Stakeholders, Scenarios and cellular automata; spatial modelling for decision making in Doñana and surrounding area.

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ABSTRACT: *Doñana National Park, object of the present study, demonstrates a very high rate of change in the configuration of land uses in the vicinity of the protected natural area. This is the result of both increased intensive agriculture and urban and infrastructure development outside the boundaries of the protected space. The changes detected are potentially hazardous to the natural values that have made Doñana worthy of the highest level of natural protection that it enjoys, declared a national park in 1969 and World Heritage natural property by UNESCO in 1994. Cellular Automata based land use modelling allows us to extend the trends observed in the dynamics of land use to a horizon of 25-30 years, generating future scenarios, simulations of possible future configurations of land uses. These scenarios form the basis for a discussion and consultation process through participatory workshops with key stakeholders in the territory, such as farmers, managers and researchers, about the future of the landscape (Palomo et al 2011). The main contribution of this paper consists of land use maps generated from the Doñana future scenarios for the AC model. We emphasize the participatory process, understood as part of the modeling chain itself, with the ultimate goal of contributing to a more sustainable future for Doñana and its territory.*

KEYWORDS: Participatory modelling, cellular automata, land use dynamics, Doñana, scenarios.

1 INTRODUCTION

The Doñana Natural Area (hereafter Doñana), comprises a system of interconnected ecosystems of outstanding importance for biodiversity. It was declared a national park in 1969 and is recognized as a world heritage site by UNESCO since 1994. Doñana has suffered, however, severe degradation and significant loss of large areas of marsh, dunes and coastal habitat since 1950. This has been the result of the expansion of tourism infrastructure, increased intensive agriculture, and the establishment of areas of afforestation with non-native fast maturing species such as eucalyptus. These processes have contributed to over-exploitation and pollution of the aquifer. Despite the implementation of a series of measures to promote more sustainable development for Doñana and its hinterland, this important natural space has continued to deteriorate, forcing us to rethink the current model of economic "production and consumption without limits" (Montes 2007), and strive for a more sustainable future. In this communication, we present results of the DUSPANAC project (funded by the Autonomous Body for National Parks, 2010 funding stream). Although the project is approximately mid-way through, some interesting results hava already been obtained. Here we present the land use modelling procedure employed in Doñana, based on cellular automata (CA). The software used in developing the model is called Metronamica ® and was developed by the Research Institute for Knowledge Systems (RIKS), Maastricht.

2 AIMS OF THE PAPER

The paper is divided into 3 sections:
1. Background.
2. Methodology, which describes the process of preparing the CA model (calibration), the development of a pilot model incorporating parameterization through participatory process and concurrent evaluation of the model.
3. Results of research on the dynamics of change within the natural area using technical-analytical and participatory methods and the use of the pilot model for the creation of future land use change scenarios within the Doñana.
4. Discussion and conclusions, with an appreciation of the lessons learned from the development of the AC model, incorporating participatory processes and the importance of future scenarios to support decision making in natural areas.

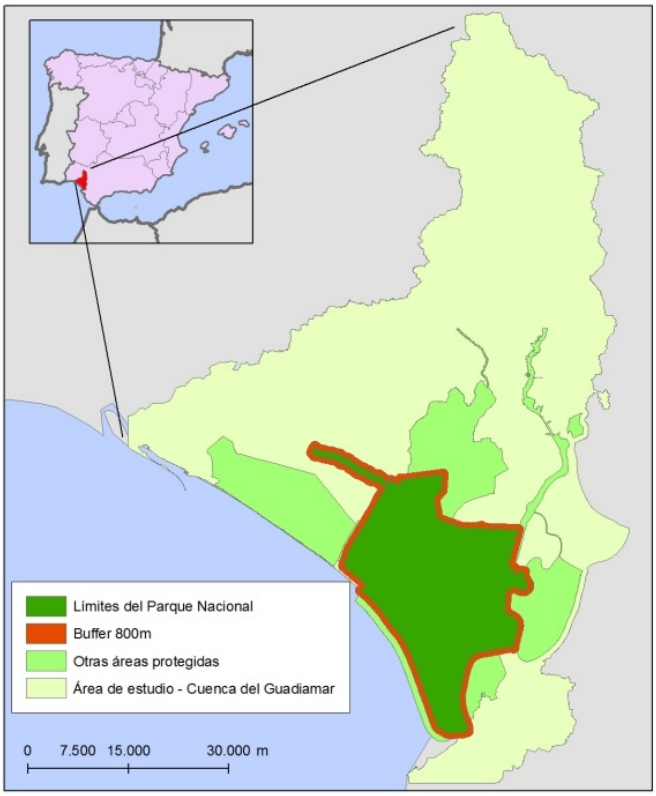

Figure 1: Doñana Natural protected area. The pilot model, described in this paper, including the national park (dark green), plus a buffer zone (buffer) of 800m.

