USING A GIS TO DETERMINE CRITICAL AREAS IN THE CENTRAL CORDILLERA CONSERVATION AREA, COSTA RICA.

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Abstract: We briefly present a weighted multicriteria methodology that has been applied by CATIE. FUNDECOR and the National Park Service to determine Critical Areas in the Central Cordiliera Conservation Area in Costa Rica A raster GIS has been used to produce maps of suceptibility to deforestation and to aquifer contamination due to human pressure. with a resolution of 1 hectare.

Resumen: Presentamos una metodología de múltiples criterios que ha sido aplicada por CATIE. FUNDECOR y la Dirección General Forestal para definir Areas Críticas en el Area de Conservación de la Cordillera Volcánica Central en Costa Rica. Se usó un Sistema de Información Geográfica de formato cuadrícula para producir mapas de succeptibilidad a la deforestación y a la contaminación de acuíferos. con una precisión de 1 hectárea.

Introduction

The Fundation for the Development of the Central Cordiliera (FUNDECOR) is an NGO whose mission is "to preserve and promote sustainable development of the Natural and cultural patrimony of the Central Cordiliera Conservation Area" (ACCVC) in Costa Rica. It promotes the autofinancing of the national parks and impulses private sustainable activities in ACCVC. FUNDECOR actions are based on the principle that Conservation and Development can be complementary and can coexist in harmony.

ACCVC. which is part of the National Park Service of Costa Rica (NPS). is located in the Central sector of the country (Figure 1). It covers approximately 300.000 hectares. About 71.500 hectares correspond to protected areas by law as National Parks (National Park Braulio Carrillo. for instance). while another 100.000 hectares are covered by dense rain forest in the buffer areas. The remainder is used as pasture and agriculture.

FUNDECOR and ACCVC/NPS pretend to support the protected areas to preserve and guaranty their biodiversity. water quality and scenic beauty. through autofinancing. territorial consolidation and improved administration and planning. In the buffer zones. FUNDECOR pretends to preserve all the area covered by rain forest through sustainable management of the forest resource. They promote reforestation in the deforested areas.

Part of the strategy for Conservation and Development in the ACCVC. developped by FUNDECOR. NPS and the Direccion General Forestal (equivalent to the US Forest Service in Costa Rica) with the technical assistence of the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). consisted of building a model to predict areas where the forest and water (the principal natural resources of the zone) are more prone to be affected by human activities. In these areas. FUNDECOR would focus its resources and perform emergency corrective actions.

This paper presents the methodology to determine Critical Areas. which was based on the advice of experts, and made heavy use of a raster based Geographic Information System (GIS). The method is a standard multicriteria analysis. where weights have been assigned by pair-wise analysis of the threats to natural ressources.

Methodology

Definition of Critical Areas has been fundamental to the development of FUNDECOR's strategy. In effect, proper management activities in the area require a great input of resources which are always limited. To help in the selection of sites where FUNDECOR should intervene to preserve natural value, a scale of priority has been assigned to each hectare (the pixel size) in the ACCVC. These areas are refered to as Critical Areas throughout this paper. To this respect, *a Critical Area is defined as an area with physical and socioeconomic characteristics that have a high propability of suffering from human pressure*. In these areas FUNDECOR will promote actions that minimize the negative impact of human activities on the natural ressources.

With a raster GIS, the factors that are associated with pressure on the natural resources (threats) are combined to create the Critical Areas map, a map showing the pressure or threat on the resource. This map corresponds qualitatively to deforestation probability, or to water contamination risk. To build this map, the resources themselves have first to be priorized, and second each threat is given a relative weight. Third, the spatial variation of a given threat has to be determined, and the threat is normalized in order to be able to combine them quantitatively. Determination of critical areas consisted in 4 steps described below.

Prioritizing Natural Resources.

Forest and water have been identified as the most important resources to protect since they represent the principal source of natural richness of the ACCVC. We considered them to be equally important, but treated them individually because they require different types of protective actions. Aquifers were clasified in two categories: superficial and deep, the first one being given a priority twice as large as the second.

