Trends and driving factors in land use changes (1956-2000) in Marina Baixa, SE Spain

Juan Peña*, Andreu Bonet, Juan Bellot & Juan Rafael Sánchez
Departamento de Ecología. Universidad de Alicante.
Ap. Correos 99. 03080 Alicante. Spain.
*Contact by e-mail: jpl@ua.es

Abstract:
The analysis of changes in land cover and land use over time as sources of information and geographical diagnosis at a regional scale is primary to improving knowledge of land cover and land use modelling in Mediterranean environments.
The study area is located in the Marina Baixa (MB) county and catchment (571 km^2 and 641 km^2; Alicante, Spain). It comprises 18 municipalities which for the period under study present a landscape mosaic; Benidorm is the capital city of the county. In its turn, this region has undergone great socio-economic changes over recent decades, which can be attributed to tourism development and agricultural intensification.
The main driving forces of landscape change are economic and social (tourism development and agricultural intensification) but urban planning is also a key element to take into account in the land use model. The main change attractors can be described as coastal proximity and water availability factors, that are responsible for the transformation from traditional land uses to new land uses with higher water demand and sea-shore zones highly urbanized.
Analysis of aerial photographs for the years 1956, 1978 and 2000 in MB revealed an increment of artificial surfaces mostly near the shoreline; an augment of irrigated crops surface; and a significant decline in traditional dry crops due to the abandonment because of their low productivity, therefore it is a growth of natural areas.
We have studied the evolution of land cover and land use in MB catchment through time (1956-1978-2000). However, in this study we test the hypothesis that landscape changes in Marina Baixa in 2000 could be predicted from 1956-1978 land use changes. In order to generate land use and land cover map of 2000, we use a combined Cellular Automata, Markov Chain and Multi-Criteria land cover prediction procedure. The application of multiple models is powerful to represent the spatial contiguity as well as knowledge of the likely spatial distribution of transitions to Markov chain analysis. The span between two studied periods is 22 years. The goal is to calibrate the model to predict, as well as possible, the land use changes in 2000, with the purpose to predict the long-term changes beyond.

Keywords: Modelling land use changes, Markov Chain, Cellular Automata, Multi-Criteria and Geographical Information Systems.

JEL code: R14 Land Use Patterns.

Acknowledgements:
This research is founded by EU Commission, AQUADAPT Project (EVK1-CT-2001-00104). We also thank the support of Instituto de Cultura Alicantino Juan Gil-Albert (Excma. Diputación Provincial de Alicante) and Conselleria de Empresa, Universidad y Ciencia (Generalitat Valenciana).

1. Introduction:

During the last few decades, many parts of the planet have experienced an impressive increase of urban development, for instance most of the Mediterranean coast (from Spain to Italy, in Europe). The analysis of variations in land cover and land use over time, as sources of information and geographical diagnosis at a regional scale, is central to improving knowledge of land cover and land use changes in Mediterranean habitats. In fact, changes in land use and the way in which such changes occur can be detected by using only land cover maps handled by G.I.S.

Historical analysis is the basis of landscape evaluation. It is not possible to evaluate the present conditions of a landscape mosaic without knowing at least it's recent history. It is only by considering the evolution of a landscape that it is possible to understand the level of reaction to different types of perturbations.

Finally, the main driving forces are economic, social, territorial planning, etc., and thus these are the key elements for decision makers. Recently, land managers have begun to realize that ecosystems and landscapes are dynamic, that disturbance and succession processes operate on many scales to maintain ecosystems and landscapes in a constant state of flux, and this dynamism is essential to preserving biodiversity. The change attractors in the Mediterranean coast can be described as coastal proximity and water availability, factors that are responsible for the transformation of hydrological resources and coastal zones.

2. Study site:

Marina Baixa (M.B.) catchment is located in SE Spain, it is a county in the Alicante province and it is also a hydrological basin. It has a surface of 641 km^2, with a complex topography, it is characterised by a concentrated land use pattern, of irrigated crops, dry crops, urbanisation as well as Mediterranean shrublands and woodlands.

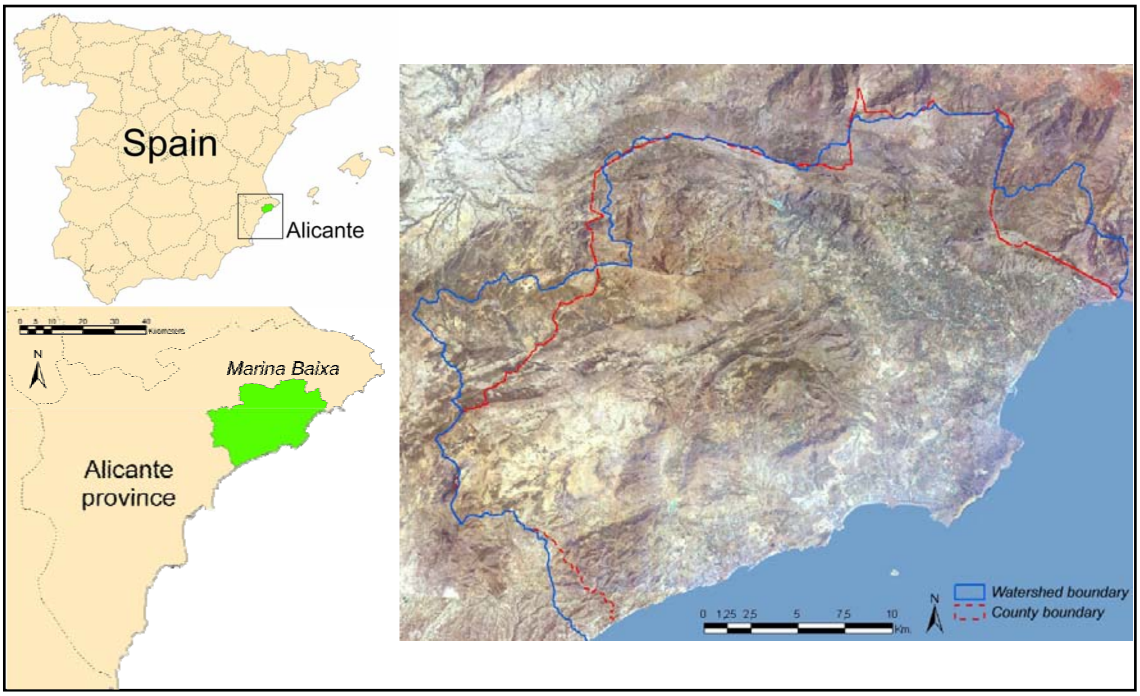


Fig. 1. The study area

M.B. comprises 18 municipalities which for the period under this study present a landscape mosaic and it is one of the regions that has experienced the greatest socio-economic change in this region due to the fact that today over 60% of the Valencian Community's tourist activity is concentrated here (mostly in Benidorm).