3.BACKGROUND

3.1Modelling with cellular automata in natural areas

The application of the cellular automata technique to geographic al modeling was originally proposed by Tobler (Tobler 1979) and has subsequently been applied in numerous models of urban growth with the common goal of better understanding their evolution (Batty 1997; Couclelis 1997; Barredo and Gomez 2008; Cauvin et al. 2010). In the last 10 years, CA modeling of land use has expanded its focus to include non-urban studies (eg Wickramasuriya et al. 2009), and has progressed from pure description and explanation of change tendencies, to, for example, applied work in natural resource management and sustainable development (eg Lavalle et al 2004, EEA et al 2005, Hernández Jiménez and Winder 2006), integrated methodologies for participation and support for decision making (Kok and van Delden 2009) and assessment of natural hazards (Barredo and Engelen 2010). However, its application to the study of land use changes in the natural environment has been generally less profuse than in urban areas - although see Moreno et al (2007) - , mainly due to the difficulties of modeling changes that are less drastic and less rapid than those found in built up areas.

In Doñana, the researcher finds two worlds, often at odds, conservation on the one hand and development on the other. The social-economic development of the area has been based mainly on tourism and intensive agriculture. This has transformed the region over 60 years, going from being one of the poorest areas of Spain to enjoy a level of income above the national average (Montes 2007). At the same time, recognition of the importance of Doñana natural space and provider of ecosystem services has increased, leading to measures for its protection. Unfortunately, during the same time period, the areas bordering the protected area have been degraded, thus beginning to suffer from the effects of proximity to the protected area (eg, see Muñoz-Reinoso 2001). This shows that the current management model, in which conservation and development are seen as inevitably opposed, has entered a crisis phase. Although the cause of the problem is obvious (a regional development model that is shortsighted and does not respect the environment), its solution is not at all obvious, because of the close link between the regional economy and the type of development (intensive exploitation of resources) that threatens the natural area. In this context, we discuss here the contribution of spatial dynamic modeling as a powerful tool for understanding this kind of complexity. Its strength in this area stems from its ability to represent the many different perspectives that stakeholders may adopt and the direct consequences they may have for the territory.

Beginning with an analysis of the patterns of change and the threats to the natural space implied by these changes, the CA model is applied in conjunction with a participatory process. This has allowed us to explore the possible future consequences of these changes, thus leading to a series of recommendations for regional planning. If the CA model allows the representation of complex and mutually exclusive choices in geographic space, the participatory process ensures that the study does not omit the human dimension and lose its real world applicability.

3.2 Forecasting alternative futures for Doñana: land use scenario modelling

Modelling of changes in land use offers a robust methodology for projecting alternative paths into the future through the creation of future scenarios, expressed as simulated land use maps, which attempt to replicate the processes or key dynamics of change in the territory. The construction of scenarios allows use to forsee possible consequences of any change processes already underway, to assess spatial planning policies by implementing them in a virtual environment, to evaluate and monitor the sensitivity of land use configurations to hypothetical drivers of change, and to test the stability of social and ecological systems (Veldkamp and Lambin 2001). If driving or constraining change dynamics are given adequate consideration within the modeling environment it is possible to represent the possible consequences on the landscape of the challenges that nature is facing, in the form of future land use scenarios. Therefore, the development of future scenarios forms the cornerstone of the modeling of land use. Although traditionally implemented in urban areas, their use includes, for example, the assessment of impacts on natural resources in Ecuador (Koning et al

1999), desertification in the Guadelantín basin in Spain (Kok and Van Delden 2009), and the implementation of the SRES scenarios of the Intergovernmental Panel on Climate Change (IPCC) to Europe (Rounsvell et al 2006).

