1	Stepwise	19
		Simultaneous	20
	Set 2	Stepwise	21
		Simultaneous	22
	Set 3	Stepwise	23
		Simultaneous	24

Zoning scenarios were designed through a land allocation process aimed at identifying the most suitable units for each protection level (C, P, A), up to reaching the land demand for that specific level. Two approaches to allocation were followed and compared: the stepwise and the simultaneous approach. The stepwise approach requires a priority ranking of protection levels to be established. In this study, priority was granted to C, followed by P and then A. Land units are then assigned first to the most important level according to their suitability (i.e., starting from the most suitable unit), and up to fulfil the land demand for that protection level. Subsequently, remaining units are assigned to the second most important level, and so on and so forth. This approach is common in GIS-based land allocation process, and it is implemented in commercial packages, such as What if? (Klosterman, 1999).

The simultaneous approach allocates units by first selecting, for each of the three protection levels, the units with the highest suitability up to the fulfilment of the land demand.

Subsequently, by comparing the results of the three selections, units are classified in the following groups: units selected for one protection level only, units selected for two or three protection levels, units never selected. All units selected for one zone only are directly allocated to that zone. Units selected for two or three zones, as well as units never selected, represent "conflicting units". The allocation of conflicting units is performed through a decision algorithm. The algorithm optimises choices, by taking into account simultaneously the suitability for all protection levels. It represents an adaptation to the vector environment (i.e., where units to be allocated are represented by polygons) of the raster-based approach described by Eastman et al. (1998). It was first proposed in Geneletti and van Duren (2008), where a detailed description can be found. An iterative process was introduced to ensure that land demands were satisfied: when the overall area of the units allocated to a given zone reach the demand, the remaining units are distributed only to the other two zones. Due to the fact that land units have different areas, the fulfilment of land demands was approximated to the closest value. Both the stepwise and the simultaneous allocation processes were repeated for the four land demand schemes, and using as input the suitability maps constructed with the three sets of weights. This resulted in the generation of 24 allocation scenarios, listed in Table 2.

Scenario comparison

The performance of the 24 scenarios was compared in terms of their consistency with the suitability maps, and their spatial configuration. For each scenario, the average suitability value of the three protection levels was computed by overlaying the zoning scheme with the suitability maps and applying local statistic functions in a GIS. Compactness and connectivity are key factors in a zoning scheme: they play a role in terms of both nature conservation, and park management. For this reason, the scenarios' spatial configuration was assessed by resorting to a set of metrics, commonly employed in landscape ecology to measure fragmentation and connectivity within a landscape (Giles and Trani, 1999; Turner and Gardner, 1991). The following metrics were computed, using the freely available software FRAGSTATS Version 3 (McGarigal and Marks, 1995):

- Number of non-adjacent zones belonging to the same protection level. The higher the number, the more fragmented the zoning scheme is, and consequently the harder it is to enforce it.

- Mean shape index. It expresses the degree of compactness of the zones and its value increases with decreasing compactness. It was computed as the average value of the shape index of all zones that form a zoning scheme. The shape index is defined as (McGarigal and Marks, 1995):

$$Shape\ Index = \frac{Perimeter}{2\sqrt{Area \cdot \pi}} \tag{1}$$

- Connectance index. It is defined on the number of functional joinings between zones of the same type, where each pair of zones is either connected or not based on a user-specified distance criterion. Connectance is reported as a percentage of the maximum possible connectance given the number of zones, according to the following formula (McGarigal and Marks, 1995):

$$CONNECT = \left[\frac{\sum_{j \neq k}^{n} c_{ijk}}{\frac{n_i(n_i - 1)}{2}} \right](100) \quad (2)$$

Where:
c_{ijk} = *joining between the zone j and k;*
n_i = *number of zone of the same type.*

Finally, a sensitivity analysis was performed to understand the degree of stability in the allocation of each unit. The analysis was carried out twice: first by considering all 24 scenarios, and then by considering separately the 12 scenarios obtained with the stepwise approach, and those obtained through the simultaneous approach. Sensitivity was assessed using as an indicator the number of times that the protection level assigned to a unit is different from the protection level most frequently assigned to that unit in the 24 (or 12) scenarios. Sensitivity classes were defined, and a map generated accordingly.