Priorizing Threats.

The criteria that defined the degree of pressure on the resources, or threat, were the following:

a) population density; b) roads and trails; c) terrain slopes; d) logging activities; e) IDA (Instituto de Desarrollo Agrario) land distribution.

To assign a weight to these factors is not an easy task since they are interrelated. We chose a pairwise analysis with the method of Saati (1977) that has been implemented in the module WEIGHT of the GIS IDRISI (IDRISI, 1993) to ensure that the resulting weights are the ones that minimize the distortion of our conceptions of these factors. The method was applied by a group of 10 experts. Using the module WEIGHT of IDRISI, we obtained weights that will be later reffered as Absolute Weights, for resources Forest and Water:

a) population density:	Forest:	0.15	Aquifers:	0.23
b) roads and trails:		0.26		0.15
c) terrain slopes:		0.08		0.06
d) logging activities:		0.38		0.35
e) IDA land distribution:		0.13		0.21

Model.

To construct the map of Critical Areas, we have to combine quantitatively the different factors with their Absolute Weights. Each threat k is given an absolute weight P_A^k determined by the pairwise analysis, as described in the preceeding section. Within a specific threat, spatial variations represented by $P_R^k(i,j)$, where (i,j) represents the position of cell (pixel) (i,j).

Multicriteria modelling can be defined as follows: Given N types of independent threats k the resulting threat $A(i,j)$ for each cell (i,j) is given by Equation 1:

$$A(i,j) \sum_{k=1}^{N} A^k(i,j)$$

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$$Ak(i,j) = P_R^k(i,j)P_A$$

The absolute weights P_A^k are scaled from 0 to 1, the sum being equal to 1. The relative weights $P_R^k(i,j)$ are also normalized to 1, with the result that on average (weighted by the areas covered by the each threat) $P_R^k(i,j)$ is 1. Hence multiplying $P_R^k(i,j)$ by P_A^k will produce the threat $A^k(i,j)$ for each cell, that will average over the entire area to a value equal to P_A^k. The methodology for the normalization is described is described in Leclerc and Rodriguez (1996).

Spatial dependence of threats.

ROADS: We digitized roads from 1:50000 scale maps and made the assumption that the pressure of the human activity along them is decreasing exponentially with the distance to the road with a characteristic distance d0 of 1km. All the types of roads (from highway to gravel) have been given the same weight. Hence the probability of entering the forest up to a distance d_0 is $P(d_0)=1/e=0.37$.

FOREST MANAGEMENT PLANS. Logging activity is taken into acount through forets management plans aproved by the DGF after 1989. The plans have been digitized from 1:50000 scale maps. To simulate the pressure that the logging activity in an area can bring to the neighbourhoods, we selected a buffer zone of 1km around the actual management plans, an gave it a weight of 1. The management plans supervised by FUNDECOR or approved by FUNDECOR have been given a weight of 0, which implies that these plans do not present any risk to the environment. In the neighborhood of these areas, however, FUNDECOR has a responsability since the logging activities, although well managed, imply road construction which opens the way to uncontrolled logging in the buffer zone.

POPULATION DENSITY: Since 1945, Costa Rica has put tremendous efforts and money to improve education, and as a consequence it has a lower rate of illiteracy than the USA. As soon as there are a few children in an area, a school is built and a teacher assigned. This allowed us to generate a better estimate of population density than from the villages that appear on the outdated maps. Schools, digitized as points from the 1:50000 scale maps of the Ministery of Education, were assigned a weight equal to the number of registered students. Then applying 100 successive passes of a 3x3 average filter, we generated a gaussian distribution, 2.5km wide and centered on the school, which represents student density.