3. Objectives of the study:

The global purpose of this study is the understanding of the relationships between the social system and spatial system. In other words, we attempt to observe, quantify and model land use changes in Marina Baixa during last decades.

The main goals of this study were:

- To analyse evolution of land cover and land use over 44 years in Marina Baixa.
- To examine spatial transitions between different land use categories.
- To construct land use scenarios using Markov, MultiCriteria Evaluation and Cellular Automata analyses.

4. Methodology:

Land cover and land use in the Marina Baixa basin has been mapped using aerial photographs and image processing techniques. Stereopairs of photographs of 1956 were provided by Universidad de Alicante at a scale of 1:33.000. Stereopairs of photographs of 1978 were provided by Universidad de Alicante at a scale of 1:18.000. Stereopairs of photographs of 1998, 1999 and 2000 were given by Diputación de Alicante at a scale of 1:25.000. Data has been incorporated into GIS platform ArcGIS 8.3 (instead of IDRISI), obtaining land cover maps in polygonal vector format. The work scale has been improved from 1:25.000 in previous year work to a better-quality 1:10.000.

Land cover and land use legend designs belong together with a physiognomic classification that is a representative summary of the situation in the field using diagnostic approaches. This classification system describes the names of the categories and the approach used to distinguish them, being an independent classification of the scale, and the means used to collect the information. The approaches that were used to establish the classification of the main land covers and land uses are, therefore, physiognomic (photointerpretation).

The chosen nomenclature is based on CORINE and LUCC projects whose classification is hierarchical. This type of classification offers more flexibility, due to its ability of accommodating different levels of information, from structured classes of a superior level and by means of dichotomic divisions to other subclasses of an inferior level. Most of legend categories can be easily identified in the images based on their particular visual answer. However, in some cases it is necessary to use a stereoscope for discrimination and assignment.

Hierarchical dichotomic classification was used for the creation of land cover and land use maps differentiating 33 categories in the second detail level (see Figure 2). Also, the legend of 8 general classes was summarized in the first level, because it is far more appropriate to analyse the main changes at a regional level. It is necessary to highlight that in the forest areas legend, abandoned fields categories are included and having a double meaning: historical-architectural for the previous agrologic land use, and functional for the current vegetation land cover.

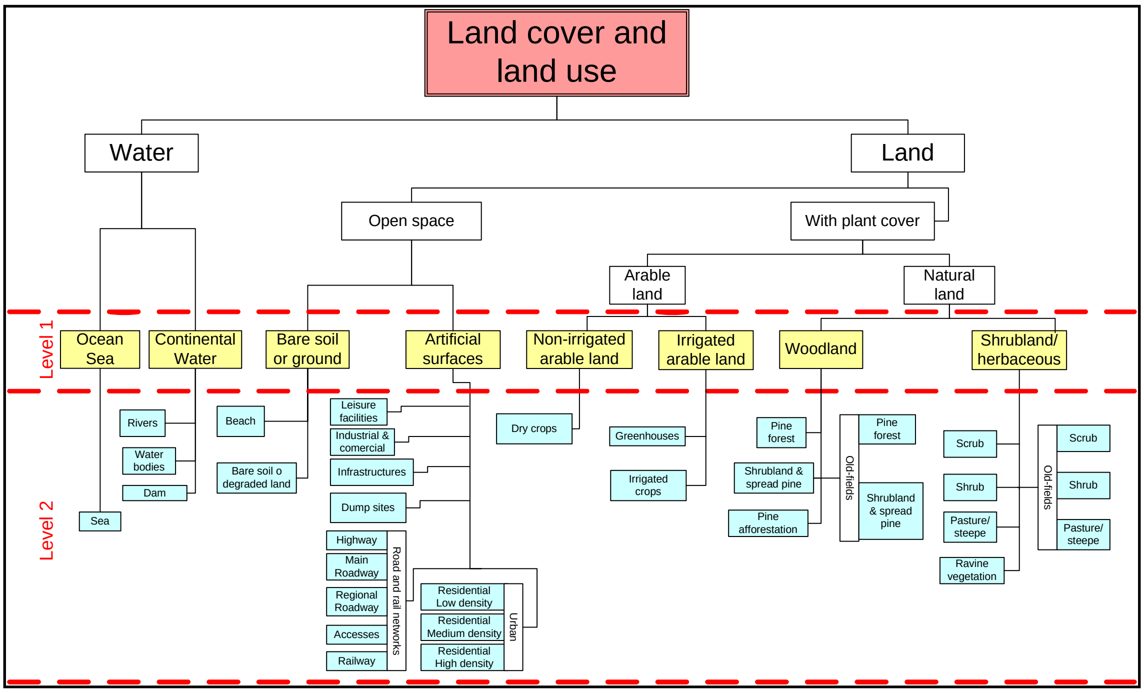


Fig. 2. Land use and land cover nomenclature classification.

The following activities (Fig. 3) summarize the steps that comprise the analytical procedures to achieve a prediction map of Marina Baixa for 2000 using information of the period 1956-1978:

a) Land cover and land use maps in Marina Baixa have been mapped manually using aerial photographs and image processing techniques. Data were incorporated into ESRI ArcGIS 9. These maps were obtained in vectorial format and their land use dynamics were analysed during the same period (1956-2000), handled by G.I.S. software.

b) Cartographical information extraction into thematic layers in order to take in account a set of different parameters in study area for further analyses.

c) The Markov chain procedure analyzes a pair of land use images and outputs a transition probability matrix, it is a matrix that records the probability that each land cover category will change to every other category. This analysis establishes the quantity of expectating land use change from each existing category to each other category in the next time period. In other words, we can predict how much our study area will change, but not where.

d) Multi-criteria evaluation (MCE) is most commonly achieved by one of two procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second is known as weighted linear combination wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. The result is a continuous mapping of suitability that may then be masked by one or more Boolean constraints to accommodate qualitative criteria, and finally thresholded to yield a final decision. Using Multi-criteria evaluation we can construct our suitability maps for each land use supplied by the user. Starting from thematic layers we establish the inherent suitability of each pixel for each land cover type by means of a combination of the following layers: land use, altitude, slope, aspect, distance to the sea, distance to the inhabited settlements and distance to the roads.

e) Cellular Automata analysis applies the distance values to allocate land use changes. The filter is integral to the action of the Cellular Automata component. Its purpose is to down-weight the suitabilities of pixels that are distant from existing instances of the land cover type under consideration. The net effect is that to be a likely choice for land use conversion, the pixel must be both inherently suitable and near to existing areas of that class.

