VEGETATION CHANGES FROM LES LLAUNES NATURAL RESERVE (NE IBERIAN PENINSULA) AFTER SEVENTEEN YEARS OF MANAGEMENT: EVALUATION BY MEANS OF GIS

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VEGETATION CHANGES FROM LES LLAUNES NATURAL RESERVE (NE IBERIAN PENINSULA) AFTER SEVENTEEN YEARS OF MANAGEMENT: EVALUATION BY MEANS OF GIS

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GIS
CARTOGRAPHIE VÉGÉTALE
GROUPEMENTS VÉGÉTAUX
GESTION
PÉNINSULE IBÉRIQUE

RÉSUMÉ. – Dans ce travail nous avons évalué l'évolution de la végétation de la Réserve Naturelle des Llaunes au cours des 17 premières années de protection. Nous proposons une méthodologie pour évaluer les effets de plusieurs activités de gestion sur les écosystèmes des petits espaces naturels protégés du littoral. Cette méthode est basée sur l'analyse et la comparaison de cartes de végétation de différentes années, au moyen de systèmes d'information géographique. L'étude montre comment les variations de quelques facteurs des communautés végétales (groupe écologique, état de conservation et intérêt botanique) laissent détecter les changements les plus importants du système. Les zones où la végétation a subi les variations les plus considérables coïncident avec celles où les activités de gestion (inondation, pâturage, changement des utilisations du sol, etc...) ont été mises en application. Le travail montre comment une même action de gestion peut dériver vers des résultats complètement différents (positifs ou négatifs) selon la communauté végétale initiale.

GIS
DIGITAL CARTOGRAPHY
VEGETAL COMMUNITIES
MANAGEMENT
IBERIAN PENINSULA

ABSTRACT. – In this essay the changes of the vegetation cover from Les Llaunes reserve (NE Iberian Peninsula) are assessed throughout seventeen years of protection. We propose a methodology to evaluate the effects of several management activities on the vegetation in the small protected natural areas, based on the analysis and comparison of vegetation maps of the area made at different times by means of geographic information systems. The variations of the vegetation cover allows to detect, in a simple way, considerable changes in the system. The areas where the vegetation has undergone the most considerable variations coincide with those where management activities (flooding, grazing, change in the soil uses, etc.) have been implemented. The study shows how one same management action may derive into completely different results (positive or negative) according to the initial plant community.

INTRODUCTION

The management of protected natural areas implies actions by the managers focussed on the preservation and improvement of their natural heritage. Sometimes these are actions addressed to all the ecosystems, although they are usually focussed on a particular biological group (birds, mammals, flora, etc.). Then, the need of assessing the effect of these performances over the rest of the system at different time scales arises in order to determine this management's suitability. In the case of actions that do affect considerable surfaces and that are maintained during long periods of time, we must find systems able to detect the most significative system's trends at reasonable economic and personal costs. In this sense, the study of the vegetation evolution can be very useful given that spatial distribution of the communities depends strongly on the edaphic, hydrologic parameters and those related to soil uses by man. The variations or substitutions of the communities all through time allow us to locate the areas where the most considerable changes have taken place and to assess whether they are positive or not, as far as management goals are concerned.

The study of the temporal vegetation's evolution can be based on the interpretation of the different documents (texts, aerial photographs, satellite images) or, when they exist, of accurate maps of the territory's vegetation. The late development of digital cartography and that of the Geographic Information System (GIS) applied on the vegetation reports and natural areas management (Clarke *et al.* 2000, Gesti *et al.* 2001, Gumbricht 1996, Kadmon

& Danin 1997, Martin 2000) has also allowed to use it in studies on vegetation's evolution, especially from the analysis of aerial photographs at different periods (Feoli *et al.* 1992, Williams & Lyon 1991, Ubalde *et al.* 1999).

In this article, we propose the combination of periodic cartography and the GIS as a monitoring tool for the vegetation and the effects of the management in protected natural areas of small size. Protected from 1983 (Fig. 1), Les Llaunes reserve (wetlands of the Empordà, Iberian Peninsula) is taken as an example of study. It is an area of littoral saltmarshes and lagoons of about 523 ha, lying between the mouths of the rivers Muga and Fluvià, which used to belong to an ancient lagoon system disappeared because of the desiccation works promoted from the eighteenth century (Matas 1986, Vaqué *et al.* 1989). The reserve is composed of different Quaternary materials placed on parallel bands on the line of the coast and with a very flat surface, with topographical levels lower than 4m. Water entrances are mainly due to sea storms, precipitation, subterranean circulation and superficial channels. The piezometric level is close to the surface all over the area with high salt concentration (2-3 g/l) (Bach 1986, Serra *et al.* 1994, Solà *et al.* 1996). The vegetation, which is edaphogenic, is closely related to soil parameters, particularly the soil flooding level, salinity and texture; this favours the relationship between variations in the vegetation cover and changes in these parameters (Gesti & Vilar 1999).

This reserve is the area where most of the management activities of the natural park have been implemented and where most of the visitors go. The most outstanding activities have been the public areas delimitation and adaptation, the agriculture activities abandonment, the vegetation monitoring through grazing and the increase of floodable surfaces to favour bird life (Fig. 2).