IDA LAND DISTRIBUTION: To simulate the fact that new IDA colonies can be located in the neighborhood of existing colonies, we considered a simple 1 km buffer. The IDA colonies and the buffer zone have been given a weight of 1

TERRAIN SLOPES The criteria of reduced slopes as a threat to the natural resources is based on the fact that steep slopes is a natural barrier for logging and for expansion of population. Flat areas, to the contrary, are prone to be invaded rapidly. The threat for slope classes has been computed using the inverse of the average slope in a given slope class, and has been normalized using the area of each class.

The parameters used by the model are globally as independent as possible but there may be areas where two parameters are redundant. For example, where population is concentrated there is sometimes a greater density of roads and the level is usually flatter, and the simple sum of the weight resulting from these parameters will overestimate the threat. To overcome this situation, we combine population and roads threats into a single threat using the maximum of the overlaping threats.

Results

Map of Critical Areas.

The Critical Areas map is the result of combining the distincts layers representing different threats as in Eq. 1. The resulting map contains quantitative real values that we can reclasify to obtain a qualitative map that is easier to interpret. Figure 2 shows the critical areas map for forest, depicting the risk that an area will suffer deforestation in the near future.

Land use change and model validation.

Based on satellite imagery, land use changes in the period 1986-1992 has been estimated for the ACCVC. To validate the model, the Critical Areas map (real values) has been reclasified in 20 levels in intervals of 0.05. For different regions of the ACCVC out of the National Parks (buffer zone), the area deforested has been determined for every level of threat. For low levels of threats, deforestation is erratic, due to the an error in the land use change map (slight misregistration of the 1986-1992 maps) and to differences in the pixel size of the source imagery. For the intermediate levels of threat, the precision of the prediction improves considerably and a linear relationship is found, which is expected if the model is appropriate.

In the zones with greatest threat, the prediction of the model looses again precision which is an indication of other factors that may contribute. These will probably differ depending on the geographic region, and the present analysis could help to identify the factors that do not contribute. For example for high threat levels, the average deforestation rate seems to become constant or decrease. This fenomena could be explained in some areas by the proximity of the forested land to National Parks, where the owners prefer to maintain the forest cover in the hope that the government will purchase them to enlarge nucleus zones. In general the model predicts correctly the land use change or deforestation in the buffer zone. Thanks to the GIS technology, the model becomes a tool that can be easily improved.

The results of the model are now part of FUNDECOR activities. For operational purposes, the Critical Areas map have been reclassified in 3 levels in order to obtain a linear relationship for deforestation showing low, average, and high priority areas. When a farmer applies for help and financing from FUNDECOR, its farm is mapped on the Critical Area map and the average priority level for that farm is obtained. Farms are then ranked with respect to their average priority levels and preference will be given to high priority areas even if their commercial value is not as high.

Conclusion

GIS have been applied succesfully for planning and decision making in a conservation area. The learning curve for a raster GIS being very steep, FUNDECOR is now performing its own analysis and models, and is applying the concept of Critical Areas at the planning and operational levels. As with any models, however, streamlining is now required, based on longer data time series and rigourous analysis involving spatial statistics.

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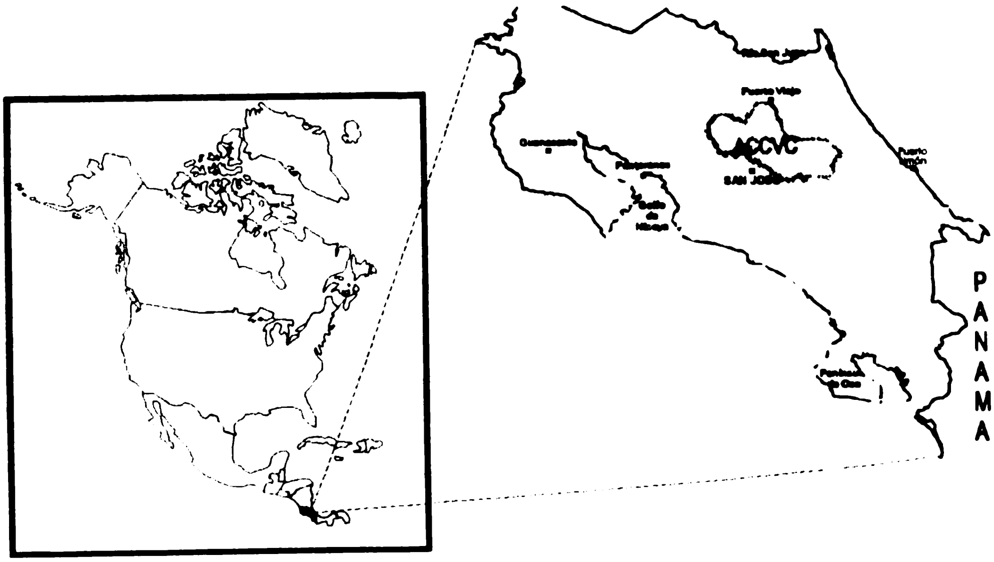