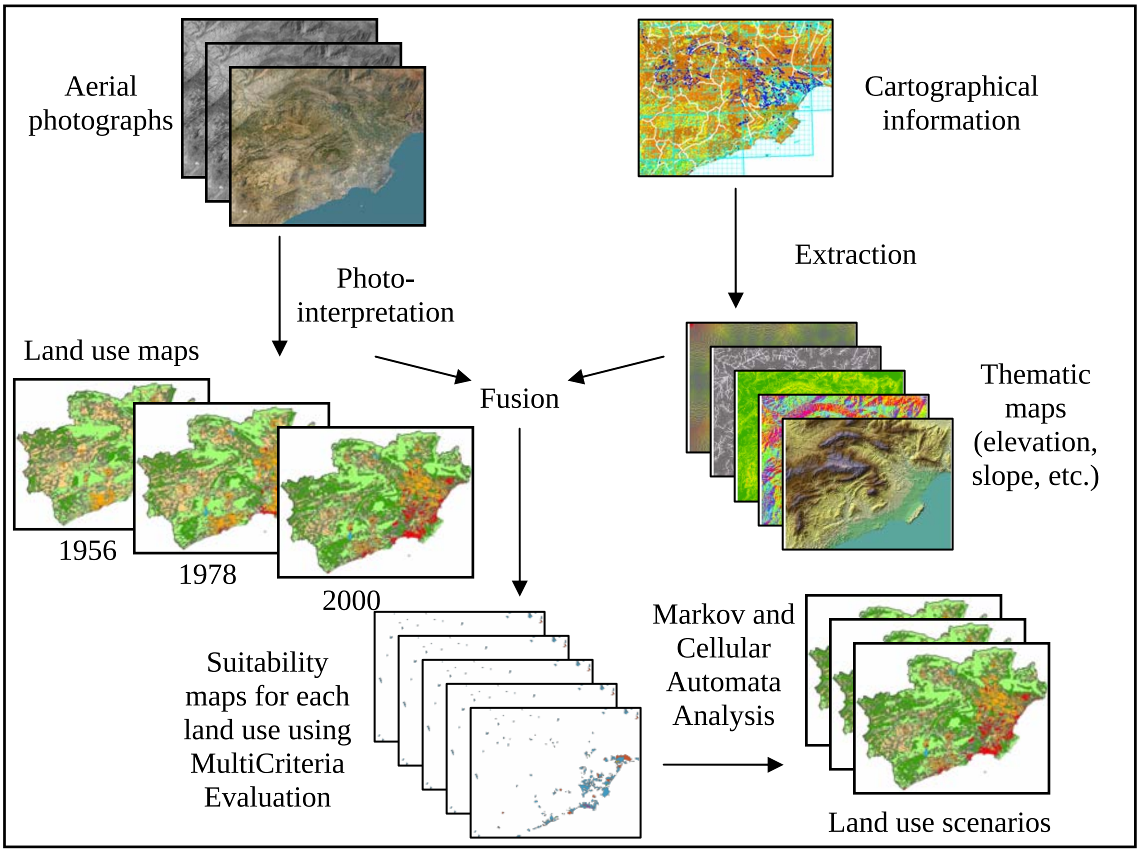


Fig. 3. Methodological approach.

5. Landscape dynamics:

The study of the evolution of land cover and land use in Marina Baixa catchment over time (1956-2000) reveals an increment to all artificial surfaces mostly near the coastline. However, there is a growth in natural areas due to the abandonment of dry crops because of low productivity. Irrigated crops increased in area in 1978, but they decreased near the coastline in 2000.

The Marina Baixa region has undergone great socio-economic changes over recent decades, which can be attributed to tourism development and intensify agricultural activity. The driving forces have transformed hydrological resources and coastline. The change attractors can be described as coastal proximity (tourism) and water availability (irrigated crops).

In Fig. 4, Fig. 5 and Fig. 6 are the corresponding land use maps for 1956, 1978 and 2000, also in Table 1 is the quantity of each land use in number of patches (N), area (A) and percentage (%) for land use classification at level 2.