MATERIALS AND METHODS

The starting point for the temporal evolution study of the vegetation from Les Llaunes reserve is, on the one hand, the vegetation map made by Velasco & Farràs (1983) on paper and, on the other hand, the map elaborated by the authors of this essay in the year 2000 on a digital format (Table I). Basic units of two maps are phytosociological communities following the sigmatist method (Braun-Blanquet 1979).

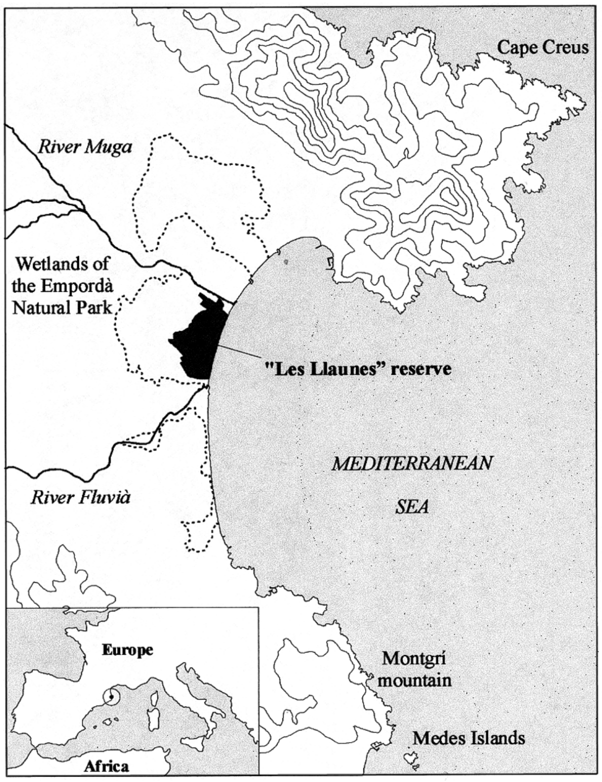

Fig. 1. – Map of the studied area (dotted line: Aiguamolls de l'Empordà natural park limit; shaded area: Les Llaunes reserve).

The map by Velasco & Farràs (1983) was scanned in order to turn it into a digital raster format, which was afterwards georeferentiated over the UTM projection through polynomial corrections based on known coordinates (by means of the GIS modules MiraMon® v.3, Pons 2000). Over this image, vegetation polygons were digitilised in a vector format respecting in the labelling the units from the initial legend.

For the elaboration of the map of the current vegetation, the first step was a photointerpretation of pictures taken from an ultra-light aircraft and of orthophotomaps of the area (ICC 1994). Afterwards, the polygons obtained were validated in the field and their phytosociological assignation were made by means of relevés according to the method of Braun-Blanquet (1979). The

Table I. – Features of the two compared vegetation maps.

	Velasco & Farràs, 1983	2000
format	paper	digital
scale	1: 5000	1: 3500
geographic projection system	--	UTM
Basic units	Phytosociological communities	Phytosociological communities
Number of polygons	516	619
Number of categories on the legend	55 (simple and complex)	45 (simple)

