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Identification of threatened areas of environmental value in the Conservation Area of Mexico City, and setting priorities for their protection

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Abstract. Almost 60% of the Conservation Area of Mexico City is to the south within the Valley of Mexico; there is an extensive area of forests, scrub, wetlands, grasslands and agricultural zones. It is important for the city's sustainability because of the environmental services provided such as aquifer recharge, carbon sequestration and biodiversity. It is being threatened by human activities despite a program of ecological regulation; this is partly because environmental problems are not always immediately visible to the government and general public in terms of the need for prompt action. The present study uses spatial evidence to identify and prioritize threatened environmentally valuable areas. Data from a variety of sources are combined, and information geo-referenced with Geographical Information Systems is verified in the field. The resultant maps show that the most threatened ecologically valuable areas are as follows: the oak wood and scrub relicts east of Milpa Alta; the forests west of Cuajimalpa, Álvaro Obregón and Magdalena Contreras; the forests of the Pelado and Malacatepec volcanoes in Tlalpan; and the forests of the Tláloc and Chichinautzin volcanoes in Milpa Alta. These results could be used by decision makers to design timely strategies to protect the Conservation Area and its supply of environmental services to Mexico City.

Key words: Environmental value zones, threats, priority areas, environmental services, *Suelo de Conservación*, Distrito Federal.

Identificación de áreas de valor ambiental amenazadas y su prioridad de atención, en el Suelo de Conservación del Distrito Federal

Resumen. Dentro de la cuenca de México, principalmente hacia el sur, se extiende una extensa área de bosques, matorrales, humedales, pastizales y zonas agrícolas que conforman casi 60% del Distrito Federal (D.F.) denominada Suelo de Conservación (SC). El SC, de gran importancia para la sustentabilidad de la ciudad de México por los servicios ambientales que proporciona (recarga del acuífero, captura de carbono, gran diversidad biológica, entre otros), está siendo amenazado por actividades humanas, a pesar de que existe un Programa de Ordenamiento Ecológico. Esto, en parte, porque el gobierno y la población no visualizan espacialmente los problemas ambientales para diseñar estrategias puntuales. Por esta

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razón, aquí se identifican los sitios de valor ambiental que se encuentran amenazados y se prioriza su atención, a partir de la recopilación y homologación de la información existente. Se identificaron como zonas de valor ambiental amenazadas, con mayor prioridad de atención: los relictos de encinar y de matorral al oriente de la Delegación Milpa Alta, los bosques del poniente en las delegaciones Cuajimalpa, Álvaro Obregón y La Magdalena Contreras; los bosques de los volcanes Pelado y Malacatepec en la Delegación Tlalpan y los de los volcanes Tláloc y Chichinautzin en Milpa Alta.

Palabras clave: Zonas de valor ambiental, amenazas, áreas prioritarias, servicios ambientales, Suelo de Conservación, Distrito Federal**.**

INTRODUCTION

Science can offer a theoretical or applied basis for constructing policies and solutions with appropriate methods or scenarios; it can assess the effective fulfilment of conservation objectives laid down in public policies. However, experience has shown that this occurs most successfully when it is integrated into the decision-making process, not only when it is explained in reviewed publications or when there are specific technical problems to be solved.

Decisions concerning conservation must have explicit objectives and establish clear priorities and options within areas that have conservation potential and alternative forms of management (Margules and Pressey, 2000). Planning of land use must be guided by the best information available on areas of great biological importance (Theobald, 2003), and for this it is necessary to use incomplete knowledge and to adapt methods to do the best with what is known (Margules and Pressey, *op. cit.*).

Evaluating and prioritizing the threats to biodiversity are important steps in planning conservation, so it is necessary to produce maps that identify with precision the natural areas and the threats that put them at risk, and thereby to monitor their distribution and spread (*Ibid.*).

Rouget *et al.* (2003) define threat as the probability of losing a proportion of the biodiversity, and Margules and Pressey (2000) as the risk that a conservation area will be transformed to a different land use. Independently of the focus, most authors define it either as an event (Araújo *et al.,* 2002) or as 'any human activity or process that has caused, is causing or may cause the destruction, degradation and/or impairment of biodiversity and natural processes' (Salafsky *et al.,* 2003).

In many studies, threats towards biodiversity have been used to prioritize conservation measures. Salafsky *et al.* (2003) proposed a detailed classification of threats; Cassidy *et al.* (2001) did this in Washington State using maps of vegetation and land use in order to identify areas with human activity; and Reyers (2004) in South Africa incorporated threats associated with road systems. Theobald (2003) developed a method in which states of conservation and levels of protection are combined with patterns of threats, in order to identify the geographical area that requires attention and thereby to adopt appropriate strategies.

Various studies (Rouget *et al.,* 2003; Theobald, 2003; Reyers, 2004) have geographically prioritized the threats and have assessed their future in terms of vulnerability by assigning conservation values as a function of rarity, endemism, species richness or state of protection and the ecological integrity of the area (Stoms, 2000; Groves, 2003). Maddock and Benn (2000) combined species, vegetation types, ecological processes, legal protection and threats of land change in order to identify conservation areas in South Africa. In Mexico, Cotler *et al.* (2004) located areas with serious environmental problems in the Lerma-Chapala basin.

To create maps of the distribution of threats, as proposed by Kramer and Richards (2002), their spatial superposition can be identified, and by combining these with maps of distribution of biodiversity it is possible to establish the effects of multiple threats (Ervin and Parrish, 2006). If there are temporal patterns (Salafsky, *op. cit.*), the maps of threats can help to foresee them and mitigate them; for example, Travis (2003) contended that the distribution of fragmentation is as important as the degree of fragmentation itself, and Stoms (2000) that the indices of density of road systems take for granted that all the segments have the same effect on biodiversity.

Ervin and Parrish (2006) described five steps for evaluating the threats: *a*) to identify them in a region; *b*) to evaluate their impact on biodiversity;

c) to estimate future threats; *d*) to analyse the root causes of the threats; and *e*) to integrate the information into conservation planning.

When integrated into the planning, the evaluations of threats can be used for the following: *a*) to develop strategies; *b)* to establish geographical priorities; *c*) to sequence and prioritize areas and strategies of conservation; and *d*) to measure the changes in the threats over time (Groves, 2003; Poiani *et al.,* 1998).

For governments and social organizations it is useful to measure the threats as indicators of the efficacy of their actions and on that basis to reconsider their planning and geographical priorities as new threats emerge and to be able to communicate complex information on biodiversity in an understandable form (Ervin and Parrish, *op. cit.*).