Scenario modeling is normally developed in two stages: in the first, the scenarios are created based on a narrative that seeks to express future events (known as storylines), and is often done through participatory processes. In the second stage, these scenarios are incorporated in the dynamic model for subsequent expression in cartographfic form as "estimates" of the possible configurations of land use for a future date. This paper focuses mainly on the second part of this process. We present the results of the pilot model, which explored the process of representation of three scenarios developed by the research team through the modelling software. In the near future, the DUSPANAC project will incorporate more detailed scenarios, developed together with stakeholders involved the management of this territory (see Palomo et al 2011).

3.3 The participatory process

To date, traditional non-participatory methods have neither failed to slow the degradation of the natural area nor unite the opposing worlds. However, in recent years, the idea that another Doñana is possible has begun to difuse. From the perspective of the services it provides (including the regulation of air quality and water, the provision of habitats and biodiversity, etc.), both tourism-related activities such as leisure and food production are beginning to see the direct benefits of environmental conservation (Montes et al 2010, Martin-Lopez et al 2011). Only by working from the bottom up with all stakeholders in the territory is it possible to achieve a future Doñana that benefits all parties. The common objectives for Doñana, a shared and sustainable territory emphasize the need for local and consensual management that takes into account the whole of the natural area, rather than an enclave protected by severe restrictions within, and *laissez-faire*-type management outisde of it.

In this project, therefore, it was important to involve stakeholders with knowledge of Doñana in the modeling process, achieving greater involvement of landscape stakeholders in the model, and allowing the incorporation of their knowledge. As Voinov and Bousquet (2010) have note, the concept of "consultation" with businesses, citizens, and stakeholders on environmental decisions that affect them is not new. In terms of participatory modeling, participation has demonstrated its validity throughout a long trajectory that begun with studies like those of Forrester (1961) and Wagner and Ortolando (1975). However, it is still too common to find supposedly participatory processes that have been subsequently appended to almost completed projects as "value-added".

As a result, the DUSPANAC project aimed to apply participatory processes as broadly as possible, involving stakeholders, not just as passive onlookers in a valedictory workshop, but from the beginning of the process in the identification and definition of the dynamics to model and parameters that should be included in the model to represent them. The benefits of this method goes beyond an independent evaluation of the modeling work, or even wider dissemination of project objectives. Perhaps even more important that these is the fact that this methodology allows the research team and local stakeholders to approach each other and start a process of shared learning and participatory research, with a greater chance of reaching common goals noted previously (Kok and Van Delden 2009).

4. Methods

4.1 Modeling land use with Cellular Automata (CA)

The software Metronamica ® belongs to a class of models known as cellular automata, or CA, as its structure is based on a matrix or grid of cells in which each cell is assigned a value. The cells in the model are autonomous, ie, they are able to attract, repel, or occupy cells in their neighborhood depending on the rules set by the user, in a process called transition, allowing the model evolve step by step to attain very complex configurations from simple initial states. Values representing land use categories are assigned to the cell matrix to allow simulation of the dynamics of land use transformation. In this way, maps are obtained, representing the possible configuration of land use at a future time. In the case of the DUSPANAC project this system was applied to develop a model of future land use change.

4.2 Description of the model

In Metronamica, beginning with an initial raster map in which each cell is assigned to a land use class, the future land use configuration will be determined by the susceptibility of each cell to take another value, ie to change to another land use. For each step of the model, therefore, it is necessary to calculate the Transition Potential (PT) - the potential for each cell to change from one category to another. Four variables determine whether a cell is likely to change category. These variables are: *Suitability* - physical conditions of each cell to be occupied by a certain category (in Metronamica typically considered physical, ecological and environmental attributes), *Zoning* (or institutional suitability) such as the level of protection for certain areas of natural value, *Accessibility*, such as proximity to major roads and their quality to meet the mobility requirements of the activities associated with the different categories of occupation and *Neighborhood dynamics* - the behavior of surrounding cells relative to a specific cell, causing a cell having one particular land-use to affect the viability of existing neighboring cells (RIKS, 2011). The total transition potential is calculated from the product of *suitability, zoning, accessibility* and *neighborhood dynamics*, and to avoid over-determinism, a stochastic parameter is applied. Thus, where ${}^{t}R_{f,c}$ is *Neighborhood dynamics*, ${}^{t}A_{f,c}$ es *Accessibility*, ${}^{t}Z_{f,c}$ *is Zoning* , $S_{f,c}$ is S*uitability* and α is a stochastic factor chosen from the Weibull distribution, the product of the variables, PT (${}^{t}P_{f,c}$) is obtained from the following formula;;

$$ {}^{t}P_{f,c} = {}^{t}R_{f,c} * {}^{t}A_{f,c} * {}^{t}Z_{f,c} * S_{f,c} * \alpha \quad (1) $$