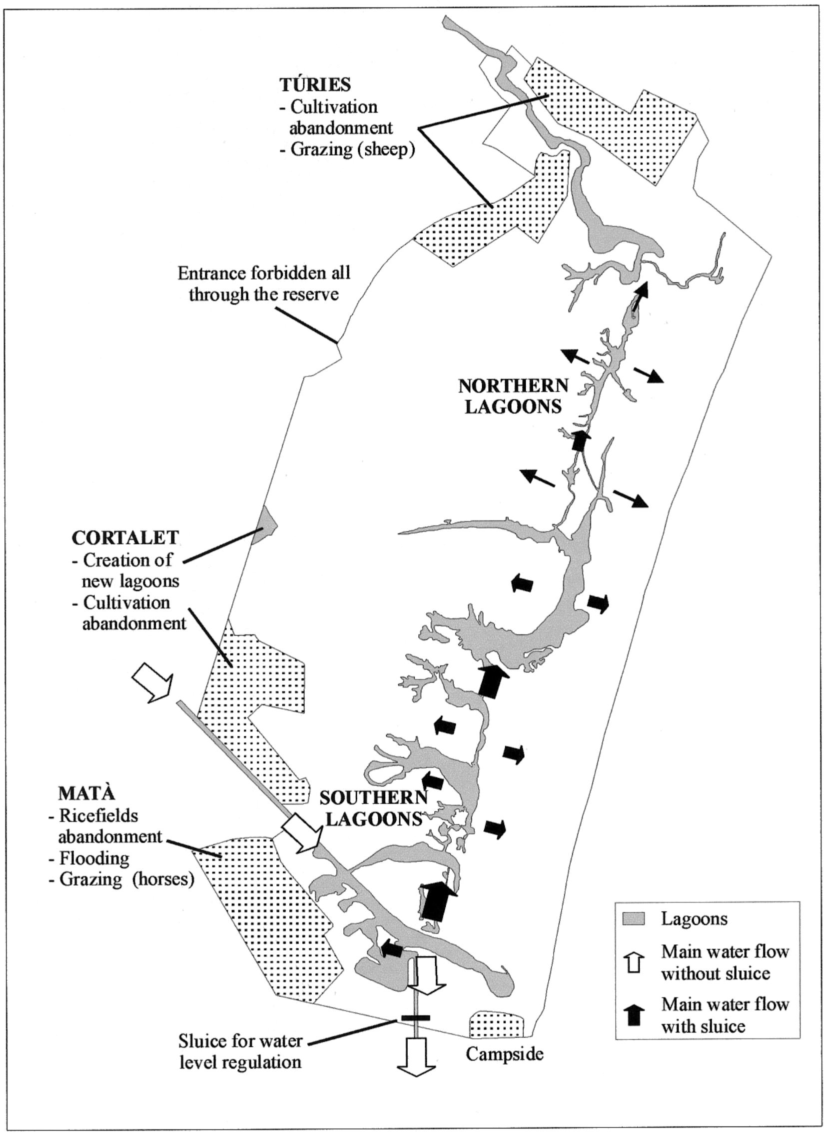

Fig. 2. – The main management activities carried out in Les Llaunes reserve (the white arrows indicate the water flow before the deployment of the sluice; the black ones indicate the water flow after the deployment of the sluice).

data obtained were digitalised on screen over the image of the orthophotomap so that it resulted, like in the previous case, in a vector map already georeferentiated over the UTM projection (Campos *et al.* 2000).

In order to be able to make a cartographic comparison of the two documents, both maps were included in a same GIS (MiraMon® v.3, Pons 2000), which allowed the reclassification of the legends and the superimposition of the maps in the common 449 ha.

With the goal of offering a methodology easy to repeat in the future, we decided to study the temporal evolution of the three parameters of the vegetation easy to be pulled out from the documents' legends: the ecological group (ECO), the vegetation conservation state (CON) and the botanical interest (BI). For each of these parameters a small number of categories was established, in order to make possible a reclassification of the initial legends of the two maps as simple and unmistakable as possible (Table II).

Ecological group (ECO): It is a very generic parameter, that gathers the communities according to large groups based on its edaphoecological preferences. In both maps, each vegetation unit is assigned to one of the following ecological groups:

0 – With no vegetation
HIG – Hygrophilous vegetation
HAL – Halophilous vegetation
PSA – Psammophilous vegetation
RIP – Riparian forest vegetation
RUD – Ruderal vegetation

Both maps elaborated from this new codification were digitally superimposed with the GIS in order to obtain a new map which allowed to bring out the areas where the ecological groups had changed between 1983 and 2000 ($ECO_{1983} \neq ECO_{2000}$).

Table II. – Values of the three parameters analysed for each legend unit of the maps (ECO: ecological group; CON: conservation state; BI: botanical interest).

UNIT	ECO	CON	BI
Lemno-Azolletum	HYG	3	1
Potamogetonetum denso-nodosi	HYG	4	3
Typho-Schoenoplectetum tabernaemontani subas. *typho-phragmitetosum*	HYG	4	2
Typho-Schoenoplectetum tabernaemontani subas. *phragmitetosum chrysanthi*	HYG	4	3
Scirpetum compacto-littoralis variant of *Scirpus maritimus*	HYG	4	2
Scirpetum compacto-littoralis variant of *Scirpus littoralis*	HYG	4	3
Paspalo-Polypogonetum viridis	HYG	3	1
Chaetomorpho-Ruppietum	HAL	4	2
Junco-Parapholidetum filiformis	HAL	4	4
Suaedo-Salsoletum sodae subas. *crypsietosum aculeatae*	HAL	4	4
Suaedo-Salicornietum patulae	HAL	4	3
Puccinellio-Arthrocnemetum fruticosi typicum	HAL	4	4
Puccinellio-Arthrocnemetum fruticosi (other subassociations and variants)	HAL	4	3
Degraded *Puccinellio-Arthrocnemetum fruticosi*	HAL	3	3
Artemisio-Limonietum virgati	HAL	4	4
Arthrocnemetum glauci	HAL	3	3
Spartino-Juncetum maritimi juncetosum variant of *Juncus maritimus*	HAL	4	4
Spartino-Juncetum maritimi juncetosum variant of *Juncus acutus*	HAL	4	3
Spartino-Juncetum maritimi subas. *spartinetosum*	HAL	4	2
Junco-Iridetum spuriae subas. *agropyretosum*	HAL	4	4
Schoeno-Plantaginetum crassifoliae	HAL	4	3
Grazed *Schoeno-Plantaginetum crassifoliae*	HAL	3	3
Formations of *Tamarix*	HAL	4	3
Cypero-Agropyretum juncei	PSA	3	2
Medicagini-Ammophiletum arundinaceae	PSA	3	3
Crucianelletum maritimae	PSA	4	4
Salsolo-Cakiletum maritimae	PSA	4	2
Rubo-Coriarietum	RIP	4	1
Populion albae	RIP	4	3
Chenopodietum muralis	RUD	2	1
Polygonion avicularis+Trifolio-Cynodontion	RUD	2	1
Trifolio-Cynodontetum	RUD	2	1
Plantagini-Hordeetum maritimi	RUD	2	3
Inulo-Oryzopsietum	RUD	2	1
Formations of *Brassica nigra*	RUD	2	2
Water	0	0	0
Buildings	0	0	0
Coast sands	0	0	0

Vegetation conservation (CON): This parameter reflects the maturity and conservation levels of the plant communities. From the notes on the original legends and the field observations, the conservation level was assigned to every unit of both maps according to the following categories:

0 – With no vegetation
1 – Anthropic vegetation
2 – Ruderal vegetation
3 – Degraded natural vegetation (low cover levels; vegetal communities not good structurated)
4 – Well-conserved natural vegetation

In the case of complex units from 1983 map, where several communities are combined, the CON final value corresponds to the mean of the index values of each of these units.