Although there have been many studies related to the Conservation Area (CA) of the Distrito Federal (D.F.) that could help in the creation and improvement of environmental policies, they are scattered in governmental and research institutions. The governmental institutions charged with environmental management require rapid diagnoses, to endorse their strategic decisions in a prompt and effective manner, above all in aspects of restoration and conservation. There is a striking absence of accurate, systematized information, and of monitoring the actions performed; also there is a lack of specialists prepared to plan them and monitor their operation, as well as a lack of finances to develop the necessary studies. The present paper is an effort to contribute to the solution of these problems; the diagnosis that it presents is the result of the application of a model of analysis and integration of cartographic information. It is easy to reproduce and interpret. It is a combination from different sources, from which has been constructed a geographic information system (GIS) to manage and analyse the data; this allows general results to be obtained rapidly in order to support decision making with respect to the identification of threats in areas of environmental value in the CA of the D.F., leading to the definition of a proposal for prioritizing measures to deal with them.

The antecedent of the proposed model is the project Servicios Ambientales en las Políticas Rurales Territoriales (TCP/MEX/29), developed by the Secretaría del Medio Ambiente del D.F. [the Secretariat for the Environment of the Federal District], with support from FAO between 2003 and 2005, in the pilot zones of the landholding cooperatives of Parres el Guarda and San Miguel Topilejo in Tlalpan, and of Magdalena Atlitic in La Magdalena Contreras. The cartographic material that was generated was handed over to the cooperatives and was considered to be of considerable use in the management of their land.

STUDY AREA

The Conservation Area (CA) lies towards the south and west of the Valley of Mexico and within the limits of the D.F. It was designated in 1987 (DDF,[1] 1987) and placed under the administration of the Secretariat for the Environment of the Distrito Federal,[2] to be differentiated from Urban Land in the face of the accelerated growth of Mexico City. It comprises ~87 000 ha, or 60% of the land surface of the D.F., distributed across nine *delegaciones* [local government areas, or boroughs], (SMADF[3] and SAGARPA,[4] 2006; Figure 1). The area is ~45% forest (conifers, oak and mixed woodlands), 4.62% xerophyll scrub, 7.57% grassland or Zacatonal, and 35.26% aquatic or subaquatic vegetation (the lacustrine area of Xochimilco and Tláhuac) and agricultural land (*Ibid.*)

Despite its being adjacent to one of the largest cities in the world, according to Velázquez and Romero (1999) this area harbours 2% of the world's biodiversity and 12% of the species of flora and fauna of Mexico, with ~3 000 species of vascular plants and 350 of terrestrial vertebrates. Those authors recorded the following: 59 mammal species,

[1] Federal District Department.

[2] Through the State Office of the Commission for Natural Resources and Rural Development (DGCORENADER).

[3] Federal District Ministry of Environment [Secretaría del medio Ambiente del Distrito federal].

[4] Federal Ministry of Agricultura, Livestock, Rural Development, Fisheries and Food [Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación].

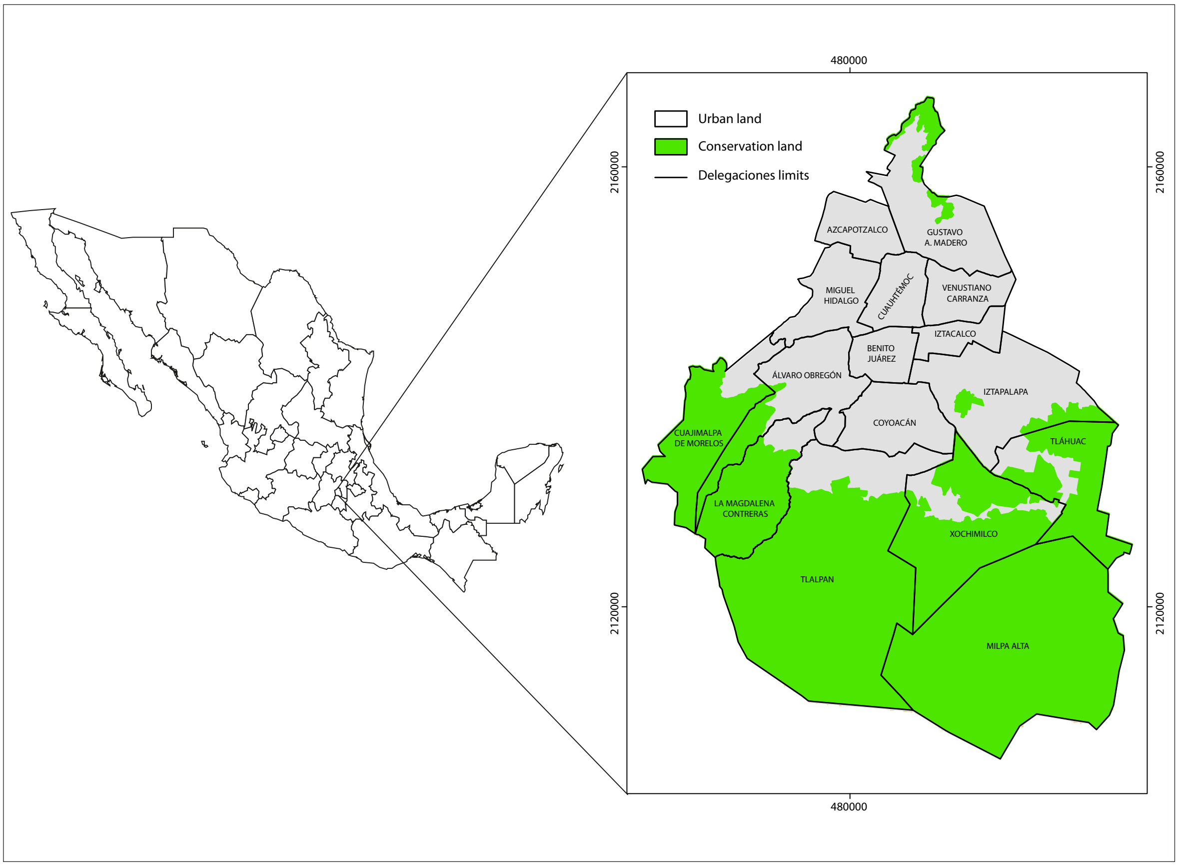


Figure 1. Conservation Area of the Federal District and its distribution across local government boroughs.

or 30% of all mammal species in the country, of which 14 are endemic; 211 bird species, or 10% of those in the whole country, and 25% of the species endemic to Mexico; and 24 amphibian species and 56 reptile species, representing 8% of the national herpetofauna.