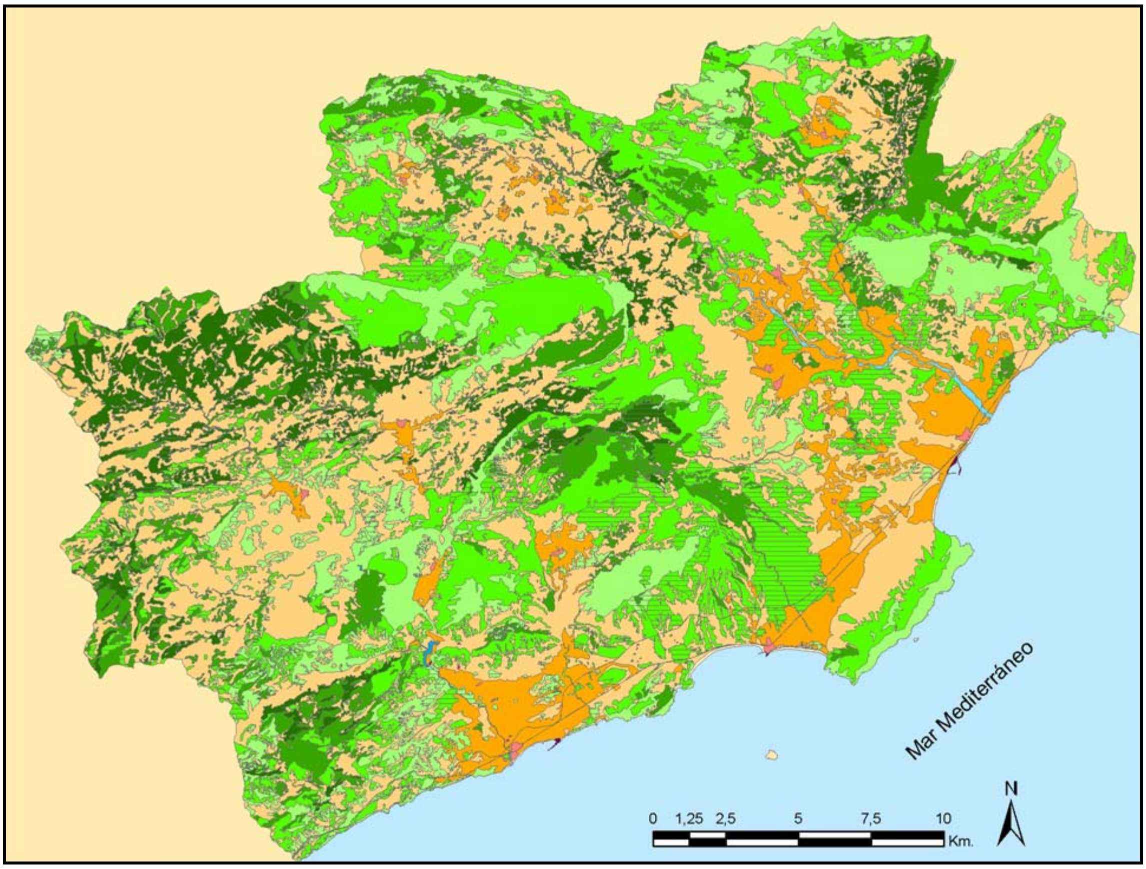


Fig. 4. Marina Baixa land use map for 1956.

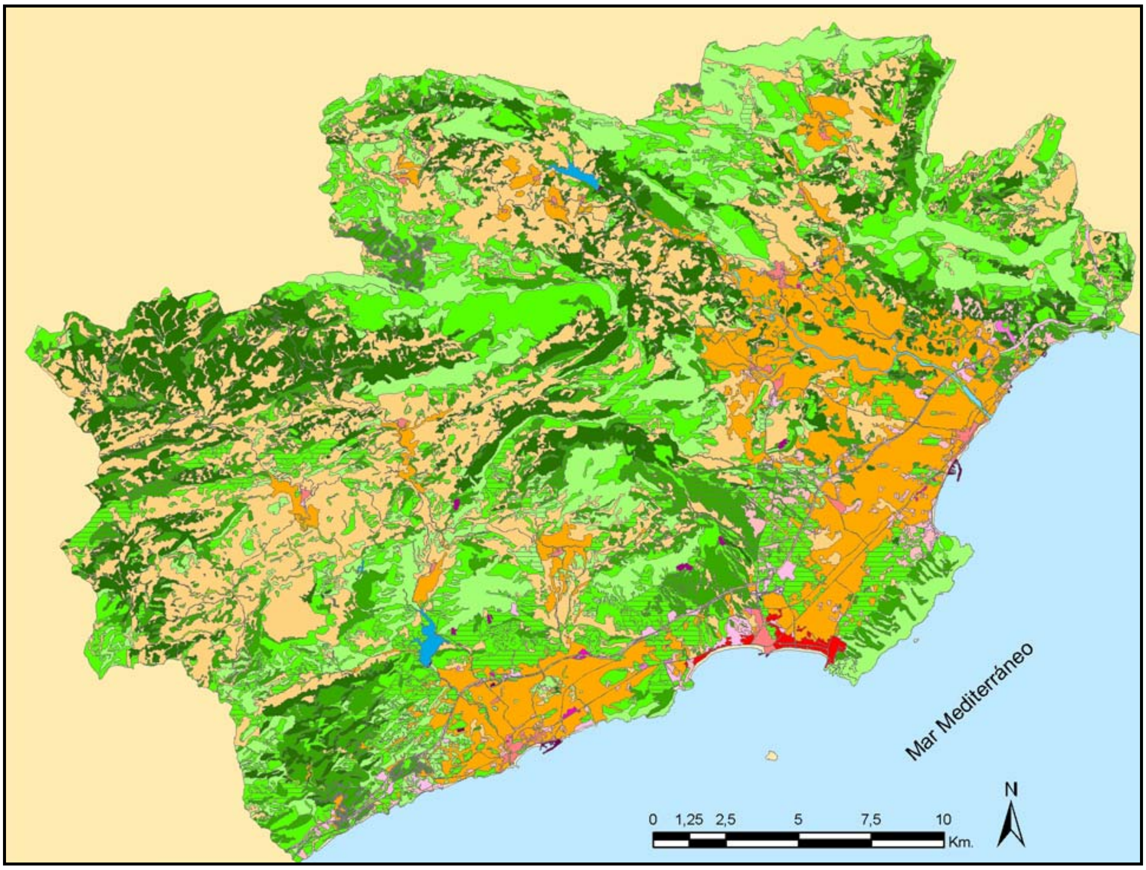


Fig. 5. Marina Baixa land use map for 1978.