Afterwards, the new elaborated conservation maps were compared in order to detect the areas where vegetation had undergone an improvement ($CON_{2000} > CON_{1983}$) or a worsening ($CON_{2000} < CON_{1983}$) of its conservation level.

Botanical interest (BI): this parameter assesses the botanical rarity of each cartographic unit according to the territorial rarity of the community and of the species that compose it (Iberian Peninsula).

0 – With no vegetation

1 – Low interest (very common species and communities)

2 – Medium interest (not very common species and/or communities)

3 – High interest (rare species and/or communities)

4 – Very high interest (very rare species and communities)

Like in the previous case, the index of the complex units was obtained from the mean of the BI values of each community that composed it.

Thanks to the superimposition of both maps reclassified at GIS we detected those areas where the botanical interest had increased ($BI_{2000} > BI_{1983}$) and those where it had decreased ($BI_{2000} < BI_{1983}$).

RESULTS

Ecological group (ECO)

Figure 3 displays the distribution of the large ecological groups in both maps, generated from the reclassification of the 1983 and 2000 legends. The substitution of large ecological groups over 17 years took place in 26.62% of the total surface, with a considerable increase of the hygrophilous communities and a great decrease of the ruderal ones. The final surface inhabited by the halophilous vegetation was similar on both maps for a compensation between the surfaces where ruderal communities had turned into halophilous (24.99 ha) and those where halophilous communities had been substituted by hygrophilous (25.72 ha) (Table III). The most widespread variations corresponded to the ancient ricefields in the farm Matà (with a transformation of ruderal vegetation into hygrophilous), the ancient crops close to the farm Cortalet and farm Túries (from ruderal to halophilous) and the southern half of the lagoon system area (from halophilous to hygrophilous).

Other variations of a smaller superficial entity can be spotted in other points of the reserve: the surroundings of the Cortalet lagoon (change from halophilous vegetation into hygrophilous through spillage of fresh water), campsite on the SE edge (into a ruderal vegetation), alteration of several points on the coast, etc.

Conservation (CON)

Figure 4 shows the appraisal of the vegetation conservation state in 1983 and in 2000 according to the reclassification of the legends included on the original maps. We can see how the most altered areas in the reserve in 1983 corresponded mostly to the western half, because of both the existence of crop areas above mentioned ($CON_{1983} = 1$; 7.99 ha) and the presence of a considerable surface of degraded or little structured halophilous vegetation ($CON_{1983} = 3$; 24.43 ha). In the year 2000, most part of these areas showed a well constituted natural vegetation; therefore, the areas inhabited by these categories with low valuations had dramatically decreased in favour of a great increase of the surface with the highest valuation. As a whole, the conservation index increased in a total of 166.54 ha (Fig. 4) whereas it only decreased in 37.78 ha. The areas with a favourable evolution corresponded mainly to three locations: the ancient ricefields of the farm Matà converted into artificial wetlands; the ancient crops of the farm Cortalet and Túries; the areas on the central saltmarsh. On the other hand, a decrease in the conservation state was observed mainly in three different areas: firstly, in the southern coast lagoons, where *Ruppia* communities disappeared; secondly, in the NW area, because of the overgrazing of several areas with halophilous vegetation which involved a loss of structure and density in the communities inhabiting those areas; finally, on the SE edge, because of the enlargement of the adjacent campside.

Botanical interest (BI)

The evaluation of this value between 1983 and 2000 allows to detect the increase in the extent of particular communities or, on the other hand, its substitution for other communities, more ordinary in the territory. In general terms, in the year 2000 a total of 174 ha maintained a vegetation of a higher botanical interest than in 1983, in contrast to the 103 ha where this index had decreased (Fig. 5). The areas where this parameter had increased corresponded mainly to the western half of the reserve. On the other hand, halophilous communities from the central area in the saltmarsh maintained a reconstitution process.

Lagoons and neighbouring areas have underwent a decrease in the botanical interest index. Finally, the valuation index also decreased in other areas of a smaller extent, including the overgrazed zones of the north-western sector before mentioned.