In addition to the great biological diversity, the ecosystems of the CA generate other intangible benefits to society. Rosa *et al.* (2004) called them environmental services and they are vital and of great economic value to Mexico City.

The environmental service most widely recognized in the Valley of Mexico is the recharge of the aquifer from which is obtained 71% of the drinking water for the City (Centro Geo, SMADF and PNUMA, 2004). According to Torres and Rodríguez (2006), the most important zones for recharge are the mountains of Chichinautzin and Las Cruces (at the south-west of the D.F.), whose average annual infiltration capacity is, respectively, 2.5 and 2.0 million litres of rainwater with a net value of USD $\$0.19/m^2$ and USD $\$0.15/m^2$. In addition, the vegetation of the CA captures carbon at an average of 90 ton/ha; this represents its contribution to mitigating the effects of climate change (Centro Geo, 2002).

Other environmental services provided by the CA include the relative stabilization of the microclimate, the containment of emissions of pollutants and suspended particles, and soil protection by the plant cover, which results in a reduction of erosion and of sediments in water storages and drainage channels. Finally, it can be considered as an environmental service that it has recreational and scenic value, little recognized and much used (Centro Geo, SMADF and PNUMA, 2004).

The CA is inhabited by ~850 000 persons distributed in 35 agricultural nuclei (28 landholding cooperatives and 7 communities) and owners of private plots of land, in legal and illegal human settlements (*Ibid*.). Some of them live by producing crops (nopal cactus, maize, vegetables, ornamental plants and forage, etc.) and cattle (GDF, 2000). The agricultural zone, nearly all rain-fed crops, is a belt running from west to east at mid to low altitudes between the Urban Land and the forests along nearly all the local authorities except Cuajimalpa, Álvaro Obregón and La Magdalena Contreras.

Like most other cities of the world, Mexico City has spread over the natural ecosystems and agricultural areas that surround it (Lu, 1999). Although there are differences in the values reported for the loss of the CA by the advance of the urban sprawl (partly because they have been estimated by different methods), what is certain is that this zone is rapidly changing. The losses reported vary from 279 ha/year (GDF, 2000), to 300 ha/year (GDF, 2003), to 495 ha/year (Simón, 2004).

Despite the General Programme of Ecological Regulation for the Distrito Federal (Programa General de Ordenamiento Ecológico del D.F.; PGOEDF), many threats continue gradually to affect the CA, such as land use change due mainly to urban growth, and also forest fires, poor agricultural practices, erosion caused by loss of plant cover, and illegal felling and hunting. The PGOEDF map was conceived as an objective, but the mechanisms for achieving it are lacking.

METHODS AND TECHNIQUES

For the model of analysis and cartographic integration, the available existing maps in universities, research centres and government agencies were identified and assembled, with information on land use, vegetation, biodiversity, threats and variables related to conservation and environmental services. The *metadata* (data originating in the cartographic archives) of the maps obtained had to have the minimum information necessary for their use and interpretation and had to include the whole of the CA.

The fraction of the CA in the northern part of the D.F., which corresponds to the Sierra de Guadalupe, was not included since insufficient cartography was found for this zone.

Once the cartography had been assembled, it was homogenized and processed with *Arc View 3.3* and *Arc GIS* 9.0 software, with the following final characteristics: archives type *shape*, projection UTM (Universal Transverse Mercator) Zone 14, *Datum* WGS84[5] and Clarke ellipsoid 1866.

All the maps used correspond to the period 2000-2005. With regard to scale, most are 1:50 000; only the one for species richness is at 1:250 000 and the one for land use and vegetation is at 1:10 000. The maps of rural villages, illegal settlements and road systems also are at 1:10 000 and were only combined among themselves.

When it was necessary to combine maps, the product was assigned the smaller scale and its interpretation took into account the loss of detail generated by the process of combination (Mas and Fernández, 2003).

Some 60 maps were reviewed and 27 were selected; in these were analysed the tables of attributes for classifying or reclassifying the data and generating 11 base maps; these were then analysed independently and combined, with two foci of attention: conservation (detecting areas of ecological importance) and threats confronted by the natural ecosystems (Table 1).

All original and derived maps and databases can be found in the Ecological Regulation branch of the SMA of the D.F., since most of them form part of the studies carried out by various institutions for the operation of the PGOEDF[6] or of internal studies carried out by the Secretariat management.

The maps were verified on a high-resolution *Quick Bird* 2005 image, using the experience acquired during four years in the area and also by consulting experts.

In addition, with the aim of combining various base maps and obtaining easily interpreted derived maps, classifications were determined on the basis

[5] World Geodetic System 84 [Sistema Geodésico Mundial 1984].

[6] General Ecological Land Use Program [Ordenamiento Ecológico del D.F.].

Table 1. Original metadata of the base maps used and the cartographic products generated. All the maps are in UTM Zone 14 projection

Base map	Source	Scale	Date	Datum	Cartographic product
Incidence of fires	DGCORENADER	1:50 000	2000-2005	NAD27	Reversible threats
Risk of erosion	UAM	1:50 000	2000	NAD27	
Deforestation	DGCORENADER	1:50 000	1997-2000	NAD27	
Rural villages, localized developments and urban infrastructure	DGCORENADER	1:10 000	1998 actualizado a 2005	WGS84	Irreversible threats
Illegal human settlements	DGCORENADER, SEDUVI and Boroughs	1:10 000	2005	WGS84	
Road systems	D.F. Land REgistry	1:10 000	2000	NAD27	
Aquifer recharge	CentroGeo	1:50 000	2005	WGS84	Environmental services
Species richness	CONABIO	1:250 000	2000	NAD27	
Carbon capture	CentroGeo	1:10 000	2005	WGS84	
Land us and vegetation	SMADF SAGARPA	1:10 000	2005	WGS84	Zones with environmental value because of ecological importance
PGOEDF	SMADF	1:50 000	2000 updated 2005	WGS84	Threats and conflicts for regulatory compliance

of the maximum number of classes that could be differentiated at the scale used (1:50 000).

The results were checked in the field with eight passes averaging four days each, through the whole of the CA from 2005 to 2007.

Base maps

Incidence of fires (Figure 2.1): this map incorporates information from the records of fires from the State Office of the Commission for Natural Resources and Rural Development (DGCORENADER[7]), during 2000-2005, on 100 ha quadrants. Incidence was classified according to the number of fires registered into the following: Low (1-5 fires), Moderate (6-10), High (11-30), Very high (31-50) and Extreme (>50). The base map was generated considering only the categories High and Very high in a sum of maps from 2000 to 2005.