Figure 1. Localization of the Central Cordiliera Conservation Area, Costa Rica.

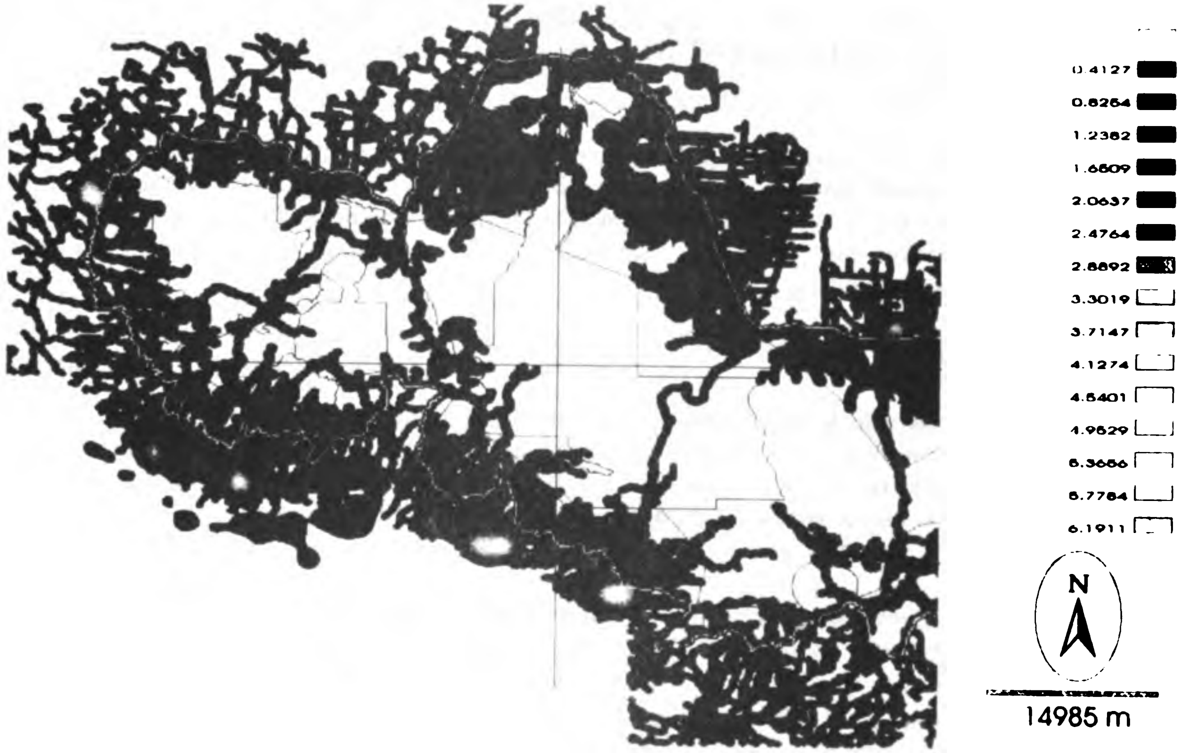

Figure 2. Critical Areas map for the Forest resource (areas succeptible to deforestation).