DISCUSSION

In the protected area, the study of its current vegetation is not a sufficient parameter to assess the state of the system or the suitability of the management actions given that the current presence of a plant community can come either from a favour-

Table III. – Quantification of the areas affected by the main modifications in the ecological group.

vegetation changes (1983 → 2000)	area (ha)	%
no changes	329.80	73.38
halophilous → hygrophilous	25.72	5.72
ruderal → halophilous	24.99	5.56
ruderal → hygrophilous	17.38	3.87
halophilous → with no vegetation	12.91	2.87
with no vegetation → halophilous	11.80	2.63
psammophilous → halophilous	8.95	1.99
others	17.89	3.98
TOTAL	449.44	100.00

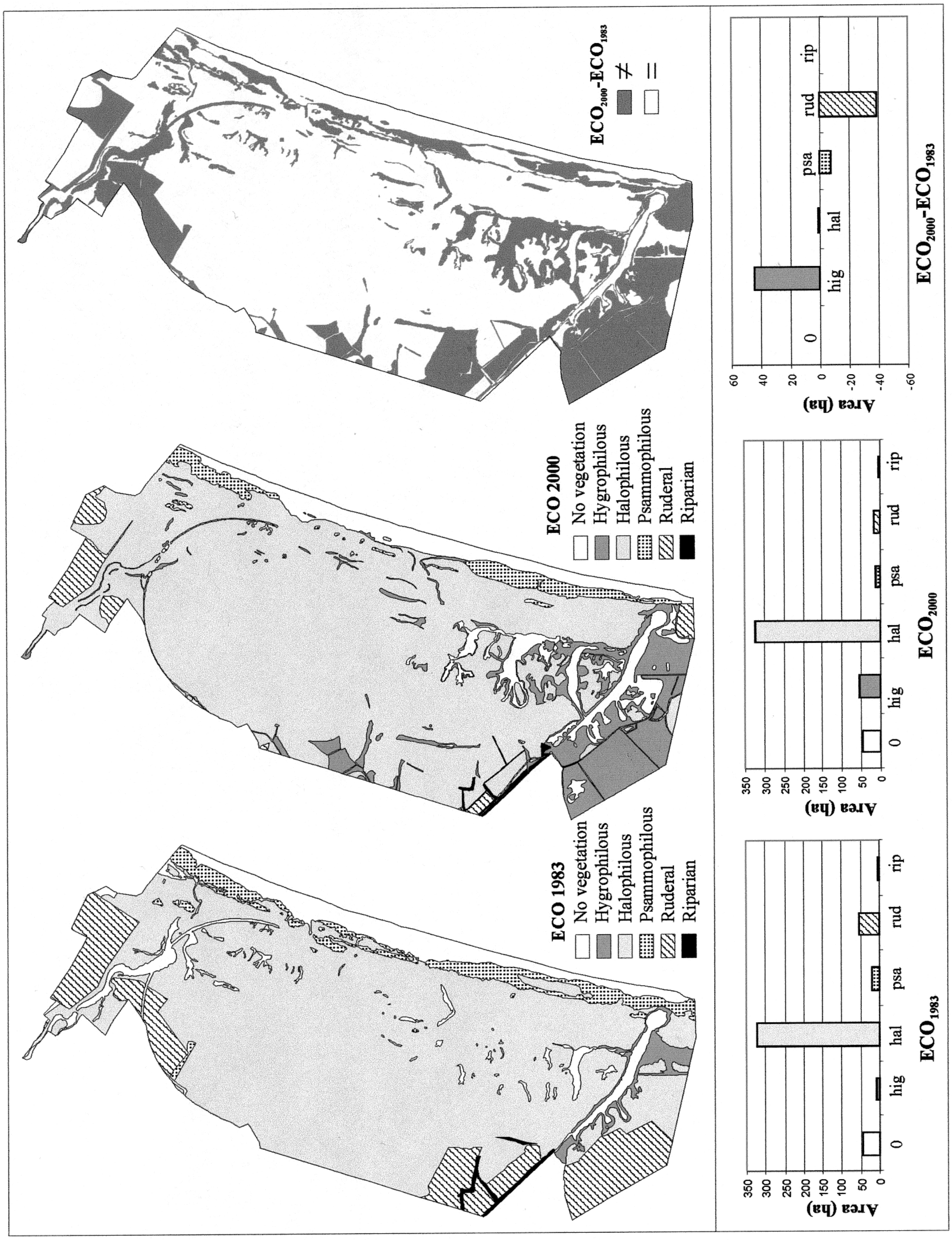

Fig. 3. – Variation of the surfaces inhabited by the different ecological groups (ECO) between 1983 and the year 2000.