Results and discussion

Land suitability assessment

The land suitability maps for C, P and A are shown in Figure 4. As to C, the maps obtained with the three weight sets present similar spatial patterns for the extreme suitability values: in all maps the highest suitability values are assigned within mountain areas, whereas the lowest values are found around existing settlements. In this respect, the correlation with the patterns of the vegetation naturalness map is quite evident (see Figure 5). However, the map obtained with weight set 1 is characterised by a small range of suitability values, resulting in a quite homogeneous evaluation all over the study area. The map of weight set 2 highlights some hotspots of suitability, particularly close to caves. Finally, the application of weight set 3 generated a map that clearly shows the effect of the presence of human-induced disturbances, such as access ways. As to P, the highest suitability values are mainly found in lowlands and flat areas, where human settlements and tourist infrastructures are located. On the contrary, mountain areas are penalised by the reduced accessibility. The map for the A simply reflects the distribution of agricultural areas and their tenure: maximum suitability occurs in private lands, medium suitability in lands held by national co-operatives, and minimum suitability in non-farmed areas.

The distribution of values in the suitability maps for C and P present the typical salt and pepper effect of pixel-based maps. This clearly showed that raster maps are an unsuitable input to the land allocation process. For this reason, the Park area was partitioned into watersheds. The difference between administrative Park borders and physical borders resulted in some basins not to be correctly identified. Geoprocessing tools were used to solve this problem, and areas smaller than 60 ha were joined to the largest adjacent basin. As a result, 137 basins were identified, as shown in Figure 6. Their average area is 200 ha. These basins were assigned the average suitability value of the pixels within them, and they represented the basic units used during land allocation.

Figure 4. Suitability maps for the three protection level: Public use (top), Conservation - weight set 1 (middle), and Agriculture (bottom)