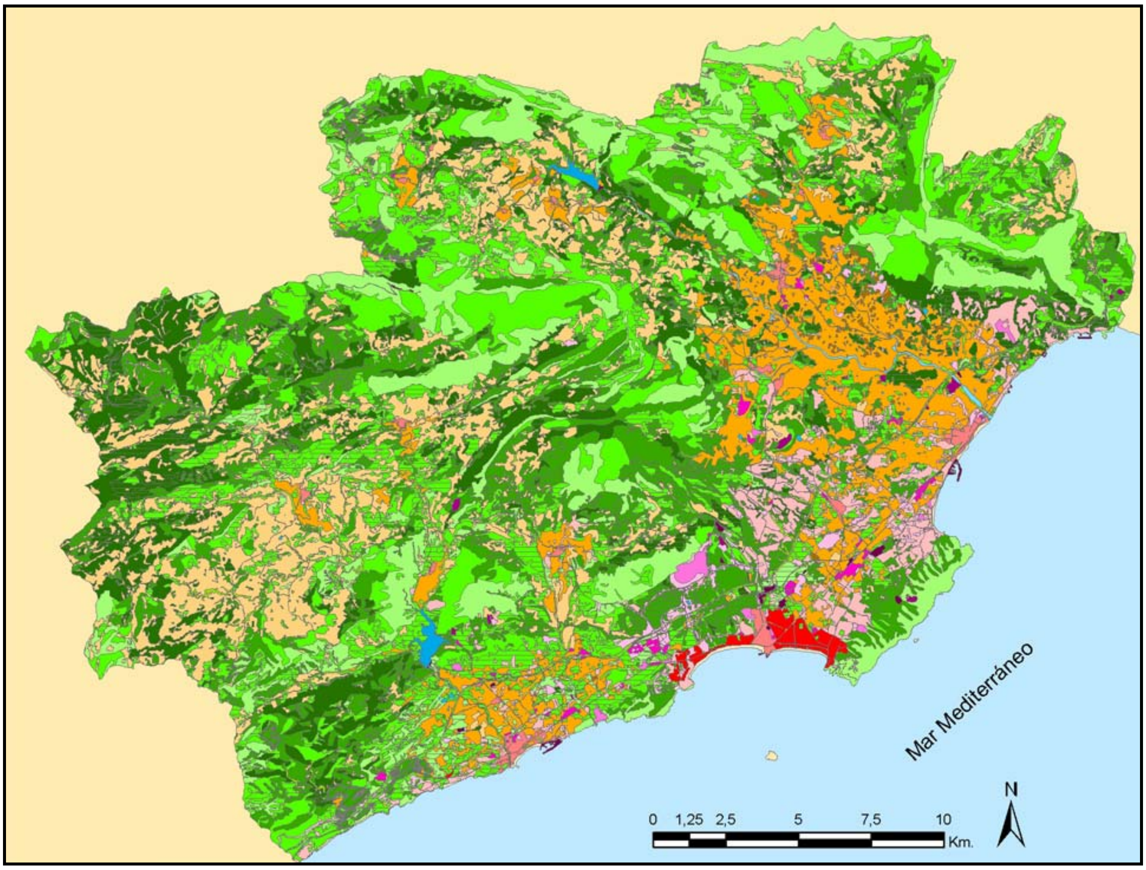
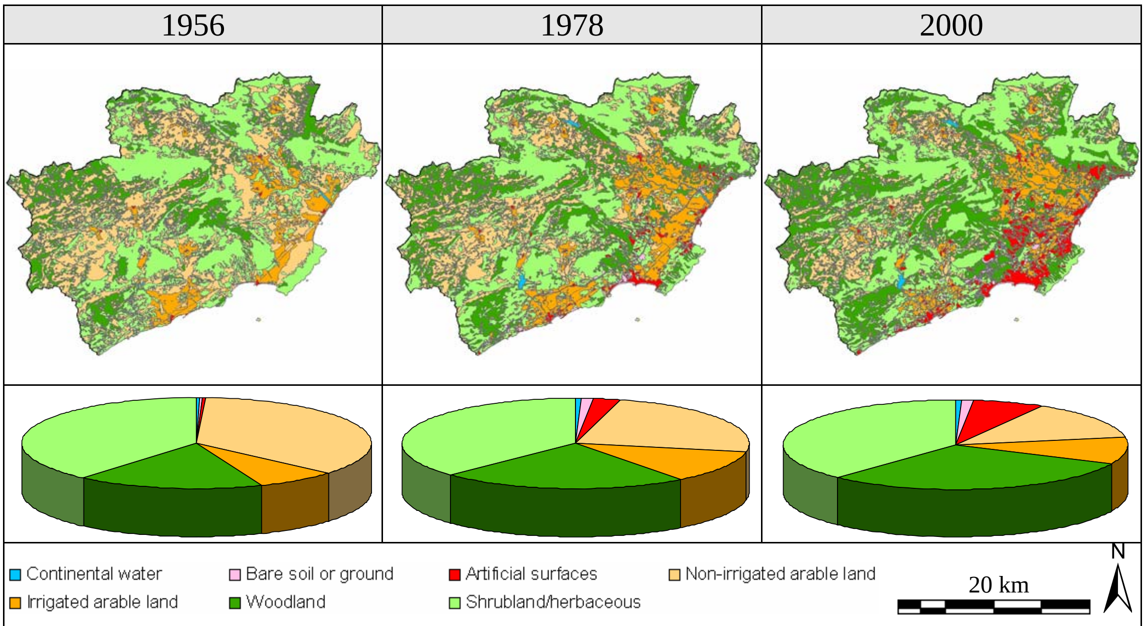


Fig. 6. Marina Baixa land use map for 2000.

Table 1. Evolution of land uses in Marina Baixa (1956-1978-2000).



Land use/cover (level 1)	Land use/cover (level 2)	1956			1978			2000		
		N	A (km²)	%	N	A (km²)	%	N	A (km²)	%
Continental water	Rivers	6	1,63	0,25	16	1,28	0,20	19	1,29	0,20
	Water bodies	0	0	0	8	0,01	0	159	0,40	0,06
	Dams	2	0,16	0,03	4	1,43	0,22	3	1,38	0,22
Bare soil or ground	Bare soil or degraded land	3	0,04	0,01	129	6,07	0,95	295	7,13	1,11
	Beaches	16	0,91	0,14	16	1,25	0,19	20	1,12	0,17
Artificial surfaces	Low density residential	6	0,02	0	230	7,15	1,12	563	22,42	3,50
	Medium density residential	27	1,15	0,18	53	3,01	0,47	76	3,91	0,61
	High density residential	0	0	0	17	1,55	0,24	19	3,11	0,49
	Leisure facilities	0	0	0	5	0,32	0,05	16	1,63	0,25
	Industrial and commercial	5	0,03	0	22	0,34	0,05	73	2,15	0,34
	Landfill and mineral extraction sites	0	0	0	8	0,39	0,06	15	0,72	0,11
	Infrastructure	4	0,14	0,02	15	0,39	0,06	29	0,93	0,14
	Principal roads	0	0	0	8	0,84	0,13	12	1,03	0,16
	Secondary roads	5	0,39	0,06	6	0,42	0,07	8	0,56	0,09
	Regional/local roads	0	0	0	5	2,05	0,32	9	2,56	0,40
	Access roads	1	0,02	0	32	0,70	0,11	124	2,32	0,36
	Railway	7	0,23	0,04	11	0,23	0,04	19	0,22	0,04
Non-irrigated arable land	Dry crops	758	228,25	35,62	733	153,14	23,89	1282	89,28	13,92
Irrigated arable land	Irrigated crops	103	47,79	7,46	265	74,65	11,64	437	59,81	9,33
	Greenhouses	0	0	0	0	0	0	280	2,50	0,39
Woodland	Pine forest	178	38,58	6,02	238	67,20	10,48	340	55,93	8,72
	Shrubland with dispersed pine	251	51,30	8,01	346	43,90	6,85	470	65,90	10,28
	Pine forest plantation	0	0	0	11	3,82	0,60	28	4,34	0,68
	Abandoned fields to pine forest	48	5,54	0,86	138	8,38	1,31	182	14,09	2,20
	Abandoned fields to shrubland with dispersed pine	296	15,99	2,49	288	24,08	3,76	819	52,21	8,14
Shrubland/herbaceous	Scrubland	259	78,62	12,27	347	95,55	14,90	248	83,58	13,04
	Shrubland	368	121,94	19,03	431	81,54	12,72	493	85,76	13,38
	Ravine vegetation	13	0,52	0,08	66	3,08	0,48	77	3,79	0,59
	Abandoned fields to scrubland	86	6,60	1,03	73	4,88	0,76	65	3,14	0,49
	Abandoned fields to shrubland	293	40,88	6,38	582	53,47	8,34	1293	67,96	10,60