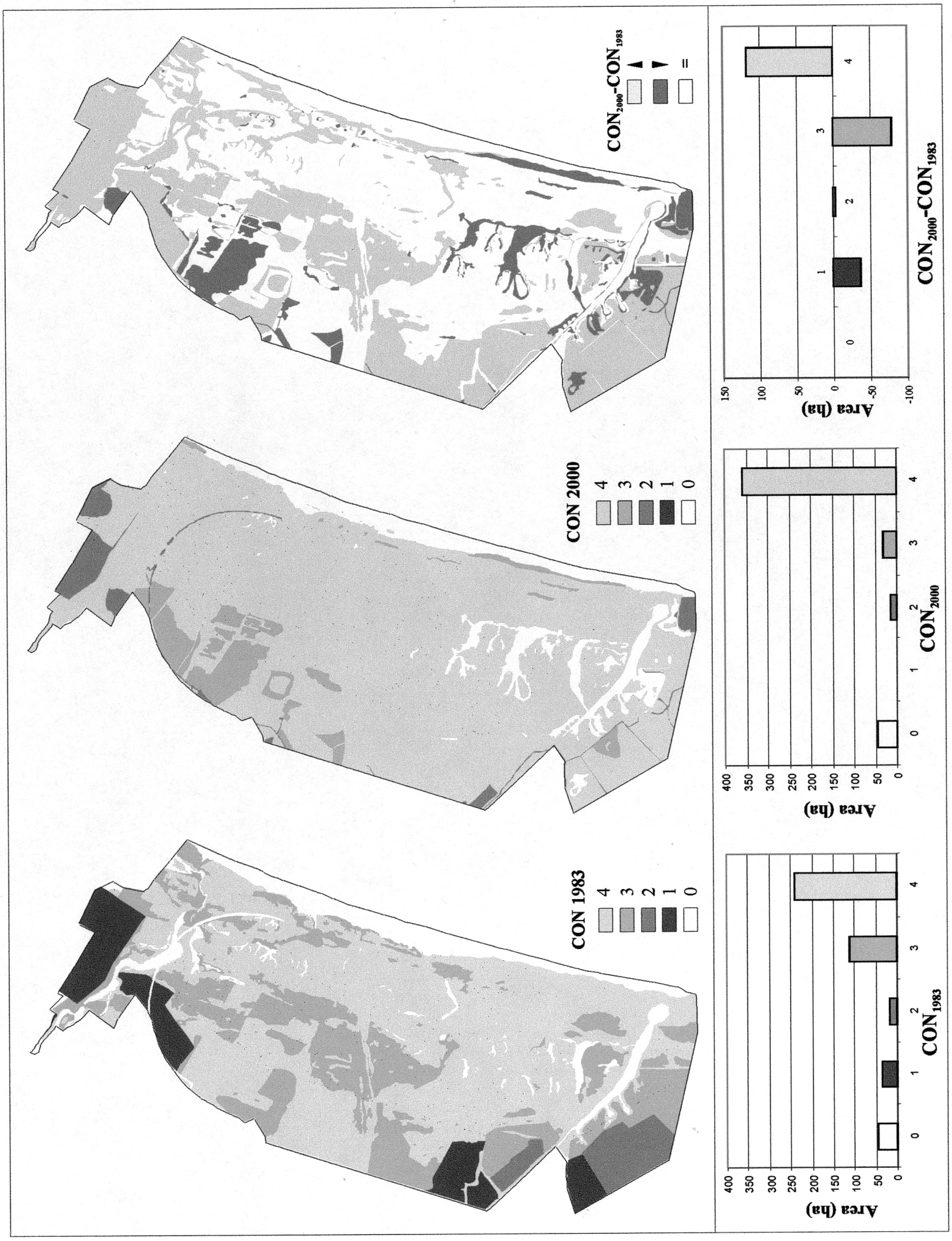

Fig. 4. Variation in the conservation index (CON) between 1983 and the year 2000.