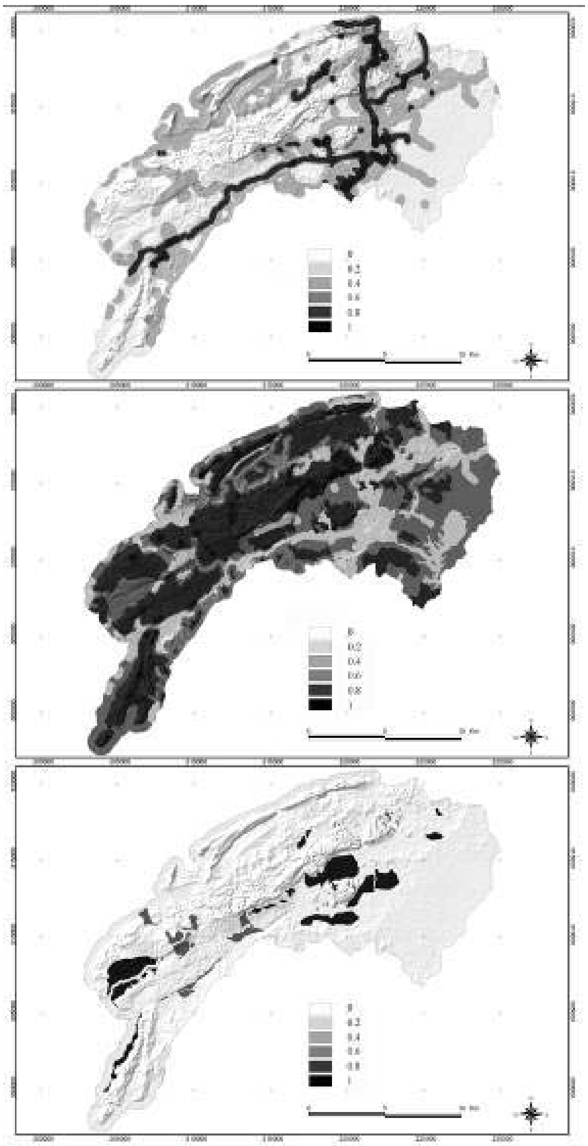


Figure 5. Vegetation naturalness map

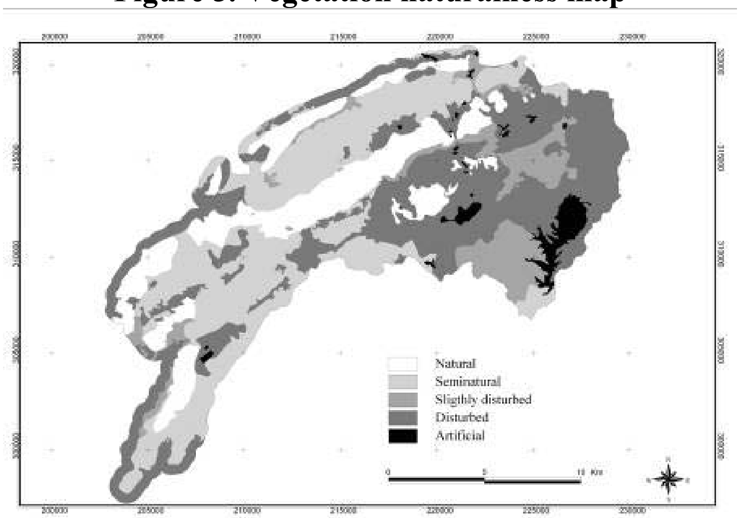
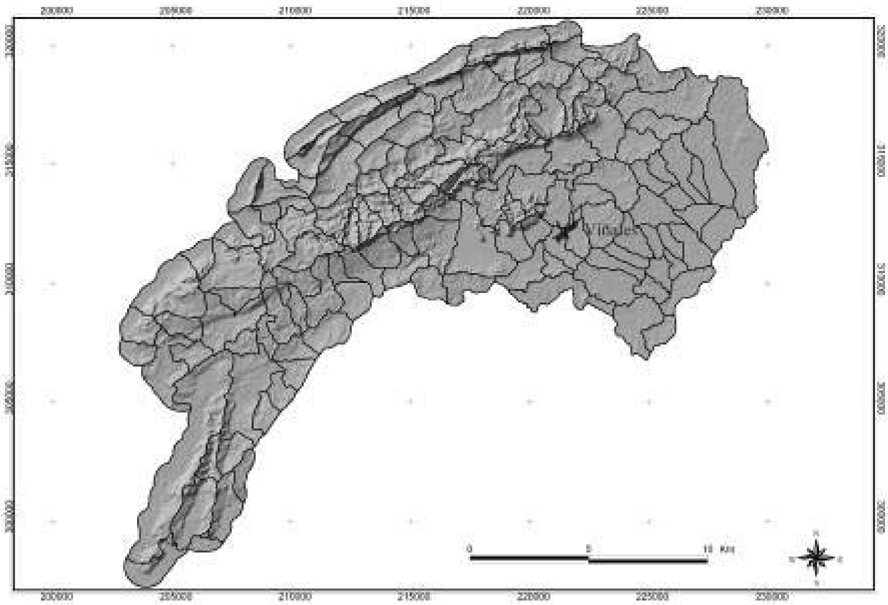


Figure 6. Watershed boundaries superimposed to a Digital Elevation Model of the area



Design and comparison of zoning scenarios

For brevity ‘s sake, we do not present here all the 24 zoning scenarios, but only a sample of them, a comparison of their performance, and a discussion of the most interesting results. Figure 7 shows one of the zoning obtained through the stepwise allocation method (scenario 1, see Table 2), whereas Figure 8 presents the zoning obtained with the same parameters, but by applying the simultaneous approach (scenario 2). It can be noticed that the main difference resides in the distribution of the units assigned to A and P, whereas the scenarios are quite similar for what concerns C areas. This is confirmed by comparing all pairs of scenarios obtained with the two allocation approaches. Table 3 presents the indicators computed to compare the performance of the zoning scenarios. As it can be seen, there are little changes between the average suitability scores of C and P zones, obtained through the stepwise and the sequential approach. On the contrary, the suitability of A zones improves dramatically when the simultaneous approach is adopted. This was expected, being A the last protection level in the priority order used in the simultaneous allocation,. However, it was also expected that this approach would improve the average suitability of P, and especially of C zones. This did not happen, proving that the stepwise method is inefficient because it reduce the efficiency with which A zones are allocated, without improving the efficiency in the allocation of the other two zones.