In order to summarise all land uses in a simplified legend for the three periods (from now on we reclassify 30 land use classes into 7 categories), we have extracted the areas of each land use for 1956, 1978 and 2000. This result is shown in the following graph.

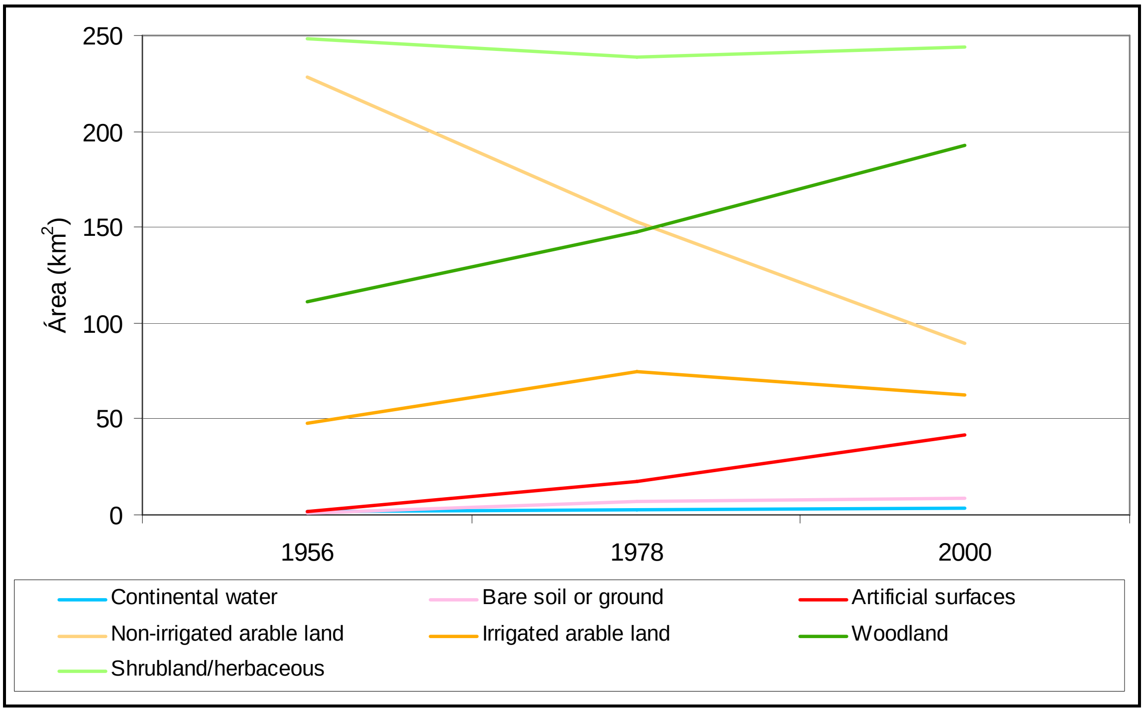


Fig. 7. Marina Baixa land use trends (land use classification at level 1).

The present situation can be described as an increasing polarization between the more inland, rural, mountain areas on the one hand, and the coast on the other. The different land uses are in competition with one another, resulting in the generation of conflicts. In fact, this evolution can be understood from the wider perspective of growth concentrating along much of the Mediterranean shoreline. This produces saturation problems due to intense competition for space (land occupation) and pressure on the resources of the area (especially water).

There is no doubt that most changes are produced by the widely human occurrence. Three opposite processes can be observed in Marina Baixa landscape: intensification of agriculture, urbanization and land abandonment. They have profound consequences on the structure and functioning of landscapes. The intensification of agriculture and urban settlements has severe consequences on the water cycle, nutrients and pollutants. On the other hand, the augment of natural land covers (361.6 km^2 to 433.6 km^2) from land abandonment indicates a decrease of human pressure in rural areas; this situation implies more wildfire risk.

5.1. Dry crops abandonment.

The abandonment of terraced dry crops is widely distributed in the research area. Some small surfaces of dry crops (almond, olive and carob) were still under management in rural areas, but almost all the cropland near the coast was abandoned.

These locations do not suffer so much the desertification effects, because in the terraces they have good conditions (soil content, flat slope, etc.), that enables the spontaneous afforestation after abandonment.

5.2. Agricultural intensification.

Agricultural intensification is defined as higher levels of inputs and increased output (in quantity or value) of cultivated or reared products per unit area and time. Such achievements (mostly medlar and citric) are economically more productive than traditional dry crops (olive, almond or carob). However, agricultural intensification requires major water consumption and soil necessities, and it is viewed skeptically by observers contemplating the future of a stressed system in which the water resources are inadequate to maintain actual pace of change.

5.3. Urbanization.

Changes in the area of urban land per se, therefore, appear to be central to land cover change in tourist areas. Urbanization as land cover, in the form of build-up or paved-over areas, occupies 6.5% in Marina Baixa in 2000, although it was 0.3% in 1956. Large-scale urban agglomerations and extended peri-urban settlements fragment the landscapes of such large areas that various ecosystems are threatened. Ecosystem fragmentation, however, in peri-urban areas may be compensated by urban-led demands for conservation and recreational land uses. Coastal cities in Marina Baixa attract a significant proportion of the local and national rural population by way of permanent and circulatory migration, just the opposite to the internal municipalities which are losing people since 1960.