Risk of erosion (Figure 2.2): map of polygons compiled from data on soil texture and slope, obtained from edaphological and topographical maps at 1:50 000 from INEGI,[8] 1970, augmented with data on plant cover obtained from a map drawn up by UNAM as input for the PGOEDF decreed in 2000. The map was validated with a three-dimensional model in GIS and with the map of *land use and vegetation 2005*. The areas with steep slopes denuded of vegetation, or near roads, are the areas at most risk of erosion. The original map had a quantitative classification and was re-classified qualitatively (*very low*, *low*, *moderate*, *high* and *very high*).

Deforestation (Figure 2.3): archive of polygons compiled in the DGCORENADER for the forested zones from the map of land use and vegetation of INEGI 1970 and from the map drawn up by UNAM as input for the PGOEDF decreed in 2000.

[7] Natural Resources and Rural Development Comittee General Office [Comisión de Recursos Naturales y Desarrollo Rural].

[8] Statistics, Geography and Informatics National Institute [Instituto Nacional de Estadística, Geografía e Informática].

This map shows the areas where original woods have been lost between the two dates. On this base map, inconsistencies in the classification of tree density on the peaks of volcanic cones (classified as grassland, grassland-pine, pine-grassland, or 'open' pine woods) were corrected on the basis of interpretation of the *Quick Bird* 2005 image and field work.

Rural villages (RV), Localized Developments (LD) and Urban Infrastructures (UI) (Figure 2.4): the base map comprised information on the polygons of the RV, LD and UI registered in the PGOEDF. In the case of the LD, although ~25% of their surface area is not built on, complete polygons are included because urbanization is allowed in these.

Illegal human settlements (IHS) (Figure 2.4): map of polygons constructed by the DGCORENADER which shows the locations of the IHS. The map is based on a digital cartographic version from 1998, updated with a *Quick Bird* 2005 image, showing the polygons of properties built in areas where they are not permitted. It was used as a base map without modification, solely verifying the contents with the same 2005 image.

Road systems (Figure 2.5): prepared by the DGCORENADER, this map is an archive of lines that show the distribution of road systems in the CA. To reflect the effect that these have, on the base map they are drawn with different thicknesses to simulate their area of influence on each side. The area of influence was determined in the field, by measuring on both sides of the road the distance between the edge of the road system and the limit of the buildings constructed along the roadside. The sizes were included in the table of attributes of shape, and are as follows: motorways, 200 m; main roads, 500 m; arterial roads and streets, 50 m; dirt roads, 100 m; and lanes, zero.

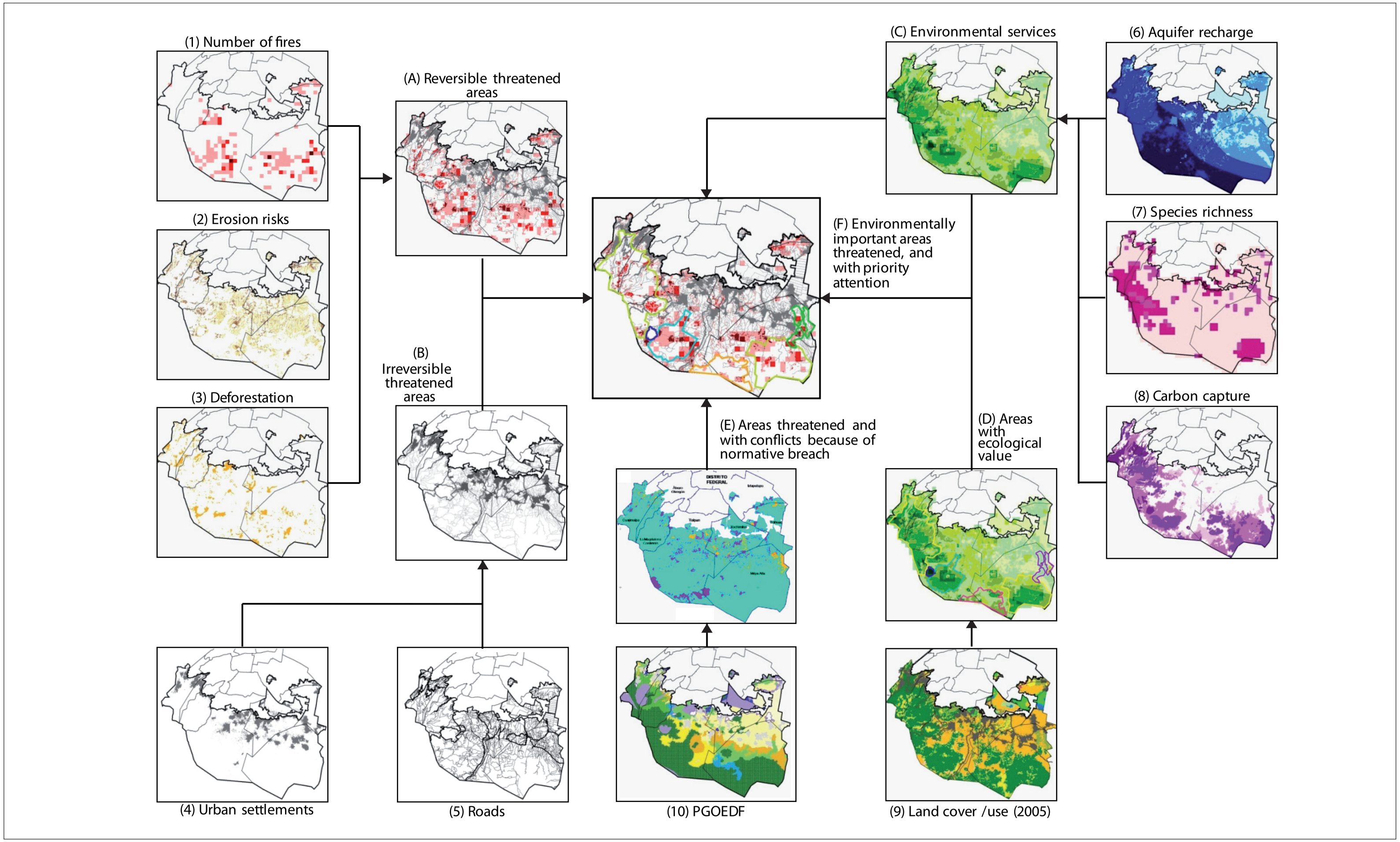
Aquifer recharge (AR) (Figure 2.6): map produced by the Centro Geo for the SMA. The map is of polygons and was obtained from data regarding geology, soil texture, hydrology, relief and precipitation, and at this level it was combined with a 2002 update of the land use map produced by the same Centro, to eliminate the new urban zones that are considered to be impermeable. The base map contained a qualitative classification of six classes (*minimum*, *low*, *medium*, *high*, *very high* and *highest*) and was used without modification.