Figure 7. Zoning scenario 1

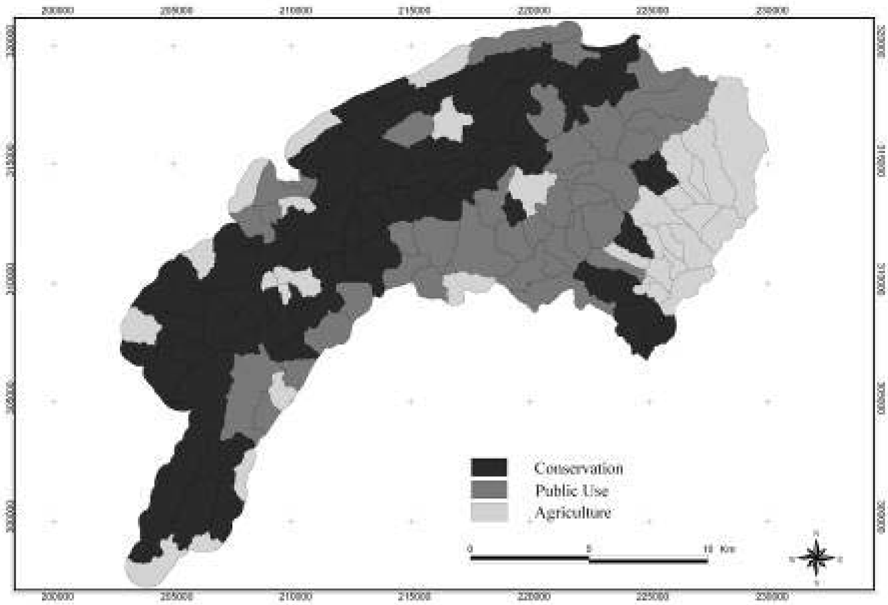


Figure 8. Zoning scenario 2

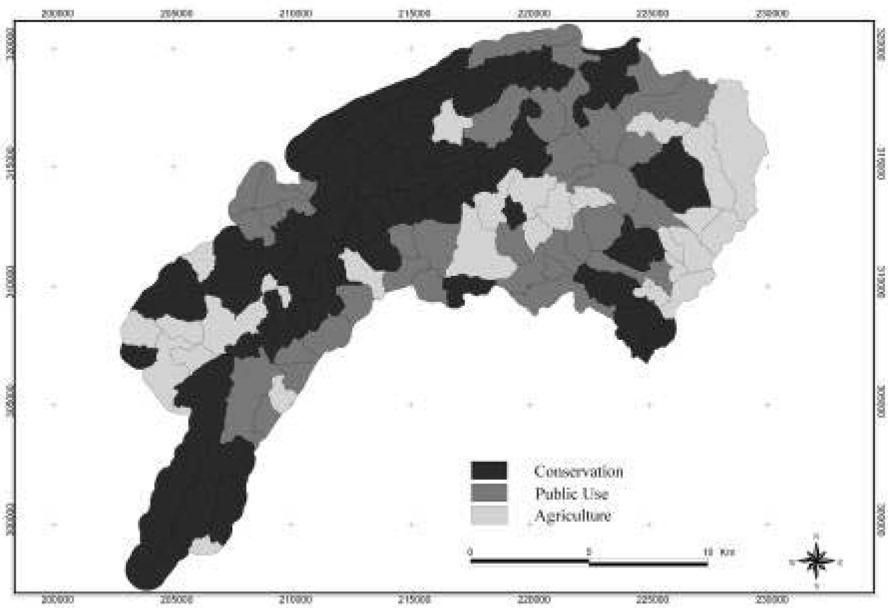
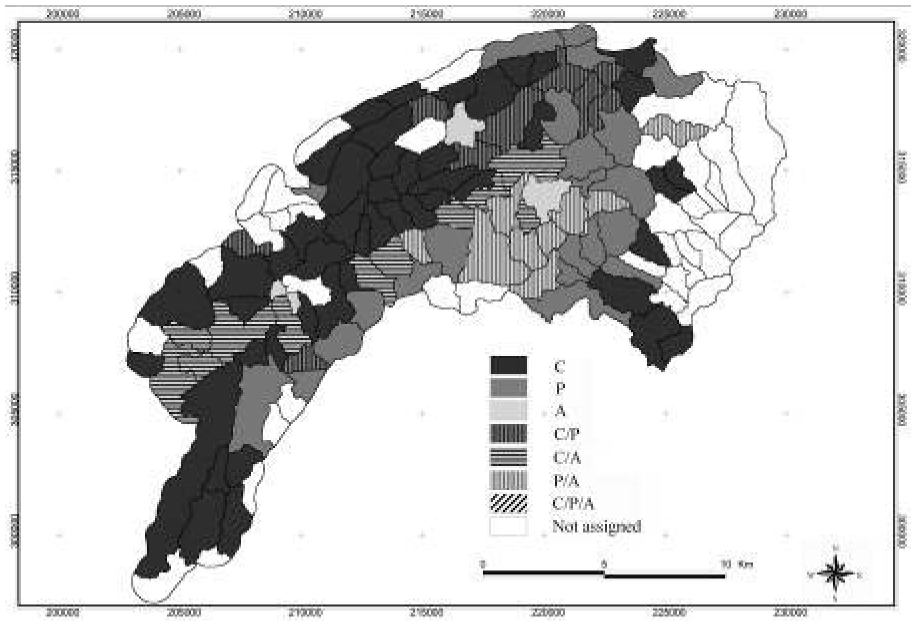