6. Landscape transitions:

A simple transition matrix model was developed to explore changes in landscape dynamics over the time period 1956-1978, in order to predict land use map of 2000. Transition matrices have been used quite commonly to model and explore landscape dynamics and change (Shugart, 1998).

Such models have at their heart a transition matrix (***A***) that describes the probability of a cell changing from state *i* to state *j* (for all classes) in some discrete time step, and a vector (x_t) containing the abundance of each class (absolute or proportional) at time *t*. Multiplying ***A*** by *xt* gives a new vector (x_{t+1}) that describes landscape composition one time step (i.e. $t + 1$) into the future. If this iterative process is repeated sufficiently then the stable stage distribution for the landscape will be reached. Thus:

$$x_{t+n} = x_t \cdot \boldsymbol{A}^n$$

A key assumption of transition models is stationarity (i.e. that transition rates do not change over time). We have crossed 1956 and 1978 land use maps of 7 categories in order to calculate landscape changes. The outcome indicates that 38.2% of the total area has changed and the remainder has not changed for 22 years. That is less than half of the catchment has altered.

The first step is calculating the land use transition using cross-tables. In the Table 2 there is the combination of land use maps from 1956 to 1978. The data into the cells shows areas in square kilometres and they correspond to each possible combination of land uses that moves from one use to other. Total summation of rows and columns is equal to the area of the catchment.

Table 2. Cross-table between 1956 and 1978 (km^2).

		Land use map 1978						
		Cont.water	Bare soil	Art.surfac	Non-irrigat.	Irrigated	Woodland	Shrubland
Land use map 1956	Cont.water	***0,83***	0,01	0,02	0,05	0,58	0,11	0,20
	Bare soil	0	***0,71***	0,17	0	0,02	0	0,01
	Art.surfaces	0	0,01	***1,97***	0	0	0	0
	Non-irrigat.	0,67	2,64	6,06	***117,76***	25,03	33,79	42,30
	Irrigated	0,59	0,58	3,91	1,42	***38,24***	1,10	1,95
	Woodland	0,20	0,01	0,48	12,73	1,11	***69,58***	27,29
	Shrubland	0,42	3,11	4,61	21,18	9,69	42,80	***166,76***

To use Markov Chain analysis it is necessary to convert data from square kilometers to probabilities in a transition matrix (Table 3). It is central to fulfill all necessary requisites to be transition matrix (Lipschutz, 1968). Therefore, it could be suitable for further projections taking in account initial state and change probabilities in that state. The summation of all probabilities of all cells of the same row must be 1.

Table 3. Transition matrix 1956-1978.

Land use map 1956 \ Land use map 1978	Cont.water	Bare soil	Art.surfac	Non-irrigat.	Irrigated	Woodland	Shrubland
Cont.water	0,46	0,01	0,01	0,03	0,32	0,06	0,11
Bare soil	0	0,78	0,18	0	0,02	0	0,01
Art.surfaces	0	0,01	0,99	0	0	0	0
Non-irrigat.	0	0,01	0,03	0,52	0,11	0,15	0,19
Irrigated	0,01	0,01	0,08	0,03	0,80	0,02	0,04
Woodland	0	0	0	0,11	0,01	0,62	0,24
Shrubland	0	0,01	0,02	0,09	0,04	0,17	0,67

In Fig. 8 we can observe with continuous lines real data and with dashed lines estimated data using Markov analysis with transition matrix of 1956-1978. From the results we can advert that it continues the tendencies of that studied period, but it does not anticipate socio-economic changes responsible of the magnitude of land use changes. For instance: there is a decline in irrigated crops due to a growing urban development, and our model is unable to predict, because it consider the initial conditions.

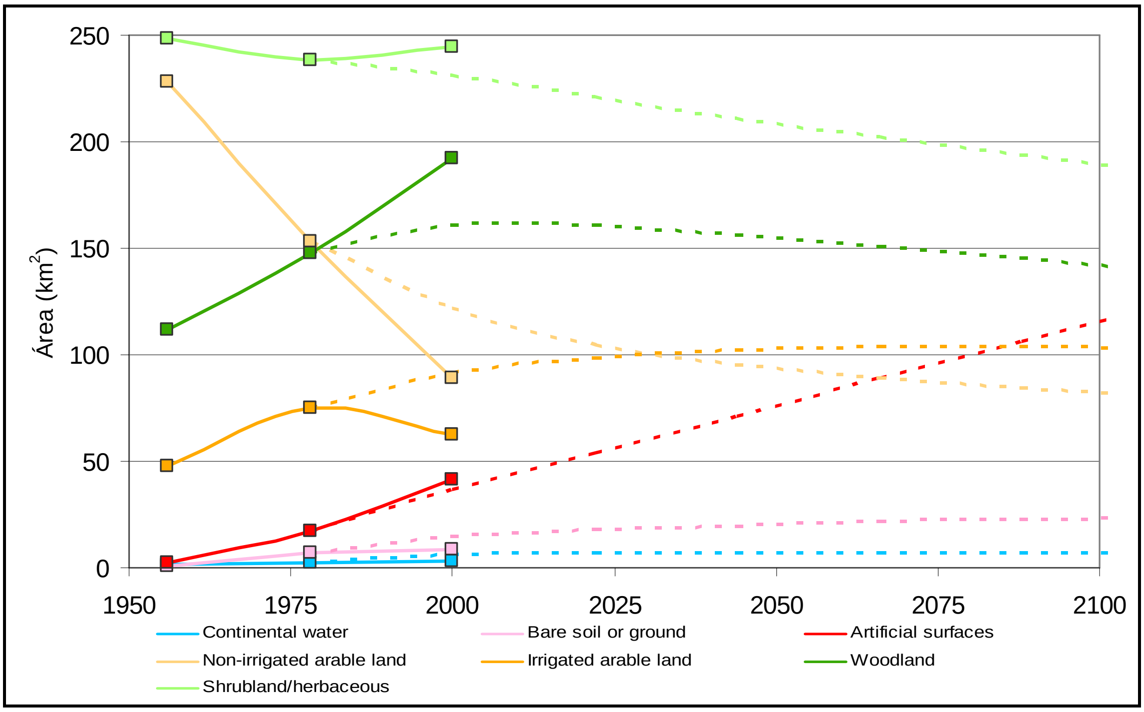


Fig. 8. Land use trends using transition matrix 1956-1978.