Species richness (Figure 2.7): archive produced for CONABIO[9] with information recorded in 100 ha quadrants. For the base map a qualitative classification had four levels (*low*, *moderate*, *high* and *very high*), since the *shape* contained only data with the number of species recorded per quadrant.

Carbon capture (CC) (Figure 2.8): archive of polygons generated in 2005 by the Centro Geo with a qualitative classification of seven classes basically associated with the vegetation type and land use: *low* (scrub and open forest, oak-woods), *moderate* (pinewoods-grassland and pine-fir [*Abies religiosa*]), *high* (pine forests), *very high* (*A. religiosa* forests), *urban*, *water bodies* and *unclassified* (grasslands, crops, mines). The base map was modified to reclassify it into six categories, considering the grasslands and the crop zone with a minimum CC value; these sites were identified from the *land use and vegetation map, 2005* (SMA/GDF and SAGARPA, 2006). The revised classification was as follows: *nil* (urban, water bodies, mines), *very low* (pastures and crops), *low* (scrub and open forest, oak-woods), *moderate* (pinewoods-grassland and *Pinus-Abies religiosa*), *high* (pine forests) and *very high* (*A. religiosa* forest).

Land use and vegetation (2005) (Figure 2.9): produced for the DGCORENADER, this map is of polygons created from supervised automated classification of satellite images *Quick Bird* 2005, and *Spot* 2004, and visual interpretation of aerial photographs, 2005, and intensive verification in the field (SMA/GDF and SAGARPA, 2006). The original had 19 categories and was simplified: crops were grouped under the generic name of agriculture (principally oats, nopal, maize, vegetables and flowers); the types of forest under a single one (conifers, oak and mixed); and greenhouses and agroforestry, reforestation and other uses all in one category ('other uses'). The other categories remained unchanged: scrub, grassland, aquatic vegetation, other plant communities, mines, water

[9] National Commission for the Knowledge and Use of Biodiversity [Comisión Nacional para el Conocimiento y Uso de la Biodiversidad].



1) Incidence of fires 2) Risk of erosion 3) Deforestation 4) Human settlements 5) Roadsystems
6) Aquifer recharge 7) Species richness 8) Carbon capture 9) Land use and vegetation (2005) 10) PGOEDF
A) Zones with reversible threats B) Zones with irreversible threats C) Environmental services
D) Zones of environmental value because of their ecological importance E) Zones of threats and conflicts through regulatory compliance
F) Areas of environmental value, their threats and priority for attention

Figure 2. Diagram of methods, integration of base maps for generating cartographic products.

bodies and urban. The map had ten categories with the aim of making it easier to combine with other maps.

General Programme of Ecological Regulation of the D.F. (2000) (Figure 2.10): the map reflects the regulations in force for the CA. The proposed zoning determines the activities that are most appropriate for suitable land use with a focus on conservation. Its production involved analyses of the geology, edaphology, topography and vegetation with digital cartography, followed by field verification. It was approved on 28 April 2000 by the Legislative Assembly of the D.F. as PGOEDF (GDF, 2000).

The map used was the version updated by DGCORENADER in 2005; it was not officially published but it records the modifications to the polygons designated Protected Natural Areas and LDs that are surrounded by the CA.

Cartographic products

The base maps were combined, superimposed or united in GIS with the basic tools of spatial and statistical analysis available with the software that was used, in order to obtain integral and reclassified maps designated *cartographic products*; in these, threats differentiated as either reversible or irreversible are conspicuous on the zones of great environmental value. These zones were defined according to their level of conservation and to the quantity of environmental services that they offer (Table 1).

Map of reversible threats: (Figures 2.A and 3.1): this was produced by combining the maps of fire incidence, erosion risk and deforestation; these are variables identified as impacts on the environment that are capable of reversal by means of preventative, recuperative and restorative strategies. The classification identifies solely the number of threats present (*one*, *two* or *three*), without specifying the type.

Map of irreversible threats: (Figures 2.B and 3.2): this was produced by superposition of the base maps of urban variables (IHS, RV, LD, UI and road systems), which, because of their degree of consolidation or their legal basis, are considered to be irreversible. It shows sites that have been transformed to urban use and roadways, and assesses their degree of influence.

Map of environmental services (Figures 2.C and 3.3): this is the product of the combination of the base maps of AR, CC and species richness (SR); it shows the sites as a function of their environmental value according to the contribution of these three environmental services.

Because the base maps have qualitative categories that are not comparable, their combination required several stages. A weighted matrix was produced (with the data of its table of attributes); in the columns were entered the categories of the AR map and in the rows those of CC (Table 2), and quantitative values were assigned 2:1. The double proportion was for the AR map because it was the more reliable and precise, because of the importance that this service has for Mexico City, and because the maps of CC and SR are directly associated with vegetation type so this variable would be being considered again when the second combination of maps was produced. The numbers obtained in the matrix were divided into four ranks so that each was a qualitative category of the resultant map. This new map was combined with the one for SR which, too, had four (qualitative) categories, and in this way a second weighted matrix was obtained. The resultant map was classified in different ways with three, four, five, etc., and the final map had ten categories with an increasing value of ES, since this classification clearly distinguished the sites of greatest environmental value in accordance with these three variables.

Map of zones of environmental value because of their ecological importance (Figure 2.D). Analysis of the base map of land use and vegetation (2005) allowed identification and digitalization of seven zones that are important because of their degree of conservation, type of vegetation and area, following the indicators used by CONABIO (2008) and INE[10] (2007) to weight their relative environmental value. These indicators are as follows: *a*) area covered by the conserved vegetation; *b*) contribution to the continuity between plant

[10] National Institute of Ecology [Instituto Nacional de Ecología].

Table 2. Matrix of values of aquifer recharge and carbon capture

Highest (10)		Aquifer recharge					
		Very high (8)	High (6)	Medium (4)	Low (2)	Lowest (2)	
Carbon capture	Very high (5)	15 very high	13 very high	11 high	9 moderate	7 moderate	7 moderate
	High (4)	14 very high	12 high	10 high	8 moderate	6 moderate	6 moderate
	Moderate (3)	13 very high	11 high	9 moderate	7 moderate	5 low	5 low
	Low (2)	12 high	10 high	8 moderate	6 moderate	4 low	4 low
	Very low (1)	11 high	9 moderate	7 moderate	5 low	3 low	3 low
	Urban (0)	10 high	8 moderate	6 moderate	4 low	2 low	2 low
	Not evaluated (0)	10 high	8 Moderate	6 moderate	4 low	2 low	2 low

Note: In parenthesis the weighting assigned to each category in the original maps in the proportion 2:1, as described in the Methods. The values in the table derive from summing the weighting assigned to the corresponding categories.

communities; *c*) presence of native vegetation or relicts thereof; *d*) presence of endemic species; and *e*) a land surface free from urban infrastructure. To each of the seven polygons was assigned a point for each characteristic presented, and the sum total represented the environmental value.