Figure 9 shows the results of the preliminary allocation performed through the simultaneous approach: it shows units assigned to one protection level only, units assigned to two or more levels, and units never assigned. Hence, the map offers a concise overview of the distribution of land use and allocation conflicts within the Park. In particular, it clearly shows that the easternmost part of the Park does not present high suitability for any of the protection levels. Other unsuitable units are scattered along the Park boundaries. The location of these units might suggest a revision of the Park boundaries. If extended to the regions surrounding the park, this analysis could be used to support the redesign of park boundaries, by adjusting them according to suitability levels. Figure 9 also shows that there is a large and connected tract of land that presents high suitability for conservation only, which encompasses the mountain ranges and most of the isolated *mogote*s. Areas suitable for P only are mainly located along the southern boundaries and in the central sector. Most units that present high suitability for A are also characterised by high suitability for either C or P. As it can be seen, there are only two units suitable for A only, whereas 18 are suitable for A and P or A and C. This is largely due to the limited data used to carry out the suitability analysis for A that was not able to grasp the whole range of values for agriculture, causing the resulting map to be rather unspecific. It is expected that when further data become available (e.g., cultivation type and intensity, cattle breeding), there will be less overlap.

Table 3. Indicators computed to compare the zoning scenarios (C: Conservation; P: Public use; A: Agriculture)

Scenario ID	Average suitability			No. of non-adjacent zones			Mean shape index			Connectance index		
	C	P	A	C	P	A	C	P	A	C	P	A
1	0.56	0.17	0.04	5	6	15	2.3	2.3	1.8	0.0	6.7	0.1
2	0.55	0.17	0.20	8	4	9	1.8	2.4	2.4	3.6	0.0	0.0
3	0.47	0.17	0.08	6	5	10	1.7	2.5	1.9	0.0	10.0	2.2
4	0.46	0.16	0.24	7	4	11	1.9	3.1	2.0	4.8	0.0	2.2
5	0.60	0.18	0.01	4	6	12	2.4	2.5	1.9	0.0	6.7	0.0
6	0.59	0.18	0.14	8	3	11	1.8	3.0	1.9	3.6	0.0	0.0
7	0.57	0.16	0.07	6	6	9	1.7	2.4	2.2	0.0	6.7	2.8
8	0.56	0.15	0.22	7	4	7	1.8	3.1	2.2	4.8	0.0	0.0
9	0.48	0.15	0.11	5	9	8	2.3	1.8	2.2	0.0	5.6	4.8
10	0.48	0.15	0.22	9	4	10	1.6	2.4	2.4	2.8	0.0	2.8
11	0.61	0.16	0.04	4	6	11	2.5	2.4	1.9	0.0	6.7	1.8
12	0.60	0.16	0.17	7	4	7	1.8	2.9	2.1	4.8	0.0	0.0
13	0.58	0.18	0.05	5	6	15	2.4	2.4	2.0	0.0	6.7	1.0
14	0.58	0.16	0.15	8	6	11	1.6	2.6	2.4	3.6	6.7	1.8
15	0.49	0.18	0.09	5	5	15	2.4	2.5	1.9	0.0	10.0	1.1
16	0.49	0.16	0.16	6	5	12	1.8	3.1	2.1	6.7	10.0	1.5
17	0.62	0.18	0.05	6	5	15	1.9	2.9	2.0	6.7	10.0	1.0
18	0.62	0.17	0.15	7	6	13	1.8	2.5	2.2	4.8	0.0	1.5
19	0.53	0.21	0.03	4	7	9	2.4	2.4	1.9	0.0	4.8	2.8
20	0.51	0.22	0.12	7	5	10	1.9	2.7	2.1	4.8	0.0	0.0
21	0.45	0.18	0.06	5	7	10	2.1	1.9	2.0	0.0	0.0	2.2
22	0.44	0.21	0.21	6	7	7	2.0	2.3	2.4	6.7	0.0	0.0
23	0.57	0.21	0.04	4	7	8	2.4	2.4	1.9	0.0	0.0	3.6
24	0.56	0.22	0.18	8	5	10	1.9	2.6	2.2	10.7	0.0	0.0