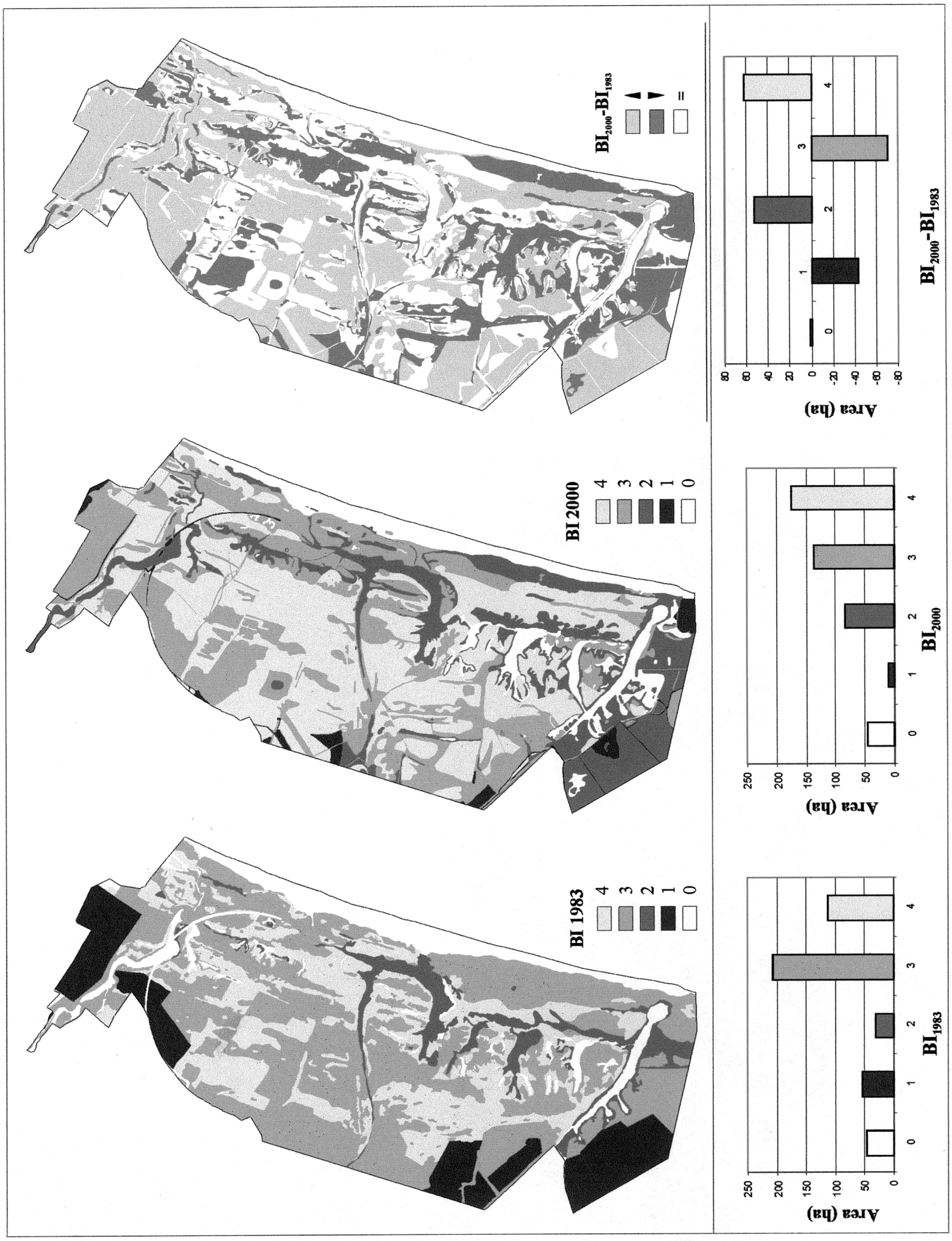

Fig. 5. – Variation in the botanical interest index (BI) between 1983 and the year 2000.

able evolution or from an unfavourable one depending on what the substituted communities are. Thus, in this paper we propose the analysis of the changes in the vegetation throughout the time to evaluate the management of natural spaces.

The analysis and comparison, by means of geographic information systems, of vegetation maps from Les Llaunes reserve shows considerable changes for the three parameters analysed during 17 years of protection (ecological group, conservation and botanical interest). The areas where the vegetation has undergone the most considerable variations coincide with those where management activities (flooding, grazing, change in the soil uses, etc.) have been implemented.

Temporal variations in the distribution of the large ecological groups summarized in the ECO parameter allow to detect changes of a great magnitude in vegetal population. These variations have to be necessarily associated with considerable changes in the environment or soil uses (changes in the flooding regimes, abandonment, pasture, etc.) which always involve the substitutions of certain communities for others which are adapted to definitely different edaphic and ecological conditions.

In the farm Matà area, the variation was caused by the change in the soil uses in that area. In 1983 the area was full of crops with ruderal communities (arvenses). In 1985 rice cultivation started; this activity was finally abandoned in 1990 when this area was turned into a wetland system managed by the natural park which persists today. The ancient plots for the ricefields are flooded with fresh water from the adjacent irrigation channel and a vegetation control is made by means of horse grazing (Sargatal 1995), following the experiences in other wetlands alike (Bakker 1985, Basset 1980, Gordon *et al.* 1990, Mesléard *et al.* 1991, 1995). Vegetation's evolution, under these conditions, produced a mosaic of hygrophilous communities of *Scirpus maritimus* (*Scirpetum compacto-littoralis* Br.-Bl. 1931 em. Rivas-Mart., Costa, Castroviejo et Valdés 1980), of *Typha angustifolia* subsp. *australis* and of *Phragmites australis* subsp. *australis* (*Typho-Schoenoplectetum tabernaemontani* Br.-Bl. et O. Bolòs 1957 subas. *phragmitetosum australis* O. Bolòs 1967).

The surrounding areas of the farms Cortalet and Túries were also inhabited by crops in 1983. With the natural park declaration, this agriculture activity stopped and nowadays the grazing of sheep is the only one allowed. The natural evolution of the vegetation in this area of the saltmarsh involved the establishment of halophilous communities, mainly *Arthrocnemum fruticosum* communities (*Puccinellio-Arthrocnemetum fruticosi* (Br.-Bl. 1928) Géhu 1976) and *Juncus acutus* formations (*Spartino versicolori-Juncetum maritimi* O. Bolòs 1962 subas. *juncetosum maritimi* O. Bolòs 1962).

The areas close to the lagoons in the southern half of the reserve underwent a transformation of the existing halophilous communities in 1983 into almost pure formations of *Phragmites australis* subsp. *australis*. This substitution is related to the change in the hydric regime promoted by the natural park from 1989, by which the fresh water entrance and permanence in the reserve increased by means of a sluice in the drainage channel of the most southern lagoon (Fig. 2). The 37 ha which used to get flooded before the flow regulation became a total of 260 ha of flooded area (Sargatal & Romero de Tejada 1995). The massive entrance of fresh water and at the same time with a high load of nutrients (from a drainage channel from an adjacent agricultural plain) involved a dramatic eutrophication and decrease in the salinity of the lagoons and areas close to them. This effect was noted all over the whole lagoon system, although it showed more pronounced in the southern areas, closer to the fresh water entrance point, where the process resulted in a rapid colonization of *Phragmites australis* over the ancient halophilous communities and in the disappearance of the grasslands of *Ruppia* from the lagoons' inside.