Map of threats and of conflicts in compliance with regulations (Figure 2.E). This is a product of the combination of the base maps of the PGOEDF and of land use and vegetation (2005). This combination allows identification of the following: *a*) zones where the land use corresponds to that indicated by the PGOEDF; *b*) zones where the land use contravenes the activities permitted by the PGOEDF; and *c*) zones where the PGOEDF does not protect areas with natural vegetation. In order to attempt to overcome the differences of scale between the maps, on the map resulting from the combination were eliminated those polygons of less than 50 ha so that those analysed would be those of the greatest area and, as a consequence, greatest conflict; note that the objective of this product is to identify the 'warning lights', not to analyse all the polygons in detail.

Final product

The cartographic products were superposed and analysed, evaluating and weighting the information on impacts or threats and the environmentally important zones, obtaining as the final product the following map.

Map of zones of environmental value, their threats and priority of attention (Figures 2.F and 3.4). The maps of zones of environmental value for their degree of ecological importance and of environmental services were analysed, and were compared with and superimposed on those of reversible and irreversible threats and conflicts through non-compliance with regulations. This allowed identification of the zones of environmental value with respect to their threats, and action was prioritized. The map shown does not present the ESs, since the classification obtained is highly complex and would not be able to differentiate in a statistical image. The order of attention required by the areas was defined by considering for each of them the sum of the values (from one to four) of the variables of ecological importance and ES, and those of the reversible and irreversible threats (Table 3).

RESULTS

This study establishes an order of priority for attention to the zones of the CA, based on the identification of areas of environmental value and the threats that confront them. The base maps and the cartographic products are the graphic representation of the analytical approximations that allow achievement of the final result, but in themselves they carry specific information that is capable of

Table 3. Priorities for attention for the areas of environmental value in the Conservation Area of Mexico, D.F.

Areas of environmental value and level of services that they supply		Threats			Valor environmental value	Threat	Order of priority
Areas of value because of their degree of conservation	CA that they supply	Fires, deforestation, erosion	Urban growth	Inadequate land use (except urban)			
Forest on Malacatepec volcano (4)	Very high (4)	High (3)	Low (1)	High (3)	8	7	1st
Oak wood in Milpa Alta (3)	Medium (2)	High (3)	Very high (4)	Very high (4)	5	11	2nd
Scrub in Milpa Alta (3)	Medium (2)	High (3)	Very high (4)	Very high (4)	5	11	2nd
Forest on Tláloc volcano(4)	High (3)	Medium (2)	High (3)	Low (1)	7	6	3rd
Western forest (4)	High (3)	High (3)	Low (1)	Medium (2)	7	6	3rd
Forest on Pelado volcano (3)	High (3)	High (3)	Medium (2)	Medium (2)	6	7	4th
Forest on Chichinautzin volcano (4)	High (3)	Low (1)	Low (1)	High (3)	7	5	5th

being incorporated into programmes of action and public policy decisions for the protection of the CA of the D.F.

Base maps

Incidence of fire (Figure 2.1). Four zones with high incidence of fires were identified: *a*) Sierra de Santa Catarina between Tláhuac and Iztapalapa, *b*) the Ajusco volcano, *c*) the slopes of the Pelado volcano in Tlalpan, and *d*) a discontinuous strip that extends from east to west to the centre of Milpa Alta.

Risk of erosion (Figure 2.2). This shows that all the CA is at risk of erosion, but the zones found to be at greatest risk were as follows: *a*) the south-west of the D.F., particularly the southern slope of the Ajusco volcano in Tlalpan; *b*) the mountain zone to the south of Xochimilco; *c*) the Sierra de Santa Catarina to the north of Tláhuac; *d*) the zone of the motorway and the federal highway to Cuernavaca at the eastern centre of Tlalpan, which had the highest values (field study showed these to be due to poor agricultural practice, namely cultivation with furrows running down the slope and an absence of soil conservation measures); *e*) the ravines bordering the city with IHS in Cuajimalpa, Álvaro Obregón and La Magdalena Contreras; and *f*) the zone where the Magdalena and Agua de Leones rivers rise, to the south of those same communities.

Deforestation (Figure 2.3). This threat occurs throughout the CA, particularly in the zone of transition between urban and agricultural lands and in a more continuous form in the zone of transition between agriculture and forestry.

Rural villages, localized developments, urban infrastructure and IHS (Figure 2.4). The IHSs grow around the urbanized areas along the border of the CA, of the road systems and of the rural settlements, and the most consolidated are regularized by means of LDs; this leads to the generation of 'islands' or fragments of natural vegetation within the CA.

Road systems (Figure 2.5). In addition to the fragmentation of the ecosystems, there has been an increase in the road systems linked to the IHSs and to agricultural zones that have invaded the forests. The ones with the greatest effect are as follows: *a*) the Mexico-Toluca highway, which fragments the Cuajimalpa forests; *b*) the Mexico-Cuernavaca motorway and highway, which cut through the Tlalpan forests at two points; and *c*) the México-Oaxtepec highway in Milpa Alta, which affects the largest relict oak forest of the CA. Nevertheless, roadways in general have good and bad points:

although they affect the ecosystems, they also facilitate communication and provide access for reforestation, fire fighting and patrolling.

Aquifer recharge (Figure 2.6). The area with the greatest aquifer recharge extends from the Pelado volcano towards the north-west, as far as the peak of the Ajusco volcano (Tlalpan), and towards the south-east as far as the middle of the Milpa Alta territory (Chichinautzin volcano). Within this area, the agricultural centres of Parres and Topilejo (Tlalpan) are major contributors to the recharge of the aquifer; but these are also zones with a high risk of erosion and a major effect of IHSs.

Species richness (Figure 2.7). There are four zones with high species richness: *a*) the Sierra de Las Cruces to the west in Cuajimalpa, Álvaro Obregón, La Magdalena Contreras and Tlalpan; *b*) the Tláloc volcano in Milpa Alta; *c*) the Pelado and Malacatepec volcanoes in Tlalpan; and *d*) a strip at the border between the Conservation Area and urban land in the central part of Xochimilco. When the 2005 map of land use and vegetation is superimposed on the 2000 map of species richness, the human settlements cover almost the whole of this last zone.