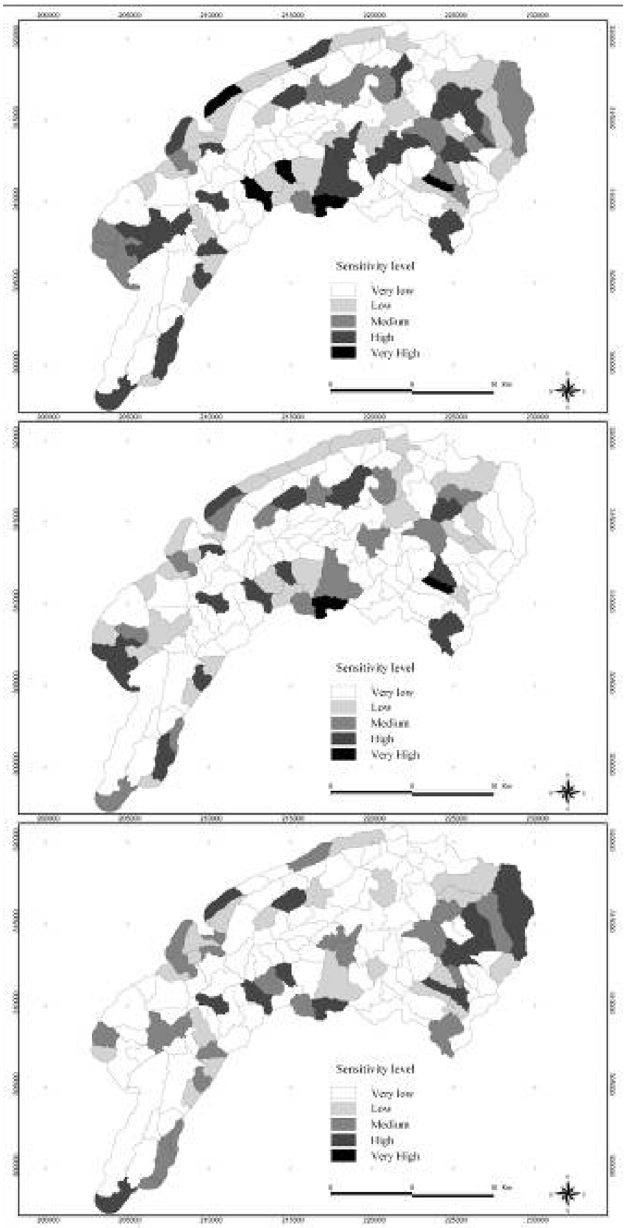
Figure 9. Preliminary allocation for scenario 1 (C: Conservation; P: Public use; A: Agriculture)



As to spatial configuration, in all scenarios A zones are the more fragmented: they are dispersed into a high number of non-adjacent zones. This is reflected also by the low values of the connectance index. Zones assigned to P are characterised by extreme conditions for what concerns connectance: in some scenarios these zones are the most connected, whereas in other ones they are the least connected (see Table 3). This can be explained by comparing Figure 7 with Figure 8. In the first one, the units assigned to P occupy a contiguous tract of land, that crosses the Park from north-east to south-west. When the simultaneous approach is adopted, this tract of land is interrupted by units assigned to A, and P receives isolated units scattered in the western sector of the Park. This is also visible in Figure 9: several units suitable for both P and A are located close to each other, and their allocation affect the overall compactness of P. The shape index value, representing the complexity of the shape of the single zones, is comparable in all allocation scenarios and for all protection levels.

The difference in the allocation results obtained with the 24 scenarios is summarised in Figure 10. For each unit, the number of times that its protection level differ from its most frequent protection level was counted. The result was then sliced into five sensitivity levels: very high (if a unit is allocated to a different protection level more than 50% of the times), high (36-50%), medium (20-35%), low (<20%), and very low (never). The analysis was performed together for the 24 scenarios (Figure 10, top), and then separately for the scenarios obtained thought the stepwise approach (Figure 10, middle) and the simultaneous approach (Figure 10, bottom). By considering all 24 scenarios, the stable units cover around 48% of the Park area. By looking at the two allocation approaches separately, the results are characterised by a lower sensitivity: about 60% of the area is stable, whereas medium and high sensitivity levels cover 20% of the Park for the stepwise approach, and 25% for the simultaneous approach. In particular, the inner and mountainous areas of the Park present low sensitivity levels, whereas higher sensitivity characterise the units located along the boundaries of the Park. This confirms the historical land use trends: the inner areas represent the conservation core of the Park, that has never been used for economic activities. On the contrary, the border areas have been characterised by land-use conflicts, due to the presence of the main settlements and the pressure from tourism.

Figure 10. Sensitivity levels of the units for the 24 scenarios (top), for the scenarios obtained through the stepwise approach (middle) and through the simultaneous approach (Figure 10, bottom).