Variations in Conservation (CON) parameter (which assesses the conservation-maturity state of the communities regardless of the ecological group) allow to spot the areas where the vegetation has undergone a dynamic process either progressive or regressive. It is useful as a measurement of variations of a lower intensity which, like in the previous case, is not only related to substitution of communities, but also often to intrinsic variations in plant formations.

The areas with a favourable evolution corresponded mainly to three locations: the ancient ricefields of the farm Matà converted into artificial wetlands, where the establishment of hygrophilous communities had been favoured as before mentioned; the ancient crops of the farm Cortalet and Túries, subjected to a natural evolution by which halophilous communities were regenerated; the areas on the central saltmarsh, where the restriction of human activity allowed the maturing and recovery of the halophilous communities in a degradation state in 1983. On the other hand, a decrease in the conservation state was observed mainly in three different areas: firstly, in the southern coast lagoons, where *Ruppia* communities disappeared because of the loss of waters' salinity and transparency associated with the deployment of a sluice in the drainage channel; secondly, in the NW area, because of the overgrazing of several areas with halophilous vegetation which involved a loss of structure and density in the communities inhabiting those areas; finally, on the SE edge, because of the enlargement of the adjacent campside.

The Botanical interest (BI) parameter assesses together the taxonomic and phytosociological rarity. As it has been before described, the disappearance of the crops on the south-west (Matà, Cortalet) and north-west (Túries) edges favoured the establishment of hygrophilous and halophilous communities with a higher botanical value. On the other hand, halophilous communities from the central area in the saltmarsh maintained a reconstitution process favoured by the absence of vehicle and people traffic in the reserve.

On the other hand, the areas that underwent a decrease in the botanical interest index are mainly related to the areas affected by the flooding with fresh waters during the process of flow regulations through the sluice of the drainage channel on the southern edge. In these places (lagoons S), there took place the substitution of the halophilous communities in 1983 for hygrophilous and almost pure population of *Phragmites australis* subsp. *australis* of much lower botanical interest. Furthermore, from the most southern lagoons, *Ruppia* populations disappeared, which are characteristic from the saltwaters, because of an eutrophication and a decrease of the salinity of its habitats. The effect was also obvious, but lighter, around the northern lagoons, where halophilous communities were maintained but in many cases typical *Arthrocnemetum fruticosi* became *Spartino-Juncetum maritimi* or they incorporated hygrophilous taxons which denoted a certain decrease of the edaphic salinity. Finally, the valuation index also decreased in other areas of a smaller extent, including the overgrazed zones of the north-western sector before mentioned.

CONCLUSIONS

In this study, we establish a simple methodology to assess the long-lasting effects of the management actions over the vegetation in protected natural areas. The methodology used proposes the GIS as a tool of comparison and analysis of vegetation maps in different formats and elaborated in different years. The temporal variations in the vegetation cover are easily detected with simple parameters and with a small number of categories, what offers a methodology easy to be repeated in the future.

Due to the results described, there can be noted that the vegetation cover of Les Llaunes reserve has undergone a considerable modification between 1983 and 2000, both in the distribution of its communities and in its conservation state and, consequently, of its botanical interest. This variation has taken place both through natural processes, passive, and through active management of the natural park. In the first case, the very protection of the area, which allowed to avoid people and vehicles crossing it, favoured the natural recovery of the halophilous communities of the centre of the reserve which were considerably degraded in 1983. Similarly, the abandoned crops progressed towards natural communities with a higher biological interest.

The changes of a greater magnitude, however, are associated with the areas where there has been some kind of action, mainly changes in the soil uses, variations in the hydric regimes and grazing. There is not one same answer of the vegetation to each of these parameters but different results were obtained according to the starting point for each area.

The flooding with fresh water resulted in very satisfactory results in the ancient ricefields in the farm Matà where, starting from crop areas, we achieved to establish a mosaic of hygrophilous communities with high conservation and botanical interest indexes. On the other hand, the entrance of fresh water into the lagoon system of the saltmarsh involved an eutrophication and a decrease in the salinity causing the substitution of high botanical interest communities for populations of *Phragmites australis* of low valuation.

The grazing showed, likewise, this duality between satisfactory and undesirable results: on the one hand, in the ricefields of the farm Matà horses became a useful tool for the control of the vegetation favouring the diversification of the communities. The sheep grazing in abandoned crops of the farm Túries allowed the establishment of semihalophilous pastures which constitute seminatural communities which would not be possible without the existence of the stock. On the other hand, however, the effect of an excessive grazing on the natural halophilous communities (between Cortalet and the farm Túries) involved their degradation detected through the decrease in the conservation and botanical interest indexes.

Trying this methodology in Les Llaunes natural reserve (comparing the cartography of the vegetation previous to the area's protection with the current one), we have observed that satisfactory results have been achieved actively acting over the most degraded areas, but not over those that maintained a well-constituted natural vegetation. This fact would suggest that it is necessary to keep on working on these first areas and to let the vegetation from the better conserved areas to develop naturally.

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