The total amount of change for each land use is controlled by the *demand*, which is determined by factors exogenous to the model. In the case of an urban model, demand could be determined (for example) by the relationship between population and urban expansion. In the case of a non-urban area, as in the case of the DUSPANAC project, other factors, such as climate change (high temperatures and water shortages) or increased profitability of certain crops, such as crop intensive irrigation, could affect demand, and as a result, the final configuration of the simulated map.

Although the Metronamica model was originally developed to simulate urban dynamics, it can be adapted to other kinds of simulation transitions land use (as has been the case in this project). Of course, the task becomes more complicated for cases where the modeled uses do not evolve step by step. Simulation of agricultural occupation of adjacent land, for example, is unlikely to present much difficulty. However, the simultaneous conversion of multiple hectares of rainfed crops to irrigation is difficult to simulate through neighborhood rules. Transformations of this type can be represented in zoning parameters, using an active stimulus for irrigation over the area of change.

4.3 Creating future scenarios

The scenarios were developed in a nonlinear fashion through calibration and experimentation with the model, combined with workshops held at key points in the process that served to update both researchers and participants and also to introduce new information. In this way, experimental or "pilot" scenarios were developed in order to represent the dynamics observed from the analysis of land use change carried out beforehand. Through participatory workshops (see diagram, Figure 2, below), stakeholders examined these same land use change dynamics and established the most suitable parameters for modeling the natural area.

Figure 2: Simplified flow diagram showing the process of participatory modeling of future scenarios. Top to bottom, Analysis of land use dynamics, participatory analysis (left), pilot model (right), Provisional scenarios, participatory evaluation of provisional scenarios, final scenario. Legend indicates analytical-technical tasks in white, participatory task in grey and joint discursive-analytical tasks are hatched.

4.4 Participatory process Methodology

The participatory process was based on the Participatory Action Research (PAR) methodology, an approach with recognised applicability in rural development (Chambers 1983) and the management of natural resources (e.g. Castellanet and Jordan 2002) since the 60s. PAR tries to break down the barrier between researcher (subject) and participant (object of study), in order to involve local people in their own research to solve the problems identified.

From an initial process of identifying the most appropriate local stakeholders (Hewitt et al 2012 in press), a series of workshops were held with the simultaneous aim of informing participants about the model and also to gather key information from stakeholders for model parameterization. Although the aim was to be as inclusive as possible, in the initial workshop the number of participants was limited to those who could best contribute to achieving the objectives, ie the parameterization of the model, with the possibility of increasing the number and type of participant in subsequent workshops. One of the key activities of the first participatory workshop was to gather the views of stakeholders on land use changes that have been observed in Doñana from previous studies. To this end, participatory analysis of observed dynamics was undertaken as follows:

Working in groups, the 3 questions were discussed for each of the 9 examples of the dynamics exposed. The information discussed was transferred systematically into written form (yellow, blue, pink postit notes). Presentation of the work of each group to all participants was carried out by spokespersons appointed from within each group, who were in charge of transferring the coloured postit notes with the decisions agreed onto the wall chart. Extensive information about this workshop is available at http://www.geogra.uah.es/duspanac/taller2.html

4.5 The development of future scenarios for Doñana.

Once the model had been calibrated, we proceeded to the development of future scenarios that could result from changes the dynamics seen in the park. On the basis of the dynamics observed from the technical analysis (cross tabulation) and participatory analysis (discussed with stakeholders) three scenarios of future land use for the national park and its surroundings were developed. The scenarios were developed based on simple storylines, with the main objective of projecting into the future what broadly seemd to be the most important characteristics of the natural area to encourage discussion and check the operation of the pilot model. Although the study area to be modelled will be significantly extended in the following phases of the project, in order to understand the whole area of influence of the conservation area, for the construction of the pilot and the preparation of the interim stage the modelled extent was restricted to the national park and its neighbouring "buffer" zone of 800m. The reason for this was to allow the changes that most directly threaten the park to be defined and modelled in a small area that is easy to handle, before inquiring into the complicated dynamics of a larger area.