Carbon capture (Figure 2.8). The zones with the greatest carbon capture are associated directly with the forested areas. The particularly important ones are those of sacred fir and pine in the south-west of the D.F. in Cuajimalpa, Álvaro Obregón, La Magdalena Contreras and western Tlalpan, the forests of the Pelado volcano in central Tlalpan, joined with those of the Malacatepec volcano and those of Chichinautzin (Tlalpan and Milpa Alta), as well as those of the Tláloc volcano in Milpa Alta.

Map of land use and vegetation, 2005 (Figure 2.9). This was analysed fundamentally in order to identify zones of environmental value on account of their ecological importance, and to generate the corresponding cartographic product. Owing to its quality and precision, this map was used to analyse and update all the base maps and cartographic products.

The main zones of ecological importance corresponded to four large areas of forest (to the west, and on the Pelado, Chichinautzín and Tláloc volcanoes); the woods of Pelado and Chichinautzín that are connected with those of the Malacatepec volcano and to the east of Milpa Alta, the relicts of both oak forests and natural scrub that are the most important on account of the area that they cover in the CA.

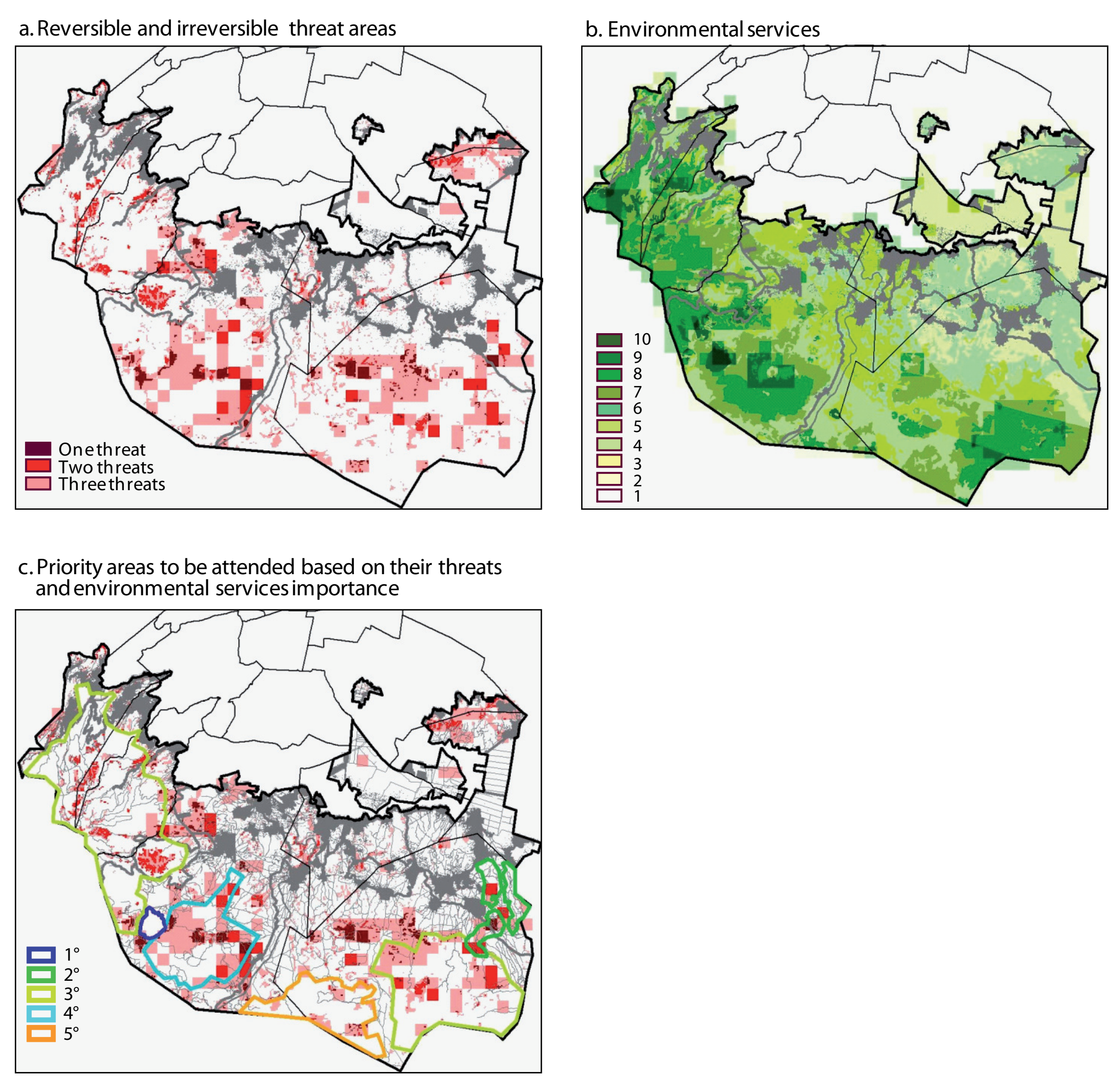
Other results of the analysis of this map show that most of the urban zones (RV, LD, UI) and small agricultural areas occur in the transition zone between urban land and the Conservation Area; the central part of the CA has a strip of agricultural zone, and the south and south-west have wooded areas that are being fragmented by agriculture. The grasslands lie in the zones of highest altitude, mainly in the west, south and east, and the humid scrub and water bodies mainly to the east.

Cartographic products

Reversible threats (Figures 2.A and 3.1). The zones with all three threats (erosion, deforestation and urban and road development) and therefore worthy of immediate attention are distributed throughout the CA. The approximate areas of the largest of these zones are as follows: *a*) to the south of the 'Mexico City Ecological Park' in Tlalpan, 200 ha; *b*) to the north of the Pelado volcano in Tlalpan, 200 ha; *c*) from the eastern slope of the Pelado volcano to its summit, 700 ha; *d*) the forests to the north of the Chichinautzin volcano in Milpa Alta, 300 ha; *e*) the western slope of the Tláloc volcano in Milpa Alta, 300 ha; *f*) the north-eastern slope of the Tláloc volcano, 400 ha; and *g*) a strip of 300 ha that crosses the Eastern Milpa Alta forests towards an important relict oak wood.

Irreversible threats (Figures 2.B and 3.2). The results show the strong and extensive pressure of these threats, principally in the band of transition at the borders between the CA and urban land and also in the environs of the Sierra de Santa Catarina and along the highways and motorways to Toluca, Cuernavaca and Oaxtepec.