We can observe that some values (artificial surfaces, bare soil and continental water) derived from Markov analysis were accurately predicted in landscape composition in 2000. Otherwise, other land uses do not adjust to the observed and predicted.

To model the sensibility is the result of the land use model critical variables and the assumptions that we need to test. The small differences in the initial set of key parameters could led to bigger differences in the development of trends through time, due to the complexity of the feed-back and accumulative processes that characterize both socio-economic and natural components of the system.

7. Land use scenarios:

On summary, we identified relationships between environmental variables and land use changes. Altitude, slope, aspect, distance to the sea and to the inhabited settlements as well as roads have a part to play in landscape development. It has yet to be established in what proportion, why, and how these various factors influence the historic sustainability of the landscape.

From these relationships we are able to construct suitability maps for each land use, which is a layer of information in the GIS that has a distribution of change probability to a determinate land use.

In this way, we run the tool CA_MARKOV in Idrisi32 software with the purpose to integrate cellular automata procedures in combination with Markov Chain analysis and MultiCriteria Evaluation routines.

The resulting image (Fig. 9) integrates the three analyses (Markov Chains, MCE and Cellular Automata) in one image in 2000. In addition, we are capable to validate this model comparing with the real land use map for the same period. Although, there are changes of land uses that are not predictable, mostly related to human activities, that respond to different factors (cultural, political, religious, etc.).

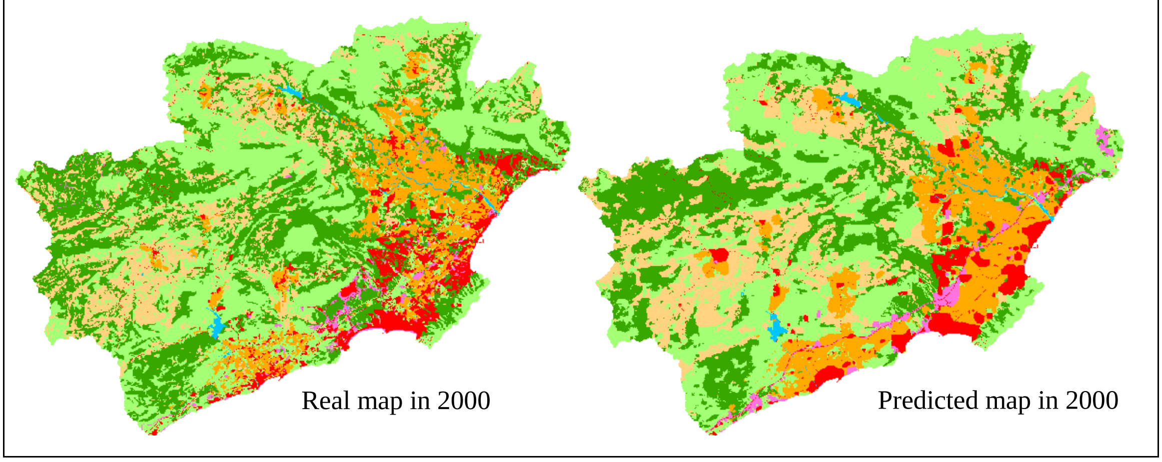


Fig. 9. Real and predicted land use map in 2000.

In this study, the potential development zones linked with land use categories extracted from the analyses of 2000 have been compared with a real land use map from aerial photographs of 2000 for validation. Results are satisfying with a good relationship between potentialities and reality development trends. More than 70% of the new built areas have been located inside areas identified by the potential model. GIS allows integration of various layers associated with such information.

8. Conclusions:

In this paper, we have attempted to demonstrate how land use changes (irrigation, tourist development and land abandonment) in the Marina Baixa county have produced important socio-environmental conflicts.

Given the social and environmental dynamics of the Marina Baixa, it can be argued that the future tendency in land use will not vary substantially from that experienced by other traditionally rural Mediterranean areas. Briefly, there are three different land use changes for the future, depending on the biophysical domain. First, the land abandonment process of the rural areas is likely to continue as a result of the continuing crisis in traditional agriculture. Second, intensive agriculture will continue to dominate the plain, but may face restrictions from the EC in Brussels either under set-aside conditions or simply by removing subsidies for crops. Finally, we can expect continuing diversity of land use that characterizes the coast, where the so-called driving forces of environmental change (agriculture and tourism) cause the greatest number of social and environmental conflicts.

The variability to distinguish directional change (such as loss of biodiversity or soil degradation) from readily reversible fluctuations, such that interpretations of degradation and desertification must be viewed cautiously (Puigdefàbregas, 1996). Landscapes in Mediterranean semi-arid zones are increasingly seen as non-equilibrium ecosystems and this risk only become true whether the practices of land use of the region are not appropriated to the natural environment (Palutikof et al, 1996).

This application has confirmed the benefits of potential modeling approach for finding suitability areas for land use changes. Of course, some limitations (closure of the studied area, choice of weights exponents, etc.) exist. But the method provides an interesting product usable for a first research in planning procedures.

These pathways indicate that land use policies and projections of the future role of land use change in Marina Baixa dynamics must not only capture the complex socio-economic and biophysical drivers of land use change, but also account for the specific human environment conditions under which the drivers of change operate. This recognition requires moving beyond some of the simplifications that persist in much of the current understanding of the causes of land use and land cover change. This does not preclude the development of a conceptually-based, land change science. Finally, these results complement previous studies in Mediterranean landscapes and emphasize the importance of consider land use models when studying landscape patterns.

9. References:

Lipschutz S. (1968). Theory and problems of probability. Schaum's Outline Series. McGraw-Hill Book Company.

Palutikof J.P., Conte M., Casimiro Mendes J., Goodess C.M. and Espirito Santo F. (1996). Climate and climatic change. In C. J. Brandt and J. B. Thornes (eds.). Mediterranean Desertification and Land Use. Wiley. Chichester. 43-86.

Puigdefàbregas J. (1996). El papel de la vegetación en la conservación del suelo en ambientes semiáridos. Erosión y recuperación de tierras en áreas marginales. Instituto de Estudios Riojanos, Logroño. 79-87.

Shugart, H.H., (1998). Terrestrial Ecosystems in Changing Environments. Cambridge University Press, Cambridge.