USE	ha 1990	ha 2000	ha 2006	E1 2030	E2 2030	E3 2030
TC	407	407	451	517	781	517
TUD	6	6	6	6	6	6
ZC	53	53	38	15,5	15,5	15,5
IDR	13	65	65	143	455	143
TRP	419	369	351	249	249	249
F	100	241	241	452,5	452,5	2000
MC	0	50	50	125	125	125
MBT	3307	4464	4939	7387	7387	7387

Table 1, demand for dynamic land uses, according to scenarios, E1 = business as usual, E2 = expansion of urban centers and tourist infrastructures, E3 = massive expansion of fruit and berry plantations. See Appendix I for Legend of the land use categories.

Scenario 1: business as usual. This scenario is used as a starting point for simulation, 3o years into the future, the continuation of the changing trends observed between 1990 and 2006. Demand for 2030 was calculated for each use from the difference in area occupied by each use between 1990 and 2006, divided by the number of years, giving a growth rate per year. This annual rate of change was added to the rate of change for each use in 2006, to reach the demand for 2007. Demand for 2007 was increased by the same amount to calculate the demand for 2008 and so on until 2030 (Table 1). Creating a baseline or business as usual is standard practice and reveals the possible future effects on the territory of the simple temporal extension of current patterns of change. This scenario allows us to know where the areas most sensitive to this kind of change are located.

Scenario 2: Expansion of urban and tourist infrastructures. The second scenario contemplates the possibility of urban expansion around existing urban centers, along with the development of facilities for recreation and tourism use, (as observed with the appearance of 52 hectares between 1990 and 2000). This scenario involves multiplying the annual demand by a factor of 5 for categories TUC and IDR.

Scenario 3: massive expansion of fruit trees and berry plantations: Finally, we created a more extreme scenario, to represent what might happen in the case of enhanced profitability of irrigated crops under category F, ie, red fruit and citrus. Although demand is extremely high (up to a total of 2000 ha in 2030, approximately 8 times the annual demand observed), the objective of the exercise was to identify the locations most sensitive to this transformation. It is important to emphasize that the usefulness of models such as this one consists mainly in displaying the possible outcomes or impacts of changes in the territory in a future time, not to give a precise picture of the future. For this reason, the most adecuate application is found in the area of decision-support, for the consideration in their entirety of complex trends produced by the pressure exerted on the protected area resulting from the competition of forces between different land uses.

5 RESULTS

5.1 Land use dynamics

The following changes were highlighted within the park based on the cross-tabulation analysis (Table 2, Annex I)

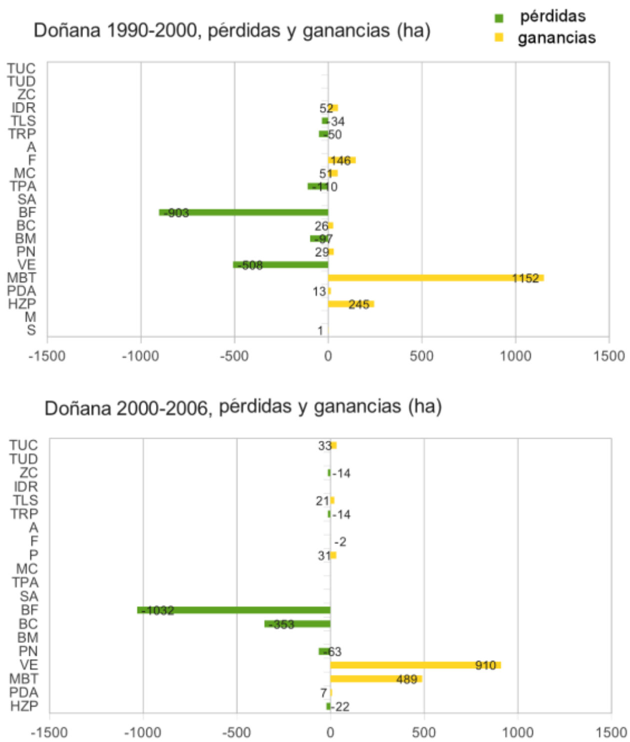

Table 2. Results of cross-tabulation analysis for Doñana national park and buffer 800m. See Appendix I for a legend for the land use categories.