Conclusions

In spite of the work carried out in the last years and of the existing political willingness, there are a number of critical issues that are currently affecting the management and conservation of protected areas in Cuba: insufficient establishment of protected areas, lack of community involvement, poor promotion at both national and international level. Additionally, the management is made difficult by the existence of sectoral interests that undermine the conservation objectives (e.g., forest exploitations), and by illegal activities and land uses (e.g., plant and animal species collecting and illegal hunting). In this context, it is important to have strong management tools, supported by sound and replicable analysis.

This study aimed at helping park managers and other stakeholders to visualise and understand the process that lead to the zoning scheme in a clear and transparent way. To this purpose, several allocation scenarios were constructed, by changing the area of the three protection levels, the importance assigned to the different criteria, and the allocation methods. This allowed comparing the effects of different allocation policies. The research provided Park authorities with an operational framework for effective decision-making, rather than with the result of the analyses only.

In the Viñales Natural Park, divergences and conflicts exist between the types of areas proposed by the Management Plan and the provisions of other tools, such as the Plan of the Viñales Cultural Landscape and the programme of the Viñales Tourist Pole. The existence of these three planning tools for the same territory makes the establishment and control of current and prospective development more difficult, especially with regards to the control of tourism activities. The results of this research offers a scientific basis to undertake the revision of the Management Plan, so as to harmonise it with the other planning tools and reduce conflicts among the involved stakeholders. The study also underlined the lack of data, particularly for what concerns the agricultural use of land and the distribution of plant and animal species. For more than one decade several institutions in Cuba have been carrying out surveys and investigations aimed at assessing the state of environment. A considerable amount of basic information on natural components and socioeconomic processes has been generated, particularly in the areas more interested by tourism development. However, at the time this study was initiated, several basic environmental data layers were still missing. This is the case for instance of flora distribution, wildlife habitat and breeding areas. On the contrary, a good database was available for what concerns infrastructures and sites of tourism interest. Therefore, prior to the definition of the new zoning scheme for the Park, detailed surveys on biodiversity should be carried out, so as to define patterns of tourism use that account for the carrying capacity of the most fragile areas.

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References

BEINAT, E. 1997. *Value functions for environmental management.* Kluwer, Dordrecht.

BOHNSACK, J. A. 1996. Marine reserves, zoning and the future of fishery management. *Fisheries* 21 (9),14–16.

BOJÓRQUEZ-TAPIA, L. A., CUEVA, DE LA H., DIAZ, S., MELGAREJO, D., ALCANTAR, G., SOLARES, M. J., GROBET, G., CRUZ-BELLO, G. 2004. Environmental conflicts and nature reserves: redisigning Sierra San Pedro Martin National Park, Mexico. *Biological Conservation* 117, 111-126.

BOTEVA, D., GRIFFITHS, G., DIMOPOULOS, P. 2004. Evaluation and mapping of the conservation significance of habitats using GIS: an example from Crete, Greece. *Journal for Nature Conservation* 12, 237-250.

BROWN, K., ADGER, N. W., TOMPKINS, E., BACON, P., SHIM, D., YOUNG, K. 2001. Trade-off analysis for marine protected area management. Ecological Economics 37, 417–434.

COLLINS, M.G., STEINER, F.R., RUSHMAN, M.J. 2001. Land-use suitability analysis in the United States: historical development and promising technological achievements. *Environmental Management* 28 (5), 611–621.

CROSSMAN, N. D., OSTENDORF, B., BRYAN, B. A., NEFIODOVAS, A., WRIGHT, A. 2005. OSS: A spatial decision support system for optimal zoning of marine protected areas. In: Zerger, A., Argent, R.M. (Eds.) *MODSIM 2005 International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand, pp. 1525-1531.

DAY, J. C. 2002. Zoning—lessons from the Great Barrier Reef Marine Park. *Ocean and Coastal Management* 45,139–156.

EASTMAN, J.R., JIANG, H., TOLEDANO, J. 1998. Multi-criteria and multi-objective decision making for land allocation using GIS, in: Beinat, E., Nijkamp, P. (Eds.) *Multicriteria analysis for land-use management*. Kluwer Academic Publishers, pp. 227-251.

EDWARDS-JONES, G., DAVIES, B., HUSSAIN, S. 2000. *Ecological Economics. An introduction.* Cornwall: Blackwell Science.