Environmental Services (Figures 2.C and 3.3). There are four zones with a value of 10: *a*) to the south-west of Cuajimalpa 100 ha, just where the IHSs end at the side of the Mexico-Toluca motorway; it is all the more important because it extends towards the south to encompass 500 ha with a value of 9; *b*) to the south-west of Tlalpan 30 ha,



a. Zones with reversible threats in the Conservation Area of the Distrito Federal (through incidence of fires, risk of erosion and deforestation) and zones with irreversible threats in the Conservation Area of the Distrito Federal (urban infrastructure).
b. Environmental services in the Conservation Area of the Distrito Federal (aquifer recharge, carbon storage, species richness).
c. Areas of environmental value, their threats and priority of attention in the Conservation Area of the Distrito Federal.

Figure 3. Cartographic products (1-3) and integration map (4) showing priorities for attention in the Conservation Area of the D.F.

on the lower south-western slope of the Ajusco volcano, which although small and pressured by a change of land use to agriculture, has particular importance because it is very near 300 ha with a category of 9; *c)* the peak of the Malacatepec volcano in Tlalpan, with 200 ha, surrounded by 400 ha of category 8; *d)* to the south-west of the Tláloc volcano in Milpa Alta, 30 ha that extends southwards to reach a 150 ha category-9 zone, both of these being surrounded by 3 500 ha of category 8. Among the category-9 zones, the following are notable in the Tlalpan borough: the Pelado volcano with 700 ha, surrounded by 1 600 ha of category 8 and the south-east of the Ajusco volcano with slightly more than 100 ha surrounded by 600 ha of category 8.

Zones with environmental value owing to their ecological importance (Figure 2.D). The seven zones identified according to the indicators used by CONABIO (2008) and INE (2007) are as follows:

1. The largest forested zone of the CA has 11 600 ha of pine, oak and sacred fir forests; it was weighted with a value of 4 and is distributed across the south-west of the boroughs of Cuajimalpa, Álvaro Obregón and La Magdalena Contreras.
2. The forested zone of the Pelado volcano has 3 850 ha of mixed woods and pine forests, its weighting is 3 and it lies in the central-south of the borough of Tlalpan.
3. The forested zone of the Chichinautzin volcano has 3 460 ha of pine and fir forests and a value of 4; it is on the southern border of Tlalpan and Milpa Alta.
4. The forested zone of the Tláloc volcano has 7 255 ha of mixed woods and pine forests, has a value of 4 and is to the south-east of Milpa Alta.
5. The forested zone of the Malacatepec volcano has forests of pine, fir and oak. Its value is 4 and it is on the south-west of Tlalpan where it forms a corridor between zones 1 and 2.
6. A relict of oak wood with an area of 500 ha east of Milpa Alta with a value of 3, which adjoins zone 4.
7. The zone of scrub east of Milpa Alta has 3 points and covers 900 ha.

Map of threats and of conflicts in compliance with regulations (Figure 2.E). Visual analysis of the map identified the zones that contravene PGOEDF regulations, and they occur mainly in the transition strip between the CA and urban lands. However, some of these activities are exercising a historically established right, since they were occurring before the PGOEDF ruling. The natural vegetation identified here as without protection is a fragment of scrubland in Tláhuac, perhaps the result of abandonment of agricultural land.

Map of zones of environmental value, their threats and priority of attention (Figures 2.F and 3.4). Analysis of the areas of environmental value because of their ecological importance and those that are under reversible or irreversible threats (Table 3) established the following order of priority for attention:

1. The forested zone of the Malacatepec volcano because it is the largest area within the CA to have been assigned a value of 10 and because it connects two important forested areas as well as being under a high level of threats.
2. The relicts of oak woods and scrubland on the east of Milpa Alta because, despite having the lowest environmental value (among the seven most important areas), they are the most threatened and, being so small, could easily be lost altogether.
3. In this category are two zones: the forests on the west and those of the Tláloc volcano in Milpa Alta; the former represent the conserved zone with the largest area, and both have a high environmental value and almost the equivalent in variables that threaten them.
4. The forests of the Pelado volcano which have the lowest environmental value of the zones identified, but which are under the greatest number of threats.
5. The forests of the Chichinautzin volcano in Milpa Alta, because they have high environmental value; however, they have the lowest priority for attention because they are under the least threat.

DISCUSSION AND CONCLUSIONS

This method is an efficient tool for rapid identification of sites of high environmental value that are under threat; hence it aids the planning of conservation and preventive measures.

Field verification checked the state of conservation of the forested areas identified as having a high environmental value, and also checked the level of threat, above all in relation to fires, deforestation and urban growth, as is the case with fires seen in the forests that abut the grasslands and crop lands mainly in Tlalpan and Milpa Alta.

The proposed priority of action was confirmed, even to the level of discovering that the relicts of oak wood and scrub of the Milpa Alta borough (priority 2) have greater disturbance than that catalogued in the model; this indicates the speed with which the ecosystems are deteriorating and hence the necessity to take immediate action in dealing with them, in accordance with the definition of priority for maintaining the supply of the environmental services that have been evaluated.

This fact also demonstrates the need for frequent updating of the model in order to maintain its currency not only in terms of information and its quality but also because of the potential it represents as a basis for monitoring and the construction of the historical environmental record of the Conservation Area of the Distrito Federal.

The results obtained can contribute in the same way to the development of territorially differentiated policies appropriate to the local problems encountered.

The work did not include variables that define cultural importance or (because they are completely contained within the urban area) zones such as the chinampas of Xochimilco and Tláhuac and el Cerro de la Estrella; this did not have serious ecological drawbacks in the use of the method, but it needs to be considered in the near future.

The method also allows spatial identification of information for planning specific actions such as the following: a more appropriate positioning of fire-fighting teams, their quarters and firebreaks for the most affected zones; better use of resources, directing them towards the most valuable zones for the conservation areas that contain them or towards those that are relicts of natural vegetation, or towards those that serve as corridors or connections between forests; or from the opposite viewpoint directing the resources towards the most severely deteriorated zones that require help: reforestation, conservation of soil and water, protection of species and updating of programmes such as the PGOEDF.

Despite the differences in timing and scale, the proposed model has demonstrated its usefulness for discerning general tendencies in the Conservation Area of the Distrito Federal.

The application of the model exposes the need for institutions that produce cartographic input always to include a description of the methods they have used. Government institutions should continue to generate geographic databases with data on the measures they undertake, by means of digitization and geo-referencing, in order to make them compatible and to improve the availability of information for planning and decision making.

The quality of the results by this method suggests that it be taken as a model of environmental evaluation; it is recommended that it continues to be applied and that its use be validated as a process of monitoring the Conservation Area of the Distrito Federal.

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