Expansion of fruit and berry plantations (F) between 1990 and 2000 (intensive cultivation of citrus and strawberry). the uses who have experienced the greatest change in surface area are natural grasslands (PN) (55 ha), irrigated crops (TRP) (44 ha) rainfed crops (TLS) (30 ha) and sclerophyllous vegetation (VE) (15 ha). Other irrigated crops also increased with corresponding loss of VE and scrub (MBT). Clearly, these changes represent agricultural intensification, this has occurred in all cases outside the national park boundaries, within the strip of land excluded from the natural park. An area of 50 hectares of irrigated crops (TRP) in 1990 has become crop mosaic (MC) by 2000. In this way it can be seen that the uses TRP, PN, TLS and MBT have high potential to be occupied by F, and MBT, and VE will be vulnerable to occupation by TRP. Moreover, given the location of the new areas of intensive cultivation, zoning will play an important role in the model.

The vulnerability of this area to the development of tourism infrastructure is evidenced by the construction of a 52 hectare site (Sports and Leisure Facilities, IDR) between 1990 and 2000 in an area of shoreline natural vegetation (sclerophyllous vegetation, VE) in a small pocket of unprotected land associated with the seaside resort of Matalascañas. A 53 ha construction are can also be observed in the second period analyzed (2000-2006), 15 hectares of which have become urban fabric.

5.2 Results of the participatory process

Participatory analysis shed light on the drivers of change (causes and drivers) for a wide range of processes unknown to the researchers. For example, the loss of several hectares of cultivated lands along the Guadiamar corridor was attributed to the recovery of vegetation following the Aznalcollar mine disaster in 1998. Stakeholders also identified specific actions of the common agricultural policy (CAP) of the European Union responsible for the increase of certain crops such as rice. The stakeholders expressed low levels of trust in some of the dynamics represented in the mapping, for example, wetlands and forest fires. In the case of other dynamics, such as increasing irrigated crops (Table 3, Figure 3), some groups felt that the actual area of crops was not adequately represented. Those doubts by workshop participants with regard to the cartography used in the preliminary analysis and the pilot model confirmed the need to change to a different cartographic database for the following phases of the project.

Dynamic (clc) 1990-2006	**drivers of change (see key to locations)**	**gains/losses**	**reliability of dynamic as presented**	**group**
1. Loss of natural areas 1990-2006	1. Agricultural implementation. 2. Urbanization 3-4. unknown	1-4 gains to agriculture, losses to the environment	High in areas known by the group.	1
	1. Elimination of eucalyptus plantations 2. Intensive agriculture, strawberries and oranges. 3. Urban development	1. Gains to autoctonous vegetation 2-3. losses to autoctonous vegetation, natural areas, grassland etc, general habitat loss 2-3 No environmental gains whatsoever. Gains in terms of more jobs in relevant municipalities	Elimination of Eucaliptus should not be considered loss of natural areas, as it is remove to make way for natural vegetation.	2
	- Public development policy - ilegal occupation, lack of effective control from land planners. - Land planning directive for Doñana and hinterland (PDTC) Doñana environmental management plan (POTAD)	gains: intensive crops losses: pine forest gains: pine plantations losses: *dehesa* grasslands losses: ecotonal areas, some influence on el Rocio marshland areas	High	3

Table 3. Example of one of the nine change dynamics analyzed in participatory workshops