GENELETTI, D. 2001. Spatial Multiobjective Decision Analysis for Land Allocation in a Natural Park. *Proceedings of the International Workshop on Geo-spatial Knowledge Processing for Natural Resource Management, June 28-29,* University of Insubria, Varese (Italy), pp. 249-253.

GENELETTI, D. 2002. *Ecological evaluation for environmental impact assessment.* Netherlands Geographical Studies, Utrecht.

GENELETTI, D. 2004. A GIS-based decision support system to identify nature conservation priorities in an alpine valley. *Land Use Policy* 21, 149-160.

GENELETTI, D., VAN DUREN, I. 2008. Protected area zoning for conservation and use: A combination of spatial multicriteria and multiobjective evaluation. *Landscape and Urban Planning* 85 97-110.

GILES, R. H., TRANI, M.K. 1999. Key elements of landscape pattern measures. *Environmental Management* 23 (4), 477-481.

HJORTSØ, C. N., STRÆDE, S., HELLES, F. 2006. Applying multi criteria decision making to protected areas and buffer zone management. *Journal of Forest Economics* 12 (2) 91-108.

JANSSEN, R., GOOSEN, H., VERHOEVEN, M.L., VERHOEVEN, J.T.A., OMTZIGT, A.Q.A., MALTBY, E. 2005. "Decision support for integrated wetland management". *Environmental Modelling and Software* 20 215-229.

JOERIN, F., THÉRIAULT, M., MUSY, A. 2001. Using GIS and outranking multicriteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science* 15 (2), 153–174.

KEISLER, J. M., SUNDELL, R .C. 1997. Combining Multi-Attribute Utility and Geographic Information for Boundary Decisions: An Application to Park Planning". *Journal of Geographic Information and Decision Analysis* 1(2), 101-118.

KLOSTERMAN, R. E. 1999. The What if ? collaborative planning support system" *Environment and Planning B: Planning and Design* 26, 393- 408.

LANG, S., LANGANKE, T. 2005. Multiscale GIS tools for site management". *Journal for Nature Conservation* 13, 185–96.

LESSLIE, R., MACKEY, B., PREECE K.L. 1988. A computer-based method of wilderness evaluation. *Environmental Conservation* 15 (3), 225-232.

MALCZEWSKI, J. 1999. GIS and Multicriteria Decision Analysis. John Wiley & Sons, Toronto.

MALCZEWSKI, J. 2004. GIS-based land-use suitability analysis: a critical overview. *Progress in Planning* 62, 3–65.

MCGARIGAL, K., MARKS, B. J.1995. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*, Gen. Tech. Rep. PNW-GTR-351.: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

PORTMAN, M. E. 2007. Zoning design for cross-border marine protected areas: The Red Sea Marine Peace Park case study. *Ocean & Coastal Management* 50, 499–522.

RIDGLEY, M.A., HEIL, G.W. 1998. Multicriterion planning of protected-area buffer zones: an application to Mexico's Izta-Popo national park. In: Beinat, E. Neijkamp, P. (Eds.) *Multicriteria evaluation in land-use management: methodologies and case studies.* Kluwer Academic Publishers, pp. 293-309.

SABATINI, M. C., VERDIELL, A., RODRIGUEZ IGLESIAS, R.M., VIDAL, M. 2007. A quantitative method for zoning of protected areas and its spatial ecological implications. *Journal of Environmental Management* 83 (2), 198-206.

SMITH, P.G.R., THEBERGE, J.B. 1986. A review of criteria for evaluating natural areas. *Environmental Management* 10 (6), 715-734.

STORE, R., 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.

STRAGER, M.P., ROSENBERGER, R.S. 2006. Incorporating stakeholder preferences for land conservation: Weights and measures in spatial MCA. *Ecological Economics* 58, 79-92.

TURNER, M.G., GARDNER, R.H. 1991. *Quantitative methods in landscape ecology: the analysis and interpretation of landscape heterogeneity.* Springer, New York.

USHER, M. B. 1986. *Wildlife conservation evaluation.* Chapman & Hall, London.

VILLA, F., TUNESI, L., AGARDY, T. 2002. Zoning marine protected areas through spatial multiple-criteria analysis: the case of the Asinara island national marine reserve of Italy. *Conservation Biology* 16 (2), 515-526.

Geneletti, D.; Salinas, E.; Marchi, A.; Orsi, F. 2010. Designing and comparing zoning scenarios for the Viñales National Park, Cuba. ***Geografía y Sistemas de Información Geográfica.*** (GESIG-UNLU, Luján). Año 2, N° 2, Sección I:164-285.
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