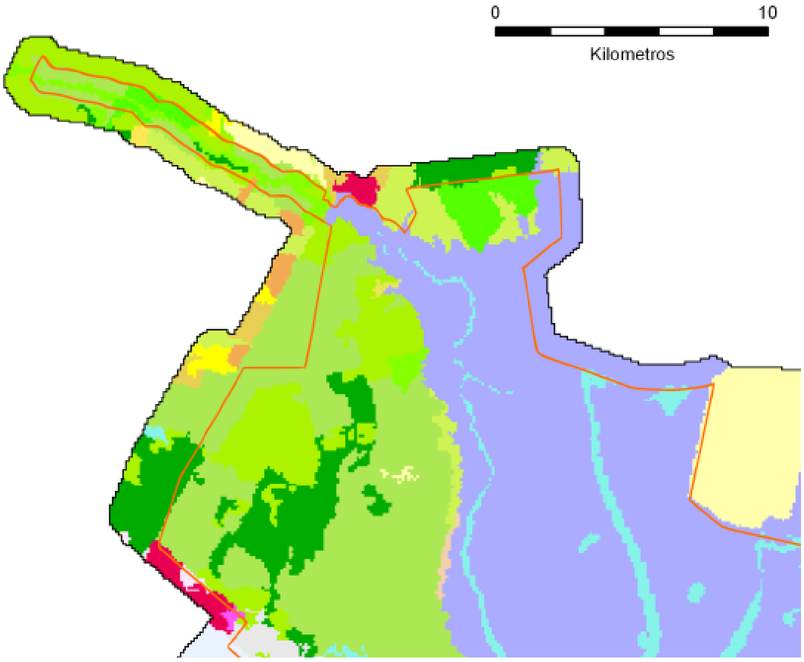

Figure 3 (above). North of the study area showing the border zone (800m buffer) of the National Park in 2006 (Corine Land Cover). Notice how the unprotected area stands out as a strip of intensive crops (brown brown and yellow). Limit of national park in orange.

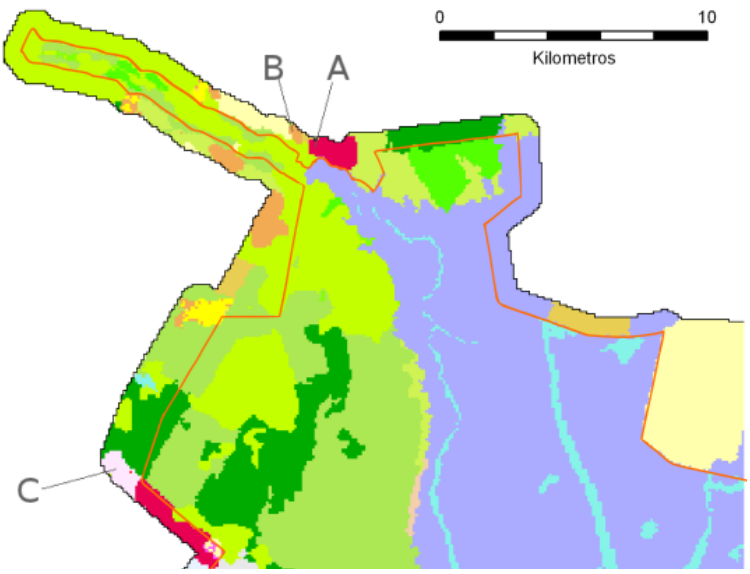

Figure 4 (above): *Scenario 1, business as usual by 2030*. A: occupation of grassland by urban land west of El Rocío, B: expansion of the area of fruit and berry plantations, C: Expansion of sports facilities associated with tourism. Limit of national park in orange.

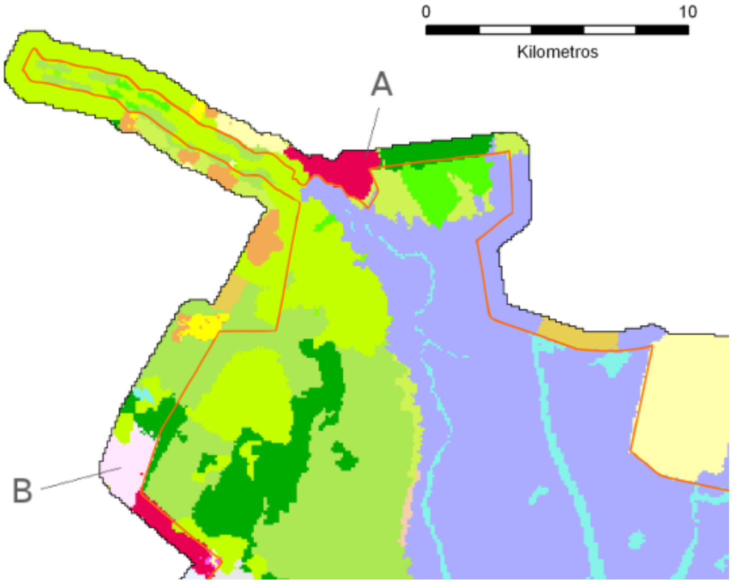

Figure 5 (above): *Scenario 2, expansion of urban and tourist infrastructures by 2030*. A: occupation of grassland by urban land on the outskirts of El Rocío, B: massive expansion of sports facilities associated with tourism. Limit of national park in orange.

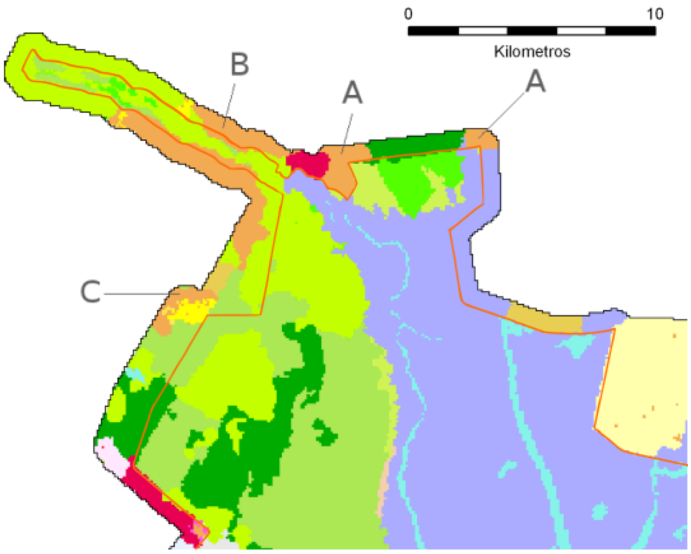

Figure 6 (above): *Scenario 3, massive expansion of fruit and berry plantations by 2030*. A: occupation of grassland by fruit and berry plantations; B: massive expansion of sports facilities associated with tourism. Limit of national park in orange.

5.3 Conclusions and future work

In Figures 4-6, the results of the generation of future scenarios for the pilot model are presented. As can be seen, scenario 1, business as usual (Figure 4), involves an expansion of urban land and sports and leisure facilities in the areas sound the park boundary. Moreover, this is accompanied by a strong increase in the area given over to fruit and berry plantations. Scenarios 2 and 3, respectively, explore the implications for the configuration of land uses, from increased development pressure and irrigated crops in the area bordering the national park. These scenarios provide the first steps for a more elaborate model. Nevertheless, comparison of the differences between the maps, does serve to give an idea of the consequences of three simple storylines that have been developed to evaluate model performance. For now, these scenarios have not been comprehensively evaluated by the stakeholder community, and this will be part of the next stage of the project (see Figure 2).

Subsequently we will proceed to develop more realistic scenarios on the basis of this evaluation, and following previous work with scenarios in Doñana (Palomo et al 2011). The initial responses from the first workshop about the data and methodologies used allow some interesting conclusions to be drawn:

1. To understand the dynamics of the natural protected area it is necessary to expand the study area to take into account all of the Guadiamar river basin, since the processes of land use change occurring in the watershed influence all the ecosystems included in the Doñana natural area.

2. Without the protection afforded by the conservation measures, the land use configuration tends toward an even more intensive exploitation than at the present time, since there are still ample places for intensification, even on the edge of the national park.

3. Some of the mapped dynamics are unreliable, in the view of the stakeholders. With these concerns in mind, we will use another database at a larger scale and a higher level of detail (Moreira 2007), which better reflects the peculiarities of this landscape.

The combination of participatory processes with analytical and technical tasks for the development of a model based on Cellular Automata provides a unique opportunity to study the territory from the point of view of the dynamics of land use change. Future projections sketched out in three different scenarios are the first step towards a series of recommendations for improving land management. By bringing participatory processes and spatial dynamic modeling together in this way allows the development of very powerful decision support systems, in which new zoning policies, or change tendencies observed from monitoring work in the territory can be evaluated to determine their long-term impacts.

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8 APPENDICES

8.1 Appendix I – Land uses classes employed in the study, from corine land cover, 1990-2006)

TUC	Continuous urban fabric
TUD	Discontinuous urban fabric
ZC	Construction areas
IDR	Sports and leisure facilties
TLS	No irrigated (rain fed) crops
TRP	Permanently irrigated land
A	Rice fields
F	Fruit and berry plantations
P	Pastureland
MC	Crop Mosaic
TPA	Principally agricultural land
SA	Agroforestry areas

BF	Broad-leaved woodland
BC	Coniferous woodland
BM	Mixed woodland
PN	Natural grasslands
VE	Sclerophyllus vegetation
MBT	Scrubland
PDA	Beaches, dunes and sands
HZP	Wetlands
M	Marshes
S	Salt marshes
LA	Water bodies
E	Estuaries
MO	Sea